

# **ANALYSIS OF ALTERNATIVES**

## **non-confidential report**

**Legal name of applicant(s):** *REACHLaw Ltd as Only Representative on behalf of Joint Stock Company “Novotroitsk Plant of Chromium Compounds”*

**Prepared by:** *CTAC Consortium*

**Substance:** *Chromium trioxide, EC No: 215-607-8, CAS No: 1333-82-0*

**Use title:** *Functional chrome plating with decorative character*

**Use number:** *3*

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### NOTE TO THE READER

**This document is the unmodified final version of the CTAC dossier of April 2015 for this use applied for, which has been developed over the course of three years.**

CTAC is the Chromium Trioxide REACH Authorization Consortium, a group of more than 150 companies formed in 2012 to jointly develop draft applications for REACH authorization of several uses of chromium trioxide. Since CTAC's creation in 2012 the applicant has been a consortium member as only representative of our client, the non-EU manufacturer of chromium trioxide, *Joint Stock Company "Novotroitsk Plant of Chromium Compounds" (JSC "NPCC")* from Russia. The main purpose of joining CTAC has been to get access to the required downstream user-specific data relating to the Chemical Safety Report, Analysis of Alternatives and Socio-Economic Analysis, as reflected in the CTAC dossier, considering that JSC "NPCC" is located on top of the chromium trioxide supply chain, and only supplies to EU importers being distributors.

The present document has already been used by other CTAC Members on the same supply chain level to apply for authorisation, namely by the CTACSubmission Consortium ('CTACSub') of several upstream suppliers that act as importers / Only Representatives / formulators, with LANXESS Deutschland GmbH in its legal capacity as Only Representative of LANXESS CISA (Pty) Ltd. as the lead applicant.<sup>1</sup> REACHLaw, on behalf of JSC "NPCC", expressed interest in joining the CTACSub Consortium or refer to its application directly, but the membership is now closed and a reference to this previous application (REACH Article 63(1)) excluded in the CTACSub contract. Therefore, we herewith submit the document as part of an individual application for authorisation (same dataset).

**In addition, we would like to note the following to support this application for authorisation:**

The volume of chromium trioxide sold to EU by our client is only a fraction of the total volume covered in the CTAC dossier, and so are the described human health, environmental and socio-economic impacts.

Over and above the work done within the frame of CTAC, REACHLaw Ltd with the support of our client have engaged in intense communication with the EU customers (importers) of JSC "NPCC", all of them distributors only, with the objective of obtaining even more detailed supply chain and use-specific data from those importers as well as their customers and downstream supply chain. REACHLaw has prepared and circulated a survey document (questionnaire) to this end, and provided it in English and German language to our client's EU customers, with the request to circulate it further down the supply chain and to return responses. To date we have received some filled questionnaires, and will continue to follow-up also after submission to continuously improve the data basis in relation to actual operational conditions and risk management measures in place. To this end REACHLaw, together with our client, continue to be in close contact with our client's EU customers and their downstream supply chain, as far as accessible to us.

*With kind regards,*

*Jouni Honkavaara,  
CEO, Partner*

***REACHLaw Ltd., acting as Only Representative of Joint Stock Company "Novotroitsk Plant of Chromium Compounds"***

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<sup>1</sup> Consultation numbers on ECHA website: **0032-01** (formulation of mixtures), **0032-02** (functional chrome plating), **0032-03** (Functional chrome-plating with decorative character), **0032-05** (Surface treatment (except passivation of tin-plated steel (ETP)) for applications in various industry sectors namely architectural, automotive, metal manufacturing and finishing, and general engineering (unrelated to Functional chrome plating or Functional chrome plating with decorative character)).

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### Abbreviations

2K/3K	Two Component Substance / Three Component Substance
AAST	Acidic Accelerator Salt Spray Test
ABS	Acrylonitrile-Butadiene-Styrene
ABS/PC	ABS with Polycarbonate
ACEA	European Automobile Manufacturer Association
Acute Tox.	Acute Toxicity
AfA	Application for Authorisation
AiF	Federation of Industrial Cooperative Research Associations (Arbeitsgemeinschaft industrieller Forschungsvereinigungen)
AoA	Analysis of Alternatives
ASTM	American Society for Testing Materials
Aquatic Acute	Hazardous to the aquatic environment
Aquatic chronic	Hazardous to the aquatic environment
BD	Black Dyeing
BedGgstV	German Commodity Ordinance (Bedarfsgegenständeverordnung)
BMBF	Federal Ministry of Education and Research
Carc.	Carcinogenicity
CASS	Copper Accelerator Salt Spray Test
CoRAP	Community Rolling Action Plan
Cr(0)	Elementary Chromium
Cr(III)	Trivalent Chromium, Chromium (III)
Cr(VI)	Hexavalent Chromium, Chromium (VI)
CrO <sub>3</sub>	Chromium Trioxide
CSR	Chemical Safety Report
CTAC	Chromium Trioxide Authorisation Consortium
CVD	Chemical vapour deposition
DGM-RAL-GZ	German Furniture Quality Association (Deutsche Gütegemeinschaft Möbel e.V)
DIN	German Organization for Standardization (German Industry Standards)
DLC	Diamond Like Carbon
DVGW	German Technical and Scientific Association for Gas and Water

EC	Electrolytic Colouring
EN	European Norm
EPA	Environmental Protection Agency
EU	European Union
Eye Dam.	Serious eye damage
Eye Irrit.	Eye irritation
FGK	Association of Electroplater on Plastic Substrate (Fachverband Galvanisierte Kunststoffe)
Flam. Liq.	Flammable liquid
Flam. Sol.	Flammable solid
FuSchiDec	Working group Funktionale Schichten mit dekorativem Charakter
GT0/GT1	Result classification in cross-cut test
HV	Vickers Hardness
IARC	International Agency for Research on Cancer
IBAD	Ion Beam Assisted Deposition
IC	Inorganic Colouring
ISO	International Organization for Standardization
IUPAC	International Union of Pure and Applied Chemistry
LTAVD	Low Temperature Arc Vapour Deposition
Met. Corr.	Substance or mixture corrosive to metals
SDS	Safety Data Sheet
Muta.	Germ cell mutagenicity
NSST	Neutral Salt Spray Test
OEM	Original Equipment Manufacturer
Ox. Liq.	Oxidising liquid
PA	Polyamide
PEEK	Polyetheretherketone
PEI	Polyetherimide
PP	Polypropylene
PTFE	Polytetrafluoroethylene (particles)
PREN	Pitting Resistance Equivalent Number
PVC	Polyvinyl chloride

PVD	Physical Vapour Deposition
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals, Regulation 1907/2006, as amended
R&D	Research and Development
Repr.	Reproductive toxicity
Resp. Sens.	Respiratory
SEA	Socio Economic Analysis
Skin Sens.	Skin sensitisation
Skin irrit.	Skin irritation
SME	Small and Medium-sized Enterprise
SST	Salt Spray Test
STOT RE	Specific target organ toxicity, repeated exposure
STOT SE	Specific target organ toxicity, single exposure
SVHC	Substance of Very High Concern
TrinkwV	German Drinking Water Ordinance (Deutsche Trinkwasser Verordnung)
UB	Units of brilliance (Unité de brilliance)
UBA	German Environmental Protection Agency (Umweltbundesamt)
UG3	Use Group 3
UV	Ultraviolet
VDA	Verband der deutschen Automobilindustrie
ZVO	Zentralverband Oberflächentechnik

## Glossary

Term	Definition
Absorption capability	The ability of a coating to absorb light.
Adhesion	Parameter describes 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	Typical method for surface treatment of parts. May also be referred to as dipping or immersion. None-bath methods include wiping, spraying, and pen application.
Category 1 Alternative	Alternative considered promising, where considerable R&D efforts have been carried out within the different industry sectors.
Category 2 Alternative	Alternative with clear technical limitations which may only be suitable for niche applications and not as a general alternative.
Category 3 Alternative	Alternative which has been screened out at an early stage of the Analysis of Alternatives and which is not applicable for the use defined here.
Chemical resistance	Parameter is defined as 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.
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	<p>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. In functional plating with decorative character, chromium trioxide is used to deposit a coating of typically 0.1- 2.0 µm, or, where increased corrosion resistance is required, a 'micro cracked' chromium deposit at thicknesses of typically 0.5 - 2.0 µm, over a nickel undercoat. 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<sup>1</sup>, which has been used, for example, in solar panel manufacture, where deposits are porous and &lt;1 µm in thickness.</p> <p><sup>1</sup>EN 15205 is to be used as the standard of detection of Cr(VI). If a Member wishes to use</p>

## ANALYSIS OF ALTERNATIVES

Term	Definition
	another standard, the Member has to prove that it is equally sensitive.
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.
Pre-treatment	Pre-treatment processes are substrate specifically used to create caverns 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

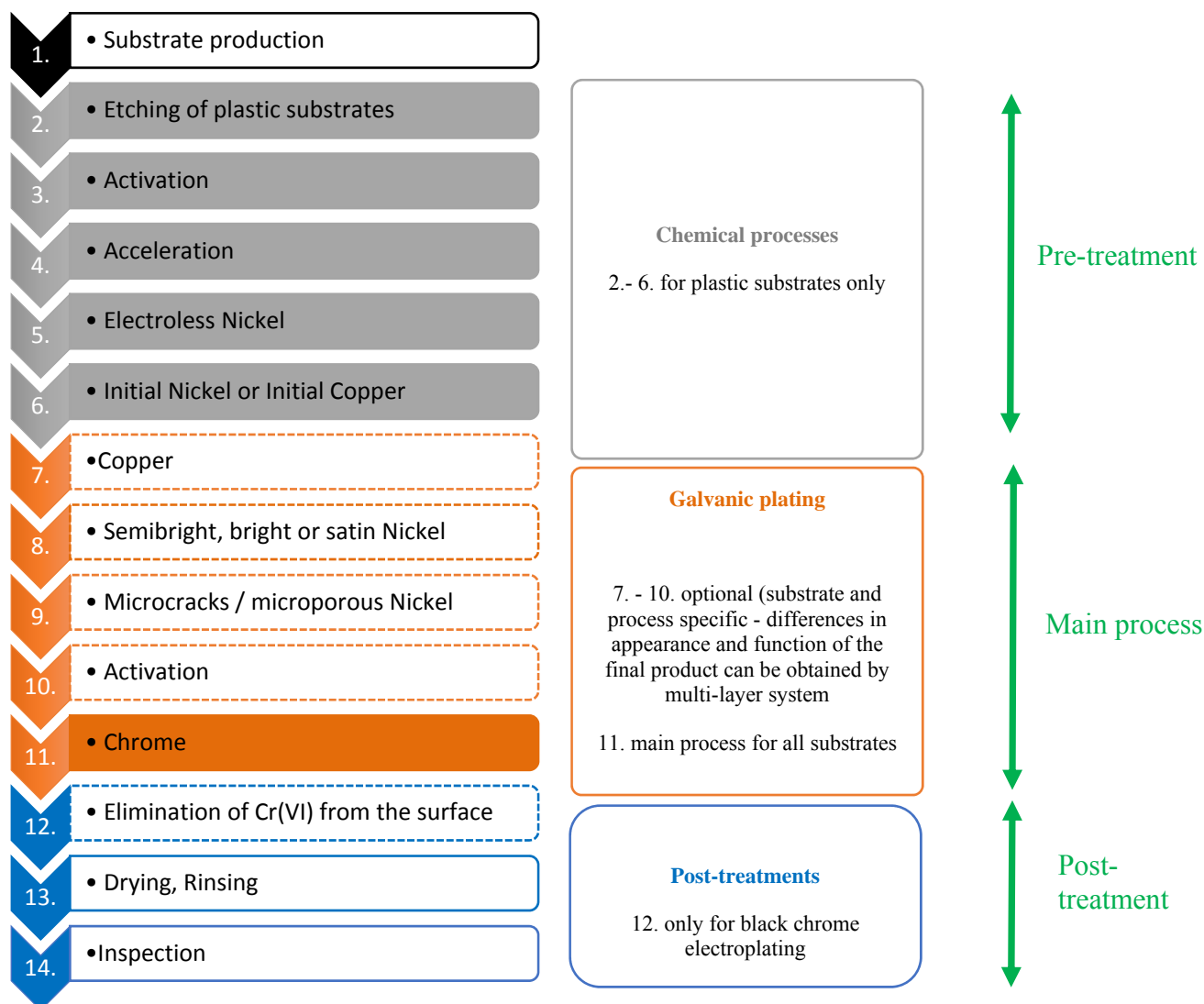
This Analysis of Alternatives (AoA) forms part of the Application for Authorisation (AfA) for the use of chromium trioxide electrolyte utilized in functional plating of articles with decorative character. Functional chrome plating with decorative character is a surface treatment process that involves depositing a thin coating of metallic chrome from the chromium trioxide electrolyte on the surface of a plastic or metallic component following product specific underplates. The final metallic chrome coating is free of Cr(VI). The coating provides the article with a resistant, durable, and safe finish, normally with a bright or matt silvery (occasionally black) appearance. The process is therefore specified for particular applications where this combination of performance characteristics is critical. Approximately 3000 tonnes of chromium trioxide are used in surface treatment applications within the scope of this AfA per year.

Plating using chromium trioxide involves immersion of the component in a series of treatment baths containing chemical solutions or rinses under specific operating conditions and is the final step in the overall surface treatment process: pre-treatments and nickel or copper coatings ('underplates') are normally applied to prepare the surface prior to chromium plating (**Figure 1**). The 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) of the final treated article, and varies depending on the required functionalities of the final product and the substrate to which it is applied.

The characteristics of chromium trioxide, a detailed description of the plating process, and the key functionality of the plated parts are discussed in Chapter 3.

The industry sectors using functional chrome plating with decorative character with chromium trioxide (such as, but not limited to automotive, consumer goods, cosmetics, electrical devices, furniture, general engineering, lamps & light fittings, locks & fittings, sanitary, store construction, tools, wheels & castors and white goods), in order to meet the strict performance criteria necessary for regulatory compliance, public safety and customer expectations are described further below and in Chapter 5.

This summary aims to shortly explain why use of chromium trioxide in functional chrome plating with decorative character is essential for the above mentioned broad range of sectors. It describes the steps and effort involved in finding and approving a replacement for chromium trioxide in these applications and evaluates potential alternatives in detail (Section 6 and 7).



**Figure 1:** Flow chart for the plating process. Data source: FGK, 2014, adapted.

### **Chromium trioxide based surface treatment systems**

Chromium has been used for more than 50 years to provide surface protection to critical components and products, where the products to which the protection is applied must operate to the highest standards, often in demanding environments, for extended time periods. Functional chrome plating with decorative character has unique technical functions that confer substantial advantage over potential alternatives. These include:

- Corrosion resistance,
- Chemical resistance,
- Wear resistance / abrasion resistance,
- Excellent health and environmental safety for finished articles,
- Adhesion between coating and substrate,
- Sunlight resistance / UV resistance,
- Temperature resistance / heat resistance and
- Aesthetics.



Additionally, black chrome electroplating on metal substrates is used as a specialized functional and decorative black metallic chrome coating for the general engineering sector, where further key functionalities are important for the sectors (e.g. electronic and optical applications):

- Electrical conductivity of the surface and
- Reflection behaviour / absorption capability.

The chromium trioxide based functional chrome plating with decorative character is complex. As described above and highlighted in **Figure 1**, chromium trioxide plating typically involves numerous steps, which are depending on the substrate. These are etching as pre-treatment (on plastic substrates) as well as several underplating steps followed by the chrome electroplating process (main process) itself (**Figure 1**). Etching using chromium trioxide has to be applied as a pre-treatment for plastic substrates. 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. Compatibility and technical performance of the overall system are primary considerations of fundamental importance during material specification.

This means that while the use of chromium trioxide may be specified for the final chrome plating step, it cannot be entirely replaced in the process without impacting the technical performance of the final article. As of today, no complete chromium trioxide free process, providing all the required properties to the surfaces of all articles in the scope of this application, is industrially available.

### **Use of chromium trioxide functional chrome plating with decorative character in all evaluated sectors**

A key advantage of chromium plating is that the metallic chrome finish is completely safe to human health and environment, a critical requirement when specifying products relied on by the public. Furthermore, the metallic chromium layer acts to *prevent* release of or contact with substances that are specified in pre-treatment coatings or underplate as part of the complex surface treatment system, so allowing safe use that complies with regulatory obligations. For example, nickel in some underplatings and coatings may be released and available to come into contact with skin, drinking water or other materials. **The prevention of nickel leaching from underplates is therefore essential for all the sectors.**

Under REACH (Restriction entry 27 (nickel and its compounds) of Annex XVII to REACH), nickel or its compounds must not be used in articles intended to come into direct and prolonged contact with the skin, e.g. jewellery, garment fasteners, mobile telephones, with or without a non-nickel coating, if the rate of nickel release from parts coming into direct and prolonged contact with the skin is greater than 0.5 µg/cm<sup>2</sup>/week. Where non-nickel final coatings, such as a metallic chrome coatings with the use of nickel underplatings for functional chrome plating with decorative character, are applied, this maximum nickel release rate must not be exceeded for a period of at least two years of normal use of the article. Such restrictions may be echoed and/or extended in national laws such as the German Consumer Goods Ordinance (BedGgstV - Bedarfsgegenständeverordnung, 1992, last update 2013). Chromium plate therefore often plays an important role in allowing complex coating systems to meet stringent public health criteria.

### **Use of chromium trioxide-based surface treatment by the automotive sector**

Chromium trioxide is used by 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.

**Considerations affecting availability of potential alternatives for the automotive sector**

Introducing new materials into the automotive market is a complex process, involving multiple phases and checks. Safety is the main driver for this.

Metallic chrome plated parts offer superior performance in terms of corrosion resistance, chemical resistance, abrasion resistance, adhesive strength, and sunlight as well as temperature resistance conserving the high aesthetic product. Potential alternatives in the automotive industry must be able to cover all of these requirements. As a drop-in replacement is not available, careful testing and evaluation of potential alternatives' functional behaviour is needed. 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.

In the case of replacing chromium trioxide, all affected components must be revalidated using alternative materials. Substance substitution may cause change of function geometry, thermal durability and leads to unexpected impacts on related parts. Even though the automobile industry is highly experienced in material testing procedures, the validation and testing of alternatives will require several years due to the sheer number of parts involved. In addition, performance of potential alternatives must be tested under conditions of large scale production.

Type approval is the confirmation that production samples of a design will meet specified performance standards. The specification of the product is recorded and only that specification is approved. Within the European automotive industry, two systems of type approval have been in existence for over 20 years. One is based around EC Directives and provides for the approval of whole vehicles, vehicle systems, and separate components. The other is based around United Nations (UN) Regulations (formerly known as UNECE Regulations) and provides for approval of vehicle systems and separate components, but not whole vehicles. Automotive EC Directives and UN Regulations require third party approval - testing, certification and production conformity assessment by an independent body.

A stepwise introduction of alternative technologies in new type-approved models (Directives 2005/64/EC and 2009/1/EC) is foreseen by the automotive industry due to the magnitude of the change and impact on the industry. To make sure production volumes of vehicles are not affected, sufficient capacities for the production of alternative coatings in Europe must be confidently in place. Furthermore, due to the high complexity of the supply chain in the automotive industry, tracking down chromium trioxide depending parts is a time-consuming and complicated task. Assembly of vehicles is carried out across a complex network of manufacturing plants, with an average number of 1500-4500 Original Equipment Manufacturer (OEM) suppliers, each of which have an average of 500-1500 suppliers themselves.

With regard to both the highly complex nature of supply chains in the automotive industry and the lifetime of vehicles, planning reliability is crucial. The average life cycle of an automobile model is about 22 years, comprising 3-5 years development time, 7 years of production and at least 10 years' service life during which there is a need to guarantee availability of spare parts. Realistically, changes to a vehicle model can only be made in a certain period of time, which decreases rapidly after type-approval by a certified body in the early stages of new model development.

The majority of European cars are removed from the fleet after 13-15 years. About 36% of the EU passenger car fleet of 224 million vehicles - approximately 80 million cars - are older than 10 years, further underlining the need for an efficient supply of past model service parts beyond the end of serial production. Commonly, past model service parts are provided for vehicles that have been out

of production for more than 20 years. A minimum of 10 years availability of spare parts must be assured to comply with legislation in some member states (E.g. Germany: Civil law code §242). To make sure that possible alternatives are interchangeable with original spare parts, a complete new type-approval is necessary. Besides these service considerations, national warranty obligations must be fulfilled.

The identification of possible alternatives and the careful validation of their functionalities is a labour/time intensive process that will certainly take several years. According to the European Automobile Manufacturer Association (ACEA), the development of suitable alternatives for functional chrome plating with decorative character using chromium trioxide for current vehicle parts will require a time period of 4 to 5 years followed by industrialization of the technique and implementation in the supply chain. The further minimum timeframe required to develop and implement an alternative is 7 years after the sunset date.

### **Use of chromium trioxide functional chrome plating with decorative character in the sanitary sector**

The sanitary sector relies on functional plating of articles with decorative character to manufacture products including, but not limited to bathroom taps, shower heads, hoses, towel rails, 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.

### **Considerations affecting availability of potential alternatives for the sanitary sector**

Introducing new coatings into the sanitary sector is a complex process, involving multiple phases and checks. Public safety is the main, but not the only driver for this.

Water quality for human consumption is closely regulated to protect public health and there is a substantial body of regulation in place that must be met before an alternative can be introduced to the market.

European Directive 98/83/EC, which aims to protect human health against harmful influences which could originate from contaminants in water designated for human consumption, has been implemented in each Member State of the EU. National laws such as the German Drinking Water Directive typically regulate the microbiological and chemical quality of drinking water by specifying maximum threshold values for key indicator parameters. Requirements on installations for the production, preparation and distribution of drinking water may also be regulated at member state level, e.g. §17 of the German Drinking Water Ordinance. For example, in Germany, materials used for the construction or maintenance of installations that are in contact with drinking water must not negatively affect human health, the smell and taste of the drinking water nor release substances into drinking water in higher concentrations than would be avoidable by using state-of-the-art techniques. In Germany, the competent authority maintains a list of substrates and materials (drinking water hygienic suitable metallic materials) which, following an approved testing method, meet the binding requirements for hygiene and are therefore allowed to be used in contact with drinking water. Where the quality of a coating can be assured, the coating and substrate can be tested together. Reproducibility or quality assurance is also a very important parameter for the sanitary sector, considering the high number of fittings produced.

Industry Standards address testing of metallic materials that are in contact with drinking water. The long-term behaviour of metallic coated products in contact with drinking water is assessed according to EN 16058 (Influence of metallic materials on water intended for human). Flexible coated parts are tested based on a regulation of the German association for gas and water (DVGW, work sheet W 543). The long-term material testing takes at least 26 weeks per test trial.

Coatings or materials that are potential alternatives to metallic chrome coating for use in contact with drinking water require careful development and evaluation according to these test methods. Experience to date is that potential alternatives to chromium will require substantial development to comply with the nickel leaching threshold: ongoing product and technology optimisation and testing is needed to satisfy performance criteria in this regard. As a reference point, compliance with the nickel threshold for the metallic chromium plated products currently in use required 4 trial cycles, and the overall process required more than 4 years in total to complete. The process is expected to be more challenging for potential alternatives. In Germany, the basis for the drinking water hygiene evaluation of the potential alternative must be developed and established by the competent authority and the individual products must also be tested.

Finally, aesthetic quality and colour matching of parts is very important, as customers expect a high quality and durability of appearance over the lifetime of the product. The sanitary sector relies on a complex supply chain involving dozens of independent companies supplying components (deck and angle valves, pipe traps, towel bars and diverters, etc.), all of which must have the same colour and appearance to sustain acceptance by the market. Furthermore, a life-time warranty on sanitary parts is provided in some countries. Therefore, spare parts need to be compatible in function and appearance to existing installations. Compatible spare parts need to be available while existing installations are in use.

An overhasty switch to alternative technologies that do not meet the quality standards will result in decreasing demands on EU products. Since chromium plated products can be imported without restriction, non EU imports based on the chromium trioxide process will provide a cheaper, better quality product.

Sanitary products typically have a production development time of more than 7 years. Planning and design starts years before parts go into production and many sales contracts stipulate a lengthy period of guaranteed delivery (up to 25 years). Accordingly, regular spare part production has to be available for around 10 years after production of the main product has stopped. There are therefore many practical considerations that influence the schedule for replacing functional chrome plating with decorative character using chromium trioxide.

In summary, potential alternatives must be authorised by public authorities before they can be considered technical alternatives. The testing procedures must demonstrate compliance with all regulations, and provide a safe product in contact with drinking water. This requires sufficient time and resources. Spare parts must be available for a minimum of 10 years after production of the main product has ceased. Overall, it is expected to take at least 10 years from identification of a preferred potential alternative until product safety and approval for the use in contact with drinking water is complete. This timeline is independent of the potential alternative material or production process.

### **Identification and evaluation of potential alternatives**

An extensive literature survey and consultation was carried out to identify and evaluate potential alternatives to chromium trioxide in functional chrome plating with decorative character. 31 potential alternatives were identified. 18 of these substances could be excluded from further consideration based on performance and 13 alternatives (including processes and substances) are

focused for ongoing research and development (R&D) programs and are examined in further detail in this report.

In summary, the analysis shows there are no technically feasible alternatives to chromium trioxide in functional chrome plating with decorative character for key applications at the current stage. Several potential alternatives are subject to ongoing R&D, but do not currently support the necessary combination of key functionalities to be considered technically feasible alternatives.

The most promising alternatives to chromium trioxide functional chrome plating with decorative character, across all sectors and substrates, are **trivalent chromium electroplating** and a combination of **lacquer + PVD + lacquer**. Intensive R&D has been performed over many years and is still ongoing on these potential alternatives. Technical improvement of these potential alternatives has been realized in recent years. However, the alternatives are not technically feasible and cannot be considered available to replace chromium trioxide as a commercial application at the current stage of development.

**Trivalent chromium coatings** do not provide colour stability under the influence of light. Parameters such as corrosion resistance and chemical resistance do not sufficiently fulfil sector specific requirements for an aesthetically acceptable and durable surface. Trivalent chromium based coatings are not likely to be available as a broad alternative to chromium trioxide plating before 7 years after sunset date.

The transition to the **lacquer + PVD + lacquer** alternative would require high investment costs for each plating company. Production by this process means the coating time is considerably longer and the throughput of parts is much reduced. This would lead to significantly increased costs per part, such that certain sectors could not continue to manufacture competitively. Besides the clear economic arguments, the technical feasibility of this alternative is not yet comparable or competitive to coatings resulting from chromium trioxide plating processes. Thus, this alternative does not represent a suitable coating alternative from a technical perspective and has clear economic disadvantages. Overall, it is unlikely that the lacquer + PVD + lacquer system could be available as an alternative to chromium trioxide plating before 7 years after sunset date.

Potential alternatives for etching of plastic as a pre-treatment are technically not feasible at the current stage of development. Additional R&D is necessary to adjust these processes to each other to finally meet the industry requirements. It is not expected that alternatives to plastic etching are technically feasible before 7 years after sunset date and even more years might be needed. It has to be noted that etching of plastic substrate is a pre-treatment and part of the process chain applying a functional coating with decorative character and that all the parts of the process chain always have to be adapted towards each other.

### **Concluding remarks**

A large amount of research over the last decades has been deployed to identify and develop viable alternatives to the use of chromium trioxide in functional chrome plating with decorative character. Due to its unique functionalities and performance, it is challenging and complex to replace chromium trioxide based plating in applications that demand superior performance for several different criteria including corrosion, chemical and wear resistance, hardness, aesthetics and safety over extended periods.

Several potential alternatives to chromium trioxide in functional chrome plating with decorative character, such as trivalent chromium plating systems and lacquer + PVD + lacquer based systems, are under intense investigation across industry sectors. However, based on experience and with

reference to the status of R&D programs, alternatives are not foreseen to be commercially available for key applications in this sector before 7 years after sunset date

As a result, a review period of 7 years was selected because it coincides with best case (optimistic) estimates by all the industrial sectors of 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 following substance is subject to this analysis of alternatives (**Table 1**)

**Table 1:** The substance of this analysis of alternatives.

Substance	Intrinsic property(ies) <sup>1</sup>	Latest application date <sup>2</sup>	Sunset date <sup>3</sup>
Chromium trioxide <u>EC No:</u> 215-607-8 <u>CAS No:</u> 1333-82-0	Carcinogenic (category 1A)  Mutagenic (category 1B)	21 March 2016	21 September 2017

<sup>1</sup> Referred to in Article 57 of Regulation (EC) No. 1907/2006

<sup>2</sup> Date referred to in Article 58(1) (c) (ii) of Regulation (EC) No. 1907/2006

<sup>3</sup> Date referred to in Article 58(1) (c) (i) of Regulation (EC) No. 1907/2006

Chromium trioxide is categorized as substance of very high concern (SVHC) and is listed on Annex XIV of Regulation (EC) No 1907/2006.

### 2.2. Uses of chromium trioxide

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

- Pre-treatment processes: etching of plastic substrates and
- Electroplating: applying a metallic chrome coating on top of specific underplates and on different types of substrates, creating either a bright (shiny) or matte look, or a black chrome coating.

### 2.3. Purpose and benefits of chromium trioxide

Using chromium trioxide has multifunctional positive effects based on the characteristics of the Cr(VI) compound. The following desirable properties of coatings produced from chromium trioxide have made this compound a state of the art substance for a wide range of applications for more than 50 years:

- Excellent corrosion protection and chemical resistance to nearly all substrates in a wide range of environments;
- Wear and abrasion properties and
- A high aesthetic surface with mirror-like reflection.

Several alternatives are being tested to replace chromium trioxide. It is a challenge to find a substitute which meets all requirements of each product and specific application while also being technically and economically feasible.

### 3. ANALYSIS OF SUBSTANCE FUNCTION

Chromium trioxide is used for a large variety of applications in a number of different sectors, such as automotive, consumer goods, cosmetics, electrical devices, furniture, general engineering, lamps and light fittings, locks and fittings, sanitary, store construction, tools, wheels and castors, and white goods. All sectors rely on the use of different kinds of metal and plastic substrates. The most commonly used metal substrates, among others, are brass, zinc, magnesium, aluminium and steel (such as stainless steels). These substrates are used in various forms generated by different production processes, such as chill casting, die casting or precision casting, extrusion, pressing or as solid material. The most commonly used plastic substrates are ABS (acrylonitrile-butadiene-styrene), (ABS with polycarbonate) and PP (Polypropylene). PA (Polyamide) is a plastic substrate which is less commonly used and only for special applications due to its specific material properties (high tensile strength: well suited for example, door handles in the interior of cars).

In the subsequent dossier, the terms “metal substrates” and “plastic substrates” are used, and with no further specification, 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 in the respective paragraphs.

Plastic is used as a common substrate for numerous applications due to several beneficial properties. The low weight of the substrate for example reduces the overall weight of the assembled product. In the automotive sector, lower weight of the assembled car results in a lower fuel consumption and therefore less CO<sub>2</sub> emission, while the lower weight of a shower head in the sanitary sector is more convenient for consumers (lower weight when holding the shower head when showering) and offers more consumer safety (lower weight reduces the risk of injury when falling).

Several consortium members are *jobplaters*, applying the functional chrome plating with decorative character for a variety of customers in different sectors, and it may be the case that not all sectors supplied by jobplaters are specifically listed. However, the jobplaters have to fulfil their customers’ requirements, and provided requirements that are in line with the requirements described for the other sectors, these applications are also covered in this dossier.

#### 3.1. Metallic chrome coatings

**Functional chrome plating with decorative character** is usually used to apply a finish to achieve an aesthetic, decorative surface with a high durability in contact with aggressive and demanding conditions (indoor or outdoor). The vast majority of finishes have a bright or matt silvery appearance. A less common variation produces a black colour (“black chrome”). 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 the even surface. The underplates vary depending on the different required functionalities of the final product and the used substrate.

Functional chrome plating with decorative character is widely used in a commercial setting and is applied on metal substrates as well as non-metal substrates. Typical product examples are provided in **Table 2** and in **Figure 2** to **Figure 8** below.

Functionalities of the metallic chrome coatings applied by chromium trioxide based electroplating were evaluated during the consultation phase within the consortium in order to determine **key functionalities** (functionalities of highest priority). These guarantee the requirements of all the sectors of a high **aesthetic** coating and a high-quality and long-lived product. Therefore, the



requirements of **corrosion resistance** properties of all sectors are stringent to prevent corrosion of the coating, the underlying layers and the whole plated product. Additionally the **chemical resistance** must be high. Chemicals in daily contact with the products (e.g. cleaning agents in a number of sectors and salts with regard to the automotive sector) can attack the surface, which can cause corrosion and result in an unaesthetic surface. Corrosion prevention prolongs the product life and guarantees the decorative appearance. A minimum **hardness** of the coating combined with a **high wear and abrasion resistance** is necessary to protect the coating and thus the product from scratches and damage, and to preserve the decorative appearance. As the metallic chrome coating from a chromium trioxide electroplating is applied as top layer, high **adhesion** between the final coating and the underlying base/underplates is required in order 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.

**Table 2:** Some sector specific product examples.

Automotive		Consumer	Cosmetics	Furniture	General Engineering	Sanitary	Store construction	White Goods	Others
Exterior	Interior								
Brand labels/ornaments	Brand labels/ornaments	Shavers	Perfume caps	Chairs	Precision parts & electrotechnical parts	Bathroom taps	Clothes rails	Frame of washing machine doors	Electric devices
Trim strips	Gear lever knobs	Parts of coffee machines	Lipstick caps	Kitchen furniture, interior	Microscopes	Shower heads	Shelves	Interior parts in fridges	Lamps & light fittings
Rims	Trim strips		Jar caps		Laser optics	Towel rails	Racks for shops	Display frames	Wheels & castors
Front skirts	Decorative frames		Nail files		Mechanical engineering parts	Hoses	Clothes rails	Knobs	Locks & fittings
Exterior rear-view mirrors	Rear-view mirrors		Nail scissors		Military applications	Soap dishes	Shelves	Oven shelves	Tools
Radiator grills	Door opener				Solar & photo cells	Mirror frames			
Door opener					Antennas				

Some sector specific examples are illustrated in the following **Figure 2** to **8**.



**Figure 2:** Sanitary sector: bathroom with different metallic chrome coated sanitary products (left); shower with different metallic chrome coated parts (right). Data Source: Dornbracht, 2014.



Data source: FGK, 2014.



**Figure 3:** Automotive sector: different interior parts with metallic chrome coating on plastic substrate.



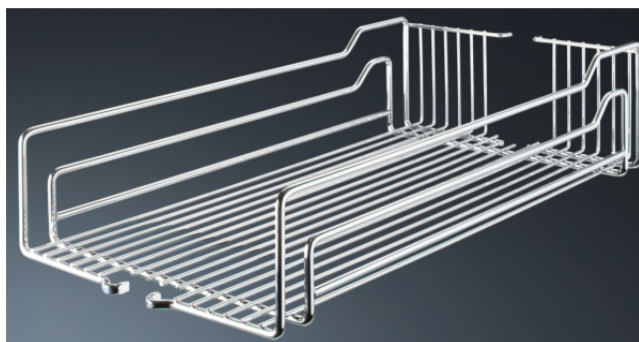
**Figure 4:** Cosmetics sector: perfume flacons (Data Source: RPC beauté Marolles SAS, 2014).



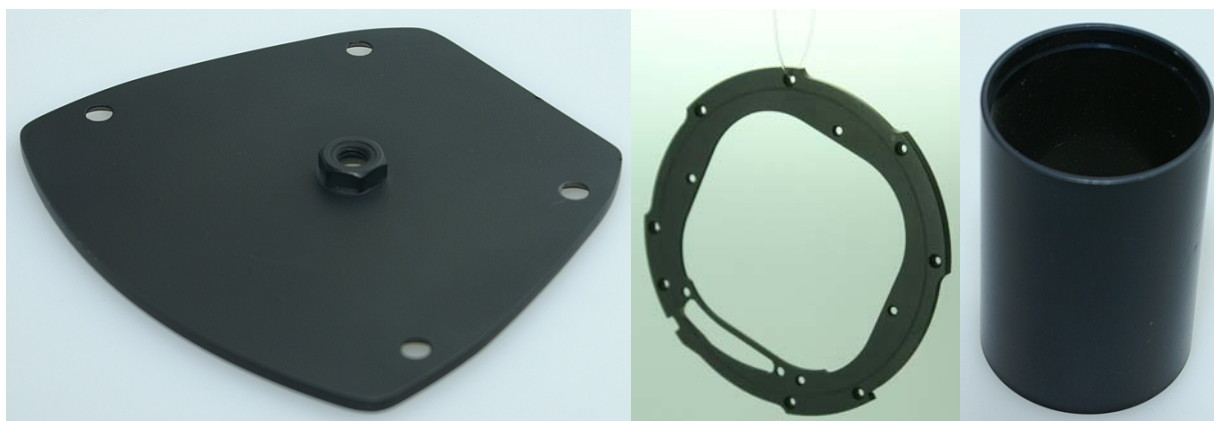
**Figure 5:** Consumer goods sector: shaver. Data source: Company HDO [www.hdo-gmbh.com](http://www.hdo-gmbh.com), 2014.



**Figure 6:**  
White goods sector: frame of washing machine. Data source: Company HDO [www.hdo-gmbh.com](http://www.hdo-gmbh.com), 2014.



**Figure 7:** Furniture sector: kitchen interior: shelf boards. Data Source: Kesseboehmer, 2014.



**Figure 8:** General Engineering sector: casing cover (left), bayonet ring (middle), lens barrel (right). Data Source: Dohmeier, 2014.

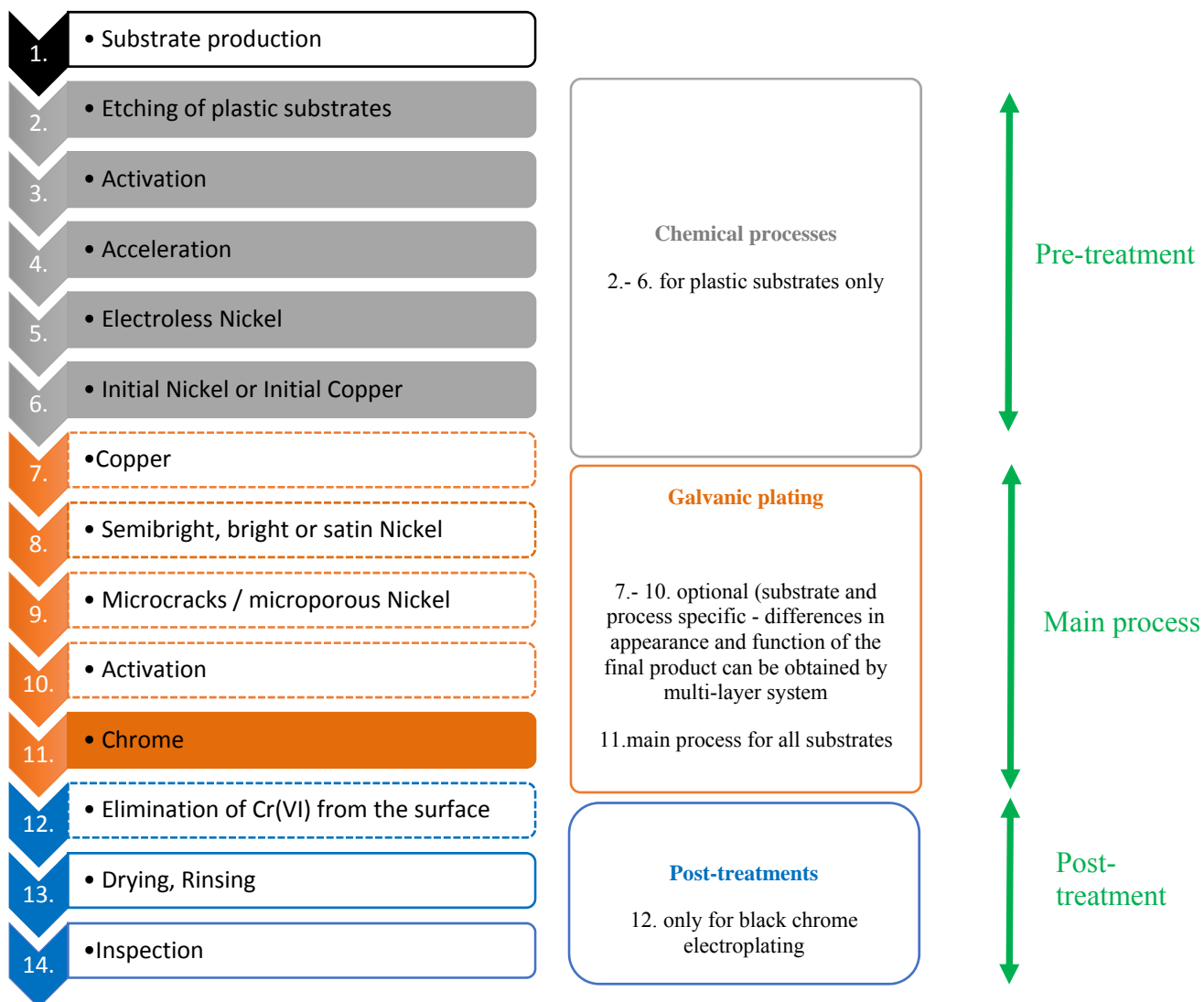
### 3.2. Process description for functional chrome plating with decorative character

A general substrate specific process description is presented in the following chapters. Applying a coating of functional chrome with decorative character is a **process chain**. First, the surface of the substrate is pre-treated. A functional multi-layer system of metal layers is then applied by electroplating, with a final metallic chrome coating using chromium trioxide electroplating. The process chain 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 in the chrome electroplating process and in the etching pre-treatment steps. It is of importance that only the process chain provide the required functional chrome coating with decorative character as a result. The assessment of alternatives for chromium trioxide needs to take into account all process steps, etching and electroplating.

Company specific and sector specific adaption to the general process description presented below are the rule rather than the exception. All the process steps are performed by dipping the substrates in a bath containing the process step specific aqueous solution. It is a **wet-in-wet** process, without intermediate storage of products at any time of the process chain, except for the final drying step. Numerous rinsing steps are performed along the process chain to prevent the carry-over of substances from one bath into another, which would otherwise lead to interference with the subsequent process step.

The electroplating process chain with wet-in-wet processes is illustrated by a flow process chart in **Figure 9**. **Figure 10** and **Figure 11** illustrate examples of an electroplating line.



**Figure 9:** Flow chart for the plating process. Data source: FGK, 2014, adapted.





**Figure 10:** Electroplating line, overview. Data source: FGK, 2014.



**Figure 11:** Electroplating line. Data source: FGK, 2014.

A detailed description of the key performance parameters and the sector specific minimum requirements is provided in chapter 3.3 ff.

### 3.2.1. Pre-treatment processes

Several pre-treatments prepare the surface of the substrates for the functional chrome plating with decorative character with its metallic chrome finish. Adequate preparation of the base substrate is a prerequisite of the process: adhesion between coating and substrate depends on the force of attraction at molecular level. Therefore, the surface of the substrate must be absolutely free of contaminants, corrosive products and other foreign material until the coating process is finished.

In the case of metal substrates, especially but not limited to aluminium, the surface must be **ground** and **polished**, then **cleaned** from any kind of dirt (for example residuals polishing paste) and **degreased**. Both oxides on the surface (created during manufacturing or transportation) and the intermetallic particles precipitated during the course of the manufacturing process must be removed. If these remain on the surface, the subsequent layer could be affected by corrosion and no uniform appearance would result. Therefore, electrolytic cleaning is applied. These pre-treatments for the purpose of functional chrome plating with decorative character are generally free of chromium trioxide.

In contrast, the etching pre-treatment of plastic substrates as described below is necessarily performed in a chromium trioxide containing etching bath.

All pre-treatments types are an important part of the process chain and not stand-alone processes.

#### 3.2.1.1 Etching of plastic substrates

**Etching of plastic substrate** with a chromium trioxide containing solution creates a rough surface by removing material from the substrate. 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 butadiene 1,3 (elementary component of ABS) is removed selectively from the plastic substrate surface creating caverns 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 cavern depth and amount of caverns.

Inadequate etching can cause two major failures: not enough and too shallow caverns, or too deep and too many caverns. 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.

For the etching of plastic substrates, an acidic oxidative mixture of chromium trioxide (between 350 and 400 g/l  $\text{CrO}_3$ ) and sulphuric acid (around 400 g/l  $\text{H}_2\text{SO}_4$ ) is used. The etching process is operated at temperatures between 66° to 70°C and lasts for approximately 10 minutes (Berndt, 2011). Besides creating caverns on the plastic surface, the surface of the substrate is cleaned simultaneously from minor impurities. Additionally, the surface becomes hydrophilic, in the sense of being wettable by aqueous solutions. All these functionalities are indispensable for the following processes to achieve the quality demands of the whole chrome plating process.

During the etching process, the Cr(VI) ions in the etching solutions are reduced to Cr(III) ions. For sustainability reasons, the etching solution is regenerated in the so called “Oxamat” bath resulting in a re-oxidizing of Cr(III) to Cr(VI). This measure limits the need for topping up the chromium trioxide based etching solution. Topping up is only needed to cover losses by protraction effects from the etching bath to the subsequent rinsing bath, and evaporation effects.

Etching is generally performed in a single process line together with the main treatment.

### **3.2.2. Intermediate pre-treatment steps - plastic substrates only**

Different intermediate steps are 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 ( $\text{H}_8\text{N}_2\text{O}_6\text{S}$ ). 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.

#### **3.2.2.1 Activation - plastic substrates only**

As plastic substrates are not conductive, the cavernous surface has to be activated. This is initiated by dipping the substrate in a colloidal tin / palladium solution (acidic hydrogen chlorine based), which is adsorbed at the caverns. The palladium catalyses the application of the subsequent electroless nickel plating.

#### **3.2.2.2 Acceleration - plastic substrates only**

The plastic substrates with colloidal palladium adsorbed at the caverns 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 cavernous surface (Fath, 2008).

#### **3.2.2.3 Electroless nickel plating - plastic substrates only**

The conductivity of the activated plastic surface is locally enhanced following the treatment of the caverns. However, this is not sufficient to generate enough adhesion for subsequent metallic layers. (Fath, 2008). Therefore, an electroless nickel plating is performed to enhance the whole substrate surface. During this process a thin nickel layer with a thickness between 0.1 to 0.5  $\mu\text{m}$  is applied by auto-catalytic deposition. The temperature of the electroless nickel bath is between 30 and 45°C with pH values between 8 and 10. This creates an overall initial metallic layer on the plastic substrate guaranteeing the adhesive properties that are required for subsequent layers.

The appearance of the coated part at this stage is illustrated in **Figure 12**. The treated parts are fixed on a rack (green). The rack is constructed in a way that all inside and outside areas of the part to be plated will be in contact with the respective bath.





**Figure 12:** Electroless nickel coated ABS, intermediate step. Data source: FGK, 2014.

#### **3.2.2.4 Initial nickel or copper layer - plastic substrates only**

The thickness of the already applied electroless nickel layer is technically not sufficient for the upcoming electrolytical deposition of subsequent multi-coatings, because the electrical current would be too high and thus burn the electroless nickel layer during deposition (Fath, 2008). Therefore, the layer thickness and electrical conductivity must be increased by applying either an initial copper layer (copper strike or copper immersion) or an initial nickel layer (nickel strike).

The initial copper layer by copper strike is electrolytically applied using a bath with a mixture of copper sulphate, sulphuric acid and chloride component. The copper immersion is applied by dipping the electroless nickel coated plastic substrate in a copper sulphate solution (without chloride component). The galvanic effect causes dissolution of the nickel and deposition of the copper onto the substrate (electroless step). In both cases, the resulting copper layer enhances the conductivity of the base substrate and protects it from corrosion during the subsequent copper plating step.

When talking about the use of an initial nickel or copper layer, this is the first layer in the multilayer plating system which is electrolytically applied.

**After activation, acceleration, electroless nickel plating and application of the initial nickel or copper layer, the plating process chain on plastic substrates is continued in the same sequence as the process for metal substrates coating.**

#### **3.2.2.5 Copper step - optional**

Depending on the required functionality and use of the final product, a copper layer can be applied on the substrate prior to the 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.

With regard to 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

equalizes tensions resulting from different coefficients of expansion of the different materials occurring in the course of temperature differences and temperature changes. The copper layer therefore prevents cracks and blistering or delamination of the subsequent coatings.

#### **3.2.2.6 Nickel step - all substrates**

The application of nickel layers prior to the final metallic chrome layer is necessary, as only the multi-layer combination is able to meet the required key functionality of the final product. These are corrosion and chemical resistance, hardness, adhesion and high aesthetic of the final product. The nickel layer as such characterizes the final appearance of the product as matt, satin or bright and is also applied in a two-layer system. It combines either semi-bright nickel layer and bright nickel layer or functional nickel layer or velour nickel layer. The two-layer nickel system outperforms the single nickel layers of the same thickness.

Nickel electroplating is similar to all other metal electrodeposition processes. The first nickel layer is sulphur-free, whereas the second layer contains sulphur. (Di Bari, 2010).

#### **3.2.2.7 Functional nickel step - optional**

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.

The **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 10000 active pores per square centimetre.

#### **3.2.2.8 Chrome activation - all substrates**

An activation step after nickel deposition and prior to chromium plating is necessary. The nickel surface must be activated by using a low concentrated chromium trioxide electrolyte and a very low current density prior to the actual chromium plating step.

#### **3.2.3. Chrome step - all substrates**

The metallic chrome layer is applied by electroplating based on the principle of electrolysis. Electroplating forms a coherent metal coating on the substrate with previously applied intermediate layers. It uses the substrate as a cathode and an inert anode (most often used are lead or tin) and induces an electrical current. The substrate is immersed in the electrolytic plating solution containing dissolved chromium trioxide and additives (electrolytes). During the electroplating

process, the hexavalent chrome (Cr(VI)) is reduced to metallic chrome Cr(0) and builds up the metallic chrome coating (electrodeposition).

In this process, the concentration of CrO<sub>3</sub> 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/dm<sup>2</sup>.

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 0.2 µm and 2.0 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.

During the chrome electroplating process chain, numerous rinsing steps are carried out 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 usually occurs in several steps following the cascade technology. The most common technique is counter-current cascade rinsing, where the part is rinsed in a succession of rinsing baths that are dedicated to the plating bath. Most of the process water is handled in a closed-loop system minimizing wastewater streams by reusing rinsing water in another process bath of the same type. Refilling of the chromium trioxide electrolyte is always performed to the same bath.

A black chrome coating is a dark, most often black variation of the metallic chrome coating resulting from using a higher current density of the chromium trioxide plating bath and using other additives such as nitrates or fluorides. Black chrome coating is 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. Black chrome coatings are special applications on plastic parts in the automotive (exterior) sector and on metal substrates for the general engineering sector. For the black chrome coated plastic substrate, the same key functionalities apply as for conventional chrome electroplated substrates (refer to chapter 3.3.2. ). For applications in the general engineering sector, the black chrome coated surfaces have to be electrically conductive with at the same time very low reflection properties (high light absorption capacity). These special functionalities make this type of black chrome coating ideal for optical applications for photo, laser and solar technology as well as for use in antennas or microscopes.

Overall, the electrolytic process of plating with chromium trioxide is performed at low temperatures (no high energy costs for heating of the bath). The coating is applied quickly and due to the bath application technique, almost all kind of articles with all different geometries (flat, complex, with inner cavities, etc.) and size (independently if small or big) can be plated.

### **3.2.4. Post-treatment processes - all substrates**

Post-treatments comprise rinsing and cleaning steps to remove potential remaining process chemicals from the product. As final step the product is dried. These post-treatments are chromium trioxide free and differ depending on the base substrate and the company or sector specific requirements.

The final appearance of a metallic chrome coated part is illustrated in the picture below (refer to **Figure 13**).



**Figure 13:** Metallic chrome coating from chromium trioxide based electroplating on ABS, final process step. Data source: FGK, 2014.

A special post-treatment is required for the plated parts after **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 bisulfite solutions to reduce residual Cr(VI) to Cr(III).

### 3.3. Key functionalities of chromium trioxide

The unique functionalities of chromium trioxide make it an ideal and not easily replaceable substance in functional chrome plating with decorative character use with the high quality requirements of the final coating to be met in the long-term. During the consultation phase, the following **key functionalities** for the metallic chrome coating applied by chromium trioxide based electroplating were identified (taking the whole surface treatment process into account):

- Corrosion resistance,
- Chemical resistance,
- Wear resistance / abrasion resistance,
- Prevention of nickel leaching,
- Adhesion between coating and substrate,
- Hardness,
- Sunlight resistance / UV resistance,
- Temperature resistance / heat resistance and
- Aesthetics.

Given the special application of black chrome coatings on metal substrates for the purposes of the general engineering sector (for example electronic and optical applications), the following two key functionalities have to be considered separately:

- Electrical conductivity of the surface and
- Reflection behaviour / absorption capability

Nevertheless, the most important key functionalities with regard to the high-quality final product are related to the chromium trioxide based electroplating step.

### 3.3.1. Key functionalities of chromium trioxide based surface pre-treatments (etching of plastic substrates)

In **Table 3**, selected **key process functionalities** for the etching pre-treatment of plastic substrates are listed.

An adequate etching pre-treatment is necessary to prepare the surface for the subsequent process steps and to achieve a high-quality end product with a functional decorative surface resulting in the key functionalities of the final product as listed in chapter 3.3.2.

**Table 3:** Key process functionalities of chromium trioxide based etching pre-treatment of plastics.

Process	Key Process Functionality
Etching of plastics	Removal of residuals from the surface
	Long-time bath stability
	Simple bath maintenance
	Simple analytical method for process control
	Rack with treated parts also usable with subsequent process step
	Etch rate: removal of butadiene-1,3
	Surface roughness: cavern depth & amount of caverns

To achieve good etching results, the **etching rate** has to be carefully chosen depending on the substrate used, whilst preventing under-etching and over-etching. If the correct etch rate is not used and the substrate is either etched too long or too short, the key functionalities of the subsequent coating may heavily be 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.

Further important key process 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. 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 process steps to avoid interferences that might affect the quality of the final product.

The key functionality of plastic etching is to create roughness to the substrate's surface by creating a specific number of **caverns** with a certain depth (typically between 1 and 3  $\mu\text{m}$ ) 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. The adhesive properties of the etched surface can be tested in peel tests with an overall peeling strength not to exceed 1 N/mm. It should be noted that etching with a chromium trioxide based solution only affects the ABS substrate (selective etching). This is especially important and necessary for the plating of parts made of two or more components (2K, 3K), for example ABS parts assembled with integrated blends (non-ABS parts, for example made of polycarbonate). For the final appearance of the two component part, only the ABS part is available for subsequent plating, not the blended part. If etching was to affect the non-ABS parts also, the surface structure and aesthetic appearance of these parts would be ruined.

### 3.3.2. Key functionalities of chromium trioxide based electroplating

To give an overview on the widespread range of requirements, **Table 4** lists the key functionalities for chromium trioxide plated surfaces in the respective sectors. More detailed information on the sector specific requirements is described in the chapters below. This list is intended to provide an evaluation basis for potential alternatives and alternative coatings and is not intended to cover all relevant electroplating process parameters.

**Table 4:** Sector specific key functionalities of chromium trioxide based electroplating

(the table is non-exhaustive and its intention is not to cover all electroplating process relevant functionalities, but those which are helpful to evaluate potential alternatives and alternative coatings).

Key Functionality	Auto-motive exterior	Auto-motive interior	Cosmetic sector	Furniture	General Engineering	Sanitary sector	Store Construct.	White Goods sector	Others (exemplarily)
<b>Corrosion resistance</b>	- 480 h NSST EN ISO 9227 (up to 1000 h) - up to 96 h CASS EN ISO 9227 - Numerous tests acc. to OEM specifications such as for example Florida or Kalahari simulation	- 240 h NSST EN ISO 9227 - 24 h CASS EN ISO 9227	24 h SST ASTM B117	- 600 h SST EN ISO 9227 - 3 cycles (each 24 h EN ISO 6270-2 plus 1 cycle (24 h in EN ISO 9227.	*	- 300 h (> 500 h to 1000 h) EN ISO 9227 4 to 24 h CASS EN ISO 9227 - 3 cycles in Kesternich Test EN ISO 6988 / DIN 50018	*	240 h in NSST EN ISO 9227	- 96 h NSST EN ISO 9227 (wheels & castors)
<b>Chemical resistance (resistance against cleaning agents)</b>	No visual degradation of the coating after testing with different chemicals	No visual degradation of the coating after testing with different chemicals	No visual degradation of the coating after testing with different chemicals	*	*	No visual degradation of the coating after testing with different chemicals	*	No visual degradation of the coating after testing with different chemicals Condensation water test to DIN ISO 6270	No visual degradation of the coating after testing with different chemicals
<b>Wear resistance / abrasion resistance (scratch resistance)</b>	- Taber abrasion: 80% remaining gloss after 20 double strokes EN 2813 - car wash resistance ISO 20566	Taber abrasion: 10,000 hubs - further tests acc. to OEM specifications, for example Abrex or Martindale	No defects after tests on "Consumer's handbag behaviour"	*	*	Taber abrasion: no visually detectable damages	25000 double strokes in abrasion testing	Taber abrasion: no visually detectable damages after 500 double strokes	
<b>Ni leaching (not toxic)</b>	0.5 µg/cm² per week (Bed GgstV)	0.5 µg/cm² per week (Bed GgstV)	0.5 µg/cm² per week (Bed GgstV)	0.5 µg/cm² per week (Bed GgstV)	0.5 µg/cm² per week (Bed GgstV)	0.5 µg/cm² per week (Bed GgstV) long-term	0.5 µg/cm² per week (BedgstV)	0.5 µg/cm² per week (BedGgstV)	0.5 µg/cm² per week (BedGgstV)

## ANALYSIS OF ALTERNATIVES

Key Functionality	Auto-motive exterior	Auto-motive interior	Cosmetic sector	Furniture	General Engineering	Sanitary sector	Store Construct.	White Goods sector	Others (exemplarily)
						Nickel release test (EN 16058 < 20 µg/L in drinking water TrinkwV			
<b>Adhesion</b>	GT0 to GT1 (after temperature cycle test) in cross-cut test EN ISO 2409 Peel resistance: > 3.5 N/cm to 9 N/cm (ABS: 7 N/cm)	GT0 to GT1 (after temperature cycle test) in Cross-cut test EN ISO 2409 Peel resistance: > 3.5 N/cm to 9 N/cm (ABS: 7 N/cm)	Cross-cut test EN ISO 2409: GT0			Cross-cut test EN ISO 2409 (GT0 to GT1 (after temperature cycle test)			Cross-cut test EN ISO 2409 (GT0) (electrical devices)
<b>Sunlight resistance (UV exposure)</b>	- 3200 h Florida simulation	- 10 exposure cycles according to ISO 75202	Simulation of 6 month exposure to artificial light in stores	*	*	Company specific sun tests	*	Suntest with a 1,500 W xenon lamp and 765 W/m <sup>2</sup> radiated power	
<b>Temperature change resistance / heat resistance</b>	OEM specification	OEM specification	*	*	Temperature resistance > 750°C	5 cycles in temperature cycle test according to EN 248	*	- 3 cycles in temperature cycle test (each 80°C for 19 h, cooling period, -20°C for 4 h) - 1 cycle in temperature shock test: 80°C for 2 h with rapid down cooling to 10°C	-3 cycles in temperature cycle test EN ISO 2409 (each 80°C for 19 h, cooling period, -20°C for 4 h) (electrical devices)
<b>Electrical conductivity</b>	Not applicable	Not applicable	Not applicable	Not applicable	High electrical conductivity of the surface	Not applicable	Not applicable	Not applicable	Not applicable
<b>Reflection behaviour / absorption capability</b>	Not applicable	Not applicable	Not applicable	Not applicable	The surface shall absorb and not reflect direct incident light and heat (low reflection behaviour)	Not applicable	Not applicable	Not applicable	Not applicable
<b>Aesthetics</b>	- Surface has to be	- Surface has to be	Surface has to be	Surface has to be free of	Surface has to be	Surface has to be	Surface has to be free	Surface has to be free of any	Surface has to be free of any

Key Functionality	Auto-motive exterior	Auto-motive interior	Cosmetic sector	Furniture	General Engineering	Sanitary sector	Store Construct.	White Goods sector	Others (exemplarily)
	free of any kind of defects such as pores, cracks and blistering - Colour testing according to EN ISO 11664 - Finish quality (bright or matt) can be tested acc. to primordial pattern	free of any kind of defects such as pores, cracks and blistering - Colour testing according to EN ISO 11664 - Finish quality (bright or matt) can be tested acc. to primordial pattern	free of any kind of defects such as pores, cracks and blistering after tests on "Consumer's handbag behaviour"	any kind of defects such as pores, cracks and blistering	free of any kind of defects such as pores, cracks and blistering	free of any kind of defects such as pores, cracks and blistering	of any kind of defects such as pores, cracks and blistering	kind of defects such as pores, cracks and blistering Brightness measuring	kind of defects such as pores, cracks and blistering

*\* no specific quantitative values on this parameter, as other parameters are more relevant for the applications of the sector*

A more detailed description of the key functionalities taking different substrates into account is given in the following paragraphs.

### 3.3.2.1 Corrosion resistance

Corrosion describes the process of oxidation of a metallic material due to chemical reactions with its surroundings, especially under the effect of humidity and water. In this context, the parameter corrosion resistance means the ability of a metal to withstand gradual destruction by chemical reaction with its environment. Corrosion resistance is one of the most important parameters for all sectors. With regard for example to the automotive and sanitary sector, meeting its minimum requirements play a key role to assure the required life time of sanitary articles and automotive parts whilst preserving the functionality and aesthetics of the plated parts as long as possible.

Corrosion resistance is tested by the companies performing functional chrome plating with decorative character by using different test methods in accordance to customer and OEM standards. Therefore corrosion resistance requirements are sector specific and depend on the applied test method.

The main tests regarding corrosion resistance performed for all sectors are **salt spray tests** according to EN ISO 9227 and/or ASTM B117.

For the **sanitary sector**, EN 248 regulates the tests to be performed for electrodeposited coatings of Ni-Cr, however the tests for corrosion resistance refer to EN ISO 9227. To fulfil the requirements, the coated parts should not show defects exceeding a dimension of 0.3 mm. In further tests, coatings are exposed to acidic rain atmosphere (sulphur dioxide) followed by a three cycle (72 h) **Kesternich test** according to EN ISO 6988 / DIN 50018. During this test, no defects should occur.

When using a Neutral Salt Spray Test (NSST) according to EN ISO 9227 or the sanitary specific EN 248, the most common minimum corrosion requirement stated during the consultation for the **sanitary sector** is **300 h**, but also higher corrosion resistance of **> 500 h** up to **1000 h** NSST were stated to be required depending on the final application (e.g. private houses vs. hotels). Corrosion requirements under the more demanding CASS (Copper Accelerated Salt Spray) test range between



**4 and 24 h.** When using the Kesternich test method, the coatings have to withstand **3 cycles** (8 h exposure / 16 h drying time). As the corrosion of a coating is also caused by chemicals, the sanitary sector uses tests with household cleaning agents for corrosion and chemical resistance at once.

The corrosion requirements of the **automotive sector** are differentiated between plated parts for exterior and for interior use. For new systems, specific tests and requirements have to be evaluated. In particular paint systems and vapor deposited layers are very different to metallic surfaces and therefore need different approaches. The most common minimum corrosion requirement for **exterior** parts (with and without prior stone chip resistance) is **480 h NSST according to EN ISO 9227** and **up to 96 h CASS** according to EN ISO 9227. The requirements for **interior** parts are **240 h NSST to EN ISO 9227** and **24 h CASS** according to EN ISO 9227. For a special application, a corrosion resistance of **1000 h** in NSST according to EN ISO 9227 was stated during the consultation phase for the automotive industry. The automotive sector performs numerous further tests according to individual OEM requirements, for example Florida simulation or Kalahari simulation.

The corrosion requirements of the **cosmetics sector** are defined as **24 h SST** according to ASTM B117 artificially simulating sweat contact.

The **white goods sector** requires a minimum of **240 h** in NSST according to EN ISO 9227 without defects on the surface.

For the **furniture sector**, the corrosion requirement is up to **600 h in NSST** according to EN ISO 9227. Furthermore, the sector requires that the coating is able to withstand a coupled humidity test (3 cycles each of 24 h according to EN ISO 6270-2 (resistance to humidity/rust generation)) and one cycle of 24 h in NSST according to EN ISO 9227. Further tests are performed in accordance to EN 68930 (requirements and testing for kitchen furniture) and DGM-RAL-GZ430 (Deutsche Gütegemeinschaft Möbel e.V., 3 testing cycles).

Example provided minimum corrosion requirements for products of **other sectors**, such as the wheels & castors sector are 96 h in NSST according to EN ISO 9227.

### 3.3.2.2 Chemical resistance / resistance against cleaning agents

The chemical resistance or resistance against cleaning agents is defined as the ability of solid materials to resist damage by chemical reactivity. The resistance against cleaning agents, that is, the resistance against corrosion after contact with aggressive agents, is one of the performance parameters of highest priority in the **sanitary sector**, the **white goods sector** and with regard to exterior parts in the **automotive sector**. In general, a coating that is not adequately resistant against cleaning agents shows corrosion. Therefore, the chemical resistance is often tested in line with corrosion resistance. The chemical modification of protective coatings or metal parts leads to increased maintenance costs and may reduce safety when travelling by car.

A number of different tests on resistance against cleaning agents are performed in the **sanitary sector**. The sanitary sector uses different cleaning agents (such as vinegar extract with a concentration of 5% or other commercially available products) and personal care chemicals (such as toothpaste, nail polish remover, shampoo) with varying concentrations for their 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 are conducted under company specific conditions. They are based on similar test criteria and include evaluation of the chemical resistance in a **spray test** as well as in a **continuous immersion test**. After the spray test and continuous immersion test, 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).

For the **cosmetics sector**, customer specific tests such as acetone test, alcohol test and bulk maculation test are performed to evaluate the resistance of the coating to chemical attacks, for example caused by the composition of the content (fragrances). The requirements are fulfilled, if no decolouration of the coating occurs after the chemical attack.

Within the **white goods sector**, the main focus is on chemical resistance of the products. A drop test is performed with the following typical chemical agents:

- Vinegar essence (with a concentration of 25%),
- Caustic soda (with a concentration of 10%),
- Chlorine bleaching lye (with a concentration of 12%),
- Hydrogen peroxide (with a concentration of 35%),
- Formic acid (with a concentration of 5%), and
- Washing detergents.

For the drop test, one to two drops of the test agents are dropped on the sample, which are then placed for 24 h in a humidior with a constant temperature of 20°C and a humidity of about 58%. After 24 h, the samples are rinsed.

Other test methods use condensed water in accordance with EN ISO 62370 AHT. A total of 20 cycles is conducted, thereof each cycle with 8 h testing at 40°C at 100% humidity and 16 h at 20°C at less than 100% humidity. Suds (washing waters) can also be subject to testing using different kinds of household and commercial - liquid and solid - washing detergents, such as Persil Megaperls, Somat Klarspueler or Tassat. After testing, the samples are visually inspected regarding their aesthetic appearance and the adhesive performance without tolerating any changes.

### 3.3.2.3 Wear resistance / abrasion resistance

The abrasion / wear resistance of a coating is its ability to resist the gradual wearing caused by abrasion and friction. The wear resistance of a coating is tested in all sectors via its abrasive behaviour.

A commonly used test method within all sectors is the **taber linear abrasion** test. During this test, a rubbing material (i.e. felt strip) is rubbed over the coated surface with a defined force and number of cycles/repetitions. Whereas the distinct test procedure is company specific, the requirement is always the same: the coating shall not show any visually detectable damages after taber linear abrasion (“no scratches”).

The wear resistance for coated parts used in the automotive sector is differentiated according to interior and exterior application. For **exterior automotive parts**, the coating must show a **remaining gloss of 80%** (detected according to ISO 2813 after 20 double strokes with taber abrasion). Exterior parts of the automotive sector also need to be car wash resistant according to ISO 20566 and stone-chip resistant according to EN ISO 20567-1. **Interior automotive parts** must withstand **10000 hubs** with a force of 10 N without optical change using Abrex or Martindale as abrasive materials. Test specifications are defined according to OEM specifications.

The **cosmetic sector** tests the abrasion resistance by simulating the random phenomena of rubbing and mechanical shock occurring in the consumer's handbag (“consumer's handbag behaviour”).

The abrasion resistance of products of the **white goods sector** is tested by using a sponge cloth with a standard tissue cover. The test is performed with 500 double strokes and a load of 350 g. After the tests, the samples are visually inspected regarding their aesthetic appearance and the adhesive performance; no changes are tolerated.

The key functionality for coated products from the **store construction sector** is the abrasion resistance of the coating. The abrasion resistance is tested by simulating the abrasion of coat-hangers to the clothes rails with a defined testing weight. The requirements are coating specific and the metallic chrome coated products serve a high-qualitative market with the highest abrasive requirements of 25000 double strokes. There are less high qualitative products of the store construction sector (for example powder coated products) with lower requirements (for example 5000 double strokes only), lower life-time serving a lower-price market. **Hardness** is defined as the resistance of solid matter to various kinds of permanent shape changes when a force is applied. The hardness of a coating depends on the hardness of the base material. Hardness measurements of thin coatings used for decorative purposes are technically difficult. Therefore, it is determined indirectly via its scratch and **abrasion resistance**.

### 3.3.2.4 Prevention of nickel leaching

The multi-layer plating of functional chrome plating with decorative character includes nickel present in underplates. These nickel layers are of great importance for all sectors and applications and guarantee quality and appearance of the final coating. 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 parameter is relevant for all sectors where the coated product comes in contact with skin, food or other materials potentially affecting the health of the consumer. Therefore, the maximum nickel leaching rate of nickel plated products is regulated by law (for more details refer to chapter 5).

The leaching occurs over a long period of time, depending on the corrodibility of the substrate's surface. The metal release rate depends on the type of coating and the coating process. **Prevention of nickel leaching is a key functionality for all sectors.**

Products which are designed to deliver drinking water are subject to national and international regulation (for example European Drinking Water Directive, German Drinking Water Ordinance TrinkwV) due to the water's fundamental impact on public health.

Parts plated in chromium trioxide plating lines have proven their quality in various leaching tests (for example NSF61; EN 16058). Alternatives must be comparable or better in their health impact – this point is important even for non-metallic coatings which may have contact with drinking water.

In the **sanitary sector**, the main use for metal parts and coated metal parts in the water supply are domestic service installations such as taps and sinks. Contact between metal and drinking water can lead to the release of metal ions into the water if the metal or metal layers (substrate) are corroded. Long-term nickel release to drinking water from substrates with a Ni coating or Ni intermediate layer can be determined with the long-term nickel release test (EN 16058).

According to Regulation (EC) 1907/2006 of the European Parliament and the Council (December 18, 2006) concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), Annex XVII (Restrictions of the manufacturer, placing on the market and use of certain dangerous substances, preparation and articles), nickel shall (amongst others) not be used in articles intended to come into direct and prolonged contact with the skin if the rate of nickel release from the parts of these articles coming into direct and prolonged contact with the skin is greater than 0.5 µg/cm<sup>2</sup> per week and in articles where these have a non-nickel coating unless such coating is

sufficient to ensure that the rate of nickel release from those parts of such articles coming into direct and prolonged contact with the skin will not exceed  $0.5 \mu\text{g}/\text{cm}^2$  per week for a period of at least two years of normal use of the article. In addition, these types of articles shall not be placed on the market unless they conform to the respective nickel release limit.

In Germany, for example, sanitary parts used in direct contact with drinking water must meet the requirements of the German Drinking Water Directive and of the Environmental Protective Agency (see chapter 5.2). These require that the nickel concentration in drinking water caused by Ni migration should not exceed **20  $\mu\text{g}/\text{l}$** .

In addition, according to § 6 No 3 and Annex 5 of the German Consumer Goods Ordinance (applicable to all industry sectors), it is not permitted to place consumer goods with Ni and Ni containing compounds on the market, if more than  **$0.5 \mu\text{g}/\text{cm}^2$  Ni per week** is released. This applies to consumer goods that come into direct and prolonged contact with the skin. For consumer goods with a Ni free topcoat (such as a metallic chrome coating), the maximum Ni leaching for a time period of **2 years** in normal use conditions shall also not exceed  **$0.5 \mu\text{g}/\text{cm}^2$** . These are important thresholds for decorative coatings as discussed within the sectors and are of particular importance for the **cosmetics sector**, the **white goods sector** and for **interior car parts of the automotive sector**. Therefore, a nickel release test is performed according to the specifications of EN 1811. No Ni allergic reactions are allowed to occur after contact with the coated parts (such as gear lever knob, taps or fragrance caps, and lipsticks).

For the **cosmetic sector**, the products must fulfil the Ni leaching thresholds, showing that the coatings are not toxic, even if the plated articles are not in direct contact with skin.

### 3.3.2.5 Adhesion

In this AoA, the parameter adhesion describes the tendency of dissimilar particles or surfaces to adhere to one another. The delamination of the different layers or the substrate is the result of a 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 life time and aesthetic appearance of all coated parts, it is important that the coatings applied to the substrates can withstand these effects.

For all sectors, the most commonly used test method of the adhesive properties of a coating to the substrate is a cross-cut test according to EN ISO 2409. For this test, a grid of six parallel and six perpendicular cuts are severing the overall coating down to the substrate. Afterwards, an adhesive tape is applied to the coating and then removed. The visual inspection after removal of the tape shall not show any detectable defects on the cuts equivalent to a **cross-cut index GT0** (best index of a six-level scale).

Further tests of the adhesive properties are performed after exposing the coating, or rather the cross-cut coating, to a temperature cycle test (“shock test”, “temperature change test”). This commonly used test is based on ASTM B571-97. A large variety of company specific and sector specific test conditions for the performance of temperature cycle and climate cycle tests are known, as the test is specified according to the field of application, type of coating, thickness of the coating, ductility and the composition of the substrate.

Test conditions vary in terms of maximum temperature (for example  $70^\circ\text{C}$ ,  $80^\circ\text{C}$ , or  $140^\circ\text{C}$ ), minimum temperature (for example minus  $40^\circ\text{C}$ , minus  $26^\circ\text{C}$ , plus  $20^\circ\text{C}$ ) and the time the coating is exposed to the respective minimum or maximum temperature (single exposure time, for example 120 seconds, 30 minutes, 4 hours, 24 hours). The number of cycles relates to the single exposure

time. Under short exposure times, a high number of total cycles is performed (for example 300 cycles). In case of long single exposure times, a small number of cycles (for example 3 cycles, 5 cycles) is performed. The visual inspection of a cross-cut coating (according to EN ISO 2409) after exposing to a temperature cycle test has to fulfil the **cross-cut index GT1**.

Adhesion of coated **plastic substrate** (for example ABS) is tested as peel resistance of the coating, i.e. according to EN ISO 1464. The peel-off requirements of coatings depend on the substrate. For **ABS** an adhesive strength of up to **9.0 N/cm** is required while for ABS with polycarbonate an adhesive strength of **7.0 N/cm** needs to be met for the use on **interior** and **exterior automotive** parts. In general, a minimum peel resistance of **> 3.5 N/cm** is required for all coatings.

In the **automotive sector** (interior and exterior parts), stone-chip resistance is tested via a strip tape test according to EN ISO 20567-1, determining also the adhesive properties of the coating under “outdoor” conditions. A common short-test for adhesion is the St. Andrews Cross Test (according to an OEM specification), where the surface is cut like a St. Andrews Cross and a special adhesive tape is used to test the local adhesion of the coating to the substrate.

Adhesion is one of the main criteria for the cosmetics sector. Therefore, local adhesive tape tests according to ASTM D3359 and cross-cut tests according to ISO 2409 are conducted.

### 3.3.2.6 Sunlight resistance / UV resistance

Sunlight resistance of a coating is defined by the ability to withstand degradation when exposed to sunlight or ultraviolet light. Long term sunlight exposure can cause UV degradation resulting in cracks and blistering of the coating. 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. Further specifications for laboratory sun tests comprise exposure of the coating to 650 Watt for 588 h. This test should be passed without showing defects.

To test UV resistance for **exterior automotive parts**, these are exposed to xenon arc lights for **3200 h** according to EN ISO 4892-1 and -2 (“Florida Simulation” according to OEM specification). This test needs to be passed without visual changes of the coating.

The **interior automotive sector** investigates visual degradation of coating according to EN ISO 75202 (1988, withdrawn in 2002 and replaced by EN ISO 105-B06-draft). In general, the coating must resist to **10 exposure cycles** without visual changes.

In the **cosmetics sector**, UV resistance is tested by simulating 6 months exposure to artificial light in stores. No changes or deterioration in shade should occur (fragility of plastics) on the coatings/articles exposed to direct sunlight or to radiation behind a display case.

The products of the **white goods sector** are tested for sunlight resistance in the sun test with a 1500 W xenon lamp and a radiated power of 765 W/m<sup>2</sup>. The samples are then visually inspected regarding their aesthetic appearance and the adhesive performance. No changes are tolerated.

### 3.3.2.7 Temperature change resistance / heat resistance

The base material (such as metal die casting, 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.

In the **sanitary sector**, the temperature change resistance of coated parts can be tested in a temperature cycle test according to EN 248. The test method specifies heating of the plated products for 30 minutes to a temperature of 70°C, followed by a 15 minutes cooling period. The parts are cooled down to minus 30°C for 30 minutes and subsequently brought back to ambient temperature. This **cycle** is repeated **5 times**. The coated parts are visually examined without additional devices from a distance of approx. 30 cm for 10 s under defined light circumstances. The surface should not show any cracks, blistering or loosening of the coating.

The temperature change resistance is tested specifically for showers (hand shower and head showers) according to EN 1112 with 300 cycles changing water temperature from 65°C to 20°C for all substrates.

For the **automotive sector**, the temperature change resistance is tested in a temperature cycle test, i.e. according to DIN 53100 or OEM specific tests. The requirements vary depending on the substrate. In long term tests coated plastic parts are exposed for 3 months to 90°C (partially up to 105°C), in short term tests they are exposed for several hours. Some coated metal parts (depending on the base material) are exposed to temperatures of up to 850°C for several hours. In addition to the temperature change tests (+80°C for 20 h, -40°C for 4 h, three times) climate change tests have to be performed. These tests are comparable to the temperature change test, however in addition there is a defined humidity (up to 80%) during the high temperature phase. The detailed temperature and humidity characteristic depends on the OEM's specifications. The tests are performed for up to 8 cycles, and a time up to 96 h. After these tests, the coatings should not show any optical change or delamination.

For the **white goods sector**, the products are tested in 3 temperature cycles. In each cycle the product is heated to a temperature of 80°C for 19 h, followed by a 30 minute cooling period. The parts are then cooled to a temperature of minus 20°C. Additionally, a temperature shock test is performed by heating the products for 2 h to 80°C followed by 10 minutes of 10°C with and without a rapid cooling down period. The water vapour and hot water resistance of the plating is tested for parts applied to washing machines. Therefore, samples are hung for 24 h in water vapour above warm water. After the tests, the samples are visually inspected regarding their aesthetic appearance and the adhesive performance without tolerating any changes.

In general, the temperature cycle tests are highly stressing to the coating and are often performed prior to tests on the adhesive properties.

For **black chrome** surfaces, a temperature resistance of the coating of a least 750°C is required.

### 3.3.2.8 Electrical conductivity

**Black chrome** surfaces show a high electrical conductivity given the metallic nature of the chrome coating from the Chromium trioxide electrolyte. This electrical conductivity is required for the use of black chromed parts in the photo and laser industry (**General Engineering sector**).

### 3.3.2.9 Reflection behaviour / absorption capability

**Black chrome** surfaces have a high absorption capability, as the black colour of the coatings absorbs all direct incident light and heat which results in a low reflection behaviour. This functionality is required when used for the photo and laser industry (**General Engineering sector**).

### 3.3.2.10 Aesthetics

Aesthetics is a very important parameter for all sectors. The functional coating with decorative character is inspected for visible and palpable surface defects, based on the manufacturers' and OEM's standards.

The product surface is classified according to the tolerance of defects. Defects in areas where they are **easily/highly visible** for the consumer (for example the top of a hand blender in the sanitary sector are the least acceptable, whereas surfaces in areas out of sight (for example underneath a spot in the sanitary sector) are more likely to be accepted. 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, for example in the case of the automotive sector, on specific agreements with the OEMs.

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 consumer decisions.

The most common aesthetic screening test for **all sectors** is the **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.

The following descriptions of the visual inspection are from the sanitary and automotive sectors. This is intended to generally demonstrate the detailed visual inspection, which may be different for the other sectors, although comparable in the level of detail required.

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 size of defects on easily visible surfaces shall not exceed **0.1 to 0.5 mm**, whereas the size of defect on less visible areas shall not exceed **0.8 to 2.0 mm**. The maximum number of defects also depends on their location on the surface and the minimum distance between the defects. In general, the maximum number of defects on areas with highest visibility is limited to **2 defects**. On less visible areas no more than **3 defects** are acceptable.

The aesthetic requirements for the automotive industry are related to reference samples and OEM specifications. Another specification concerning the visual inspection is the VDA 16, of the VDA (German Automotive Industry Association) that defines the general requirements for a visual inspection of decorative parts and is the basis for most plating companies. The automotive industry differentiates three inspection zones (A, B, C), where zone A means the area that is highly visible in direct view of the customer, zone B is the area in the perspective shadow and zone C is completely covered by other components. Usually the allowed defects vary from 0.1 to 0.2 mm in zone A and up to 0.3-0.5 mm in zone B. The number of allowed defects varies from part to part and from OEM to OEM. Often the requirements are zero defects in zone A.

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, uniformity of colour is of major importance.

For the **automotive sector**, tests regarding the colour of the coating are performed according to EN ISO 11664 for both exterior and interior parts. Further tests are performed according to individual OEM specific requirements.

One of the main criteria for the customers of the **cosmetics sector** is the aesthetic appearance of the product. Defects occurring in the simulated sweat test and consumer behaviour handbag test are

only acceptable in areas out of sight, however there is no specific requirement regarding size and number of defects which are permitted.



### **4. ANNUAL TONNAGE**

#### **4.1. Annual tonnage**

The annual tonnage band for the use of chromium trioxide in functional chrome plating with decorative character is 3000 tonnes per year.

## 5. GENERAL OVERVIEW ON SECTOR SPECIFIC APPROVAL PROCESSES

Given the multi-layered nature of functional chrome plating with decorative character, a nickel underplate is usually applied prior to the final metallic chrome coating, and a certain amount of nickel may leach out from the product in contact with skin, drinking water or other materials. Therefore, the maximum nickel leaching rate of nickel plated products is regulated by law.

According to Regulation (EC) No. 1907/2006 of the European Parliament and the council (December 18, 2006) concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), Annex XVII (Restrictions of the manufacturer, placing on the market and use of certain dangerous substances, preparation and articles), nickel shall (amongst others) not be used in articles intended to come into direct and prolonged contact with the skin if the rate of nickel release from the parts of these articles coming into direct and prolonged contact with the skin is greater than  $0.5 \mu\text{g}/\text{cm}^2$  per week and in articles where these have a non-nickel coating unless such coating is sufficient to ensure that the rate of nickel release from those parts of such articles coming into direct and prolonged contact with the skin will not exceed  $0.5 \mu\text{g}/\text{cm}^2$  per week for a period of at least two years of normal use of the article. In addition, these types of articles shall not be placed on the market unless they conform to the respective nickel release limit.

This nickel release threshold is also covered, for example, according to German law as follows: According to § 6 No 3 and Annex 5 of the German Consumer Goods Ordinance (BedGgstV - Bedarfsgegenständeverordnung, 1992, last update 2013), it is not permitted to place consumer goods with Ni and Ni containing compounds on the market, if more than  **$0.5 \mu\text{g}/\text{cm}^2$  Ni per week** is released from consumer goods coming into direct and prolonged contact with the skin. For consumer goods with a Ni free topcoat (such as a metallic chrome coatings within the use of functional chrome plating with decorative character), the maximum Ni leaching for a time period of **2 years** with normal use conditions is not to exceed also  **$0.5 \mu\text{g}/\text{cm}^2$** . Therefore, for products where functional chrome plating with decorative character has been applied, it is generally required that the Ni leaching rate shall not exceed  **$0.5 \mu\text{g}/\text{cm}^2$  within 2 years**.

### 5.1. Sanitary sector

Directive 98/83/EC (“on the quality of water intended for human consumption”) of November 3, 1998 regulates the quality of water for human consumption. It aims to protect human health against harmful effects which could originate from contaminants in water designated for human consumption, and to guarantee it is pure and suitable for consumption. Directive 98/83/EC has been transposed into the legislation of each EU Member State.

For example, in Germany, 98/83/EC was implemented in national law as German Drinking Water Directive (TrinkwV – Verordnung über die Qualität von Wasser für den menschlichen Gebrauch (Trinkwasserverordnung), 2001, last update 2013). It regulates the microbiological and chemical quality of drinking water by giving threshold values for the respective indicator parameters. Regarding the overall requirements and the values for the indicator parameters, both the European Directive and the German Drinking Water Directive refer to the same basis and threshold values.

Substrates and materials used for the construction of new installations and for the maintenance of existing installations that are in contact with drinking water, are not allowed to negatively affect human health, the smell and taste of drinking water nor to release substances (chemical indicator parameters) into drinking water in higher concentrations than would be avoidable by using current techniques. Due to the multi-layer system of metallic chrome coated parts, the chemical indicator parameters of highest interest are **nickel** and **chrome**. The concentration of nickel in drinking water (for example caused by Ni migration) shall not exceed the threshold value of  **$20 \mu\text{g}/\text{l}$**  and the total

chrome concentration in drinking water (for example caused by chrome leaching) is not to exceed **50 µg/l**.

To continue with Germany as example, the German Environmental Agency (Umweltbundesamt - UBA) has introduced test regulations including parameters and test criteria to evaluate the hygienic suitability of the substrates and materials. The UBA maintains a “positive list” (Trinkwasserhygienisch geeignete metallene Werkstoffe, 2013) of substrates and materials which meet the requirements and are therefore allowed to be used in contact with drinking water. New materials/coatings would need to pass respective testing to be included in the positive list.

German Industry Standards (DIN – Deutsche Industrie Norm) are in place for the testing of metallic materials that are in contact with drinking water. DIN 50930-10 (Corrosion of metals) provides information on the necessary evaluation process that is further specified in EN 15664-1 (metal release test, design and operation) and EN 15664-2 (metal release test, test waters). The long-term behaviour of **metallic coated products** in contact with drinking water is tested according to EN 16058 (influence of metallic materials on water intended for human) and the flexible coated parts are tested based on a regulation of the German association for gas and water (DVGW, work sheet W-543). The long-term material testing takes at least 26 weeks per test trial.

For new coatings or materials - such as potential alternatives to metallic chrome coating - compliance with the Ni leaching threshold is not expected to be reached in the first trial. This is to be expected as the UBA requires that the maximum threshold value shall not be fully exhausted. It is likely that further product and technology optimizing measures have to be performed that require re-testing. It was stated during the consultation that compliance with the nickel threshold for the current chrome plated products was reached after 4 trials and the overall procedure took more than 4 years.

An evaluation basis for the drinking water hygienic suitability for new **coatings and materials as for example for alternatives to functional chrome plating with decorative character** would need to be developed by the UBA. Together with the above described material testing procedure, it is expected to take at least **10 years** from the decision making for an alternative, until product safety and approval for the use in contact with drinking water has been achieved. This timeline is independent of the method, material or production process. Even plastics parts (or organic coatings as well) must prove their neutrality to drinking water during their complete estimated lifetime.

This example demonstrates that new substances must first be authorised by public authorities. The testing procedures are needed to comply with all regulations, to meet the required properties and finally - even more importantly - to guarantee a safe product in contact with drinking water.

Furthermore, products typically have a production time of more than 7 years. Planning and design of large orders (like equipping hotels) starts many years before the parts go into production and these contracts ask for a long guaranteed subsequent delivery of up to 25 years. For this reason, regular spare part production for products is ongoing at least 10 years after official product production has ceased.

It should be noted that some countries provide a life-time warranty on sanitary parts. Therefore, spare parts, for example installed by plumbing companies, need to be compatible in function and appearance to the already installed parts. This creates the need for a certain past-model service on sanitary products.

## 5.2. Automotive sector

### 5.2.1. Current production parts in automotive applications - general considerations

The automotive industry is a strategic industry in the European Union: 16.2 million cars, vans, trucks and buses were manufactured in 2012, employing 12.9 million people, including about 3 million high skilled jobs and having a turnover of about €840.5 billion (2011).

Chromium trioxide is used by automobile supply chains to manufacture several thousand chrome-plated parts per vehicle manufacturer. Parts depending on the use of chromium trioxide cover a wide range of applications from belt locks to injector valves in vehicle models of a long production period of 7-10 years.

Potential alternatives for chromium trioxide must be in compliance with the high demands and requirements regarding their critical performance properties within manufacturing processes and their final use. For these reasons, a simple 1:1 substitution of chromium trioxide is not possible. The identification of possible alternatives and the careful validation of their functionalities is a highly important and labour/time intensive process that will certainly take several years. According to the European Automobile Manufacturer Association (ACEA), the development of suitable alternatives for functional chrome plating with decorative character for current vehicle parts will require a further time period of 4 to 5 years followed by industrialization of the technique and implementation in the supply chain.

### 5.2.2. Current production parts - requirements for alternatives to metallic chrome coatings

Metallic chrome plated parts are unique amongst others in terms of corrosion resistance, hardness, layer thickness, adhesive strength, coefficient of friction and abrasion resistance. Potential alternatives must be able to cover all of these requirements, and careful testing and evaluation of alternative's functional behaviour is needed. Current testing procedures include: laboratory tests, summer and winter tests and continuous-operation tests. Thorough evaluation of possible alternatives is crucial to avoid failures in the field / upon daily use. Beside the safety aspects, the consequences could include expensive and highly brand damaging product recalls.

In a single vehicle, there are between 4000 to 9000 different main components and assemblies. The range of different components is illustrated in **Figure 14**.



**Figure 14:** Car dismantled into constituent parts (Volkswagen AG, 2013) (left). Principal engine parts of a car (HubPages, undated) (right).

In case one substance has to be phased out or replaced, all affected components must be revalidated using suitable alternative materials. Even though the automobile industry is highly experienced in material testing procedures, the validation and testing of alternatives would most likely not be complete until the sunset date due to the sheer number of parts involved. In particular, this is the case as potential alternatives would need to be tested in terms of their extension to large scale production and be ready for use by the sunset date in September 2017.

The automotive industry considers a stepwise introduction of alternative technologies in new type-approved models (Directives 2005/64/EC and 2009/1/EC) to be the preferred approach, but this will not be feasible by the sunset date.

In addition, to ensure production volumes of vehicles are not affected, sufficient capacity for the production of alternative coatings in Europe must be built up. Otherwise import from non-EU suppliers would be needed to bridge the supply gap. With EU based OEM's using 70-80% EU suppliers (and non EU based OEM's using 20-50% EU suppliers) a change to non EU suppliers would have a huge impact on the EU economy. With more than 10 million cars being built every year, building up sufficient capacity in Europe to cover all relevant parts is not possible by the sunset date.

A further point is the high complexity of supply chains in the automotive industry. The assembly of vehicles is performed in a complex network of manufacturing plants, which form a multi-tier system producing different parts, such as exterior sheets or engines. With an average number of 1500-4500 OEM suppliers, which have an average of 500-1500 suppliers themselves, tracking down chromium trioxide dependent parts is a time-consuming and complicated task.

Lastly, the aforementioned multi-tier system, as well as the long-lasting nature of vehicles (up to 22 years and more) makes planning reliability crucial. Average life cycles of vehicles are about 22 years and include **3-5 years development time, 7 years of production and at least 10 years of spare part guarantee**. The opportunity to introduce changes is only possible within a certain period of time, which decreases rapidly after type-approval. Combining all these facts, the introduction of possible substitution parts has a long lead-time which cannot be met within the timeframe until sunset date (refer to **Figure 15**).



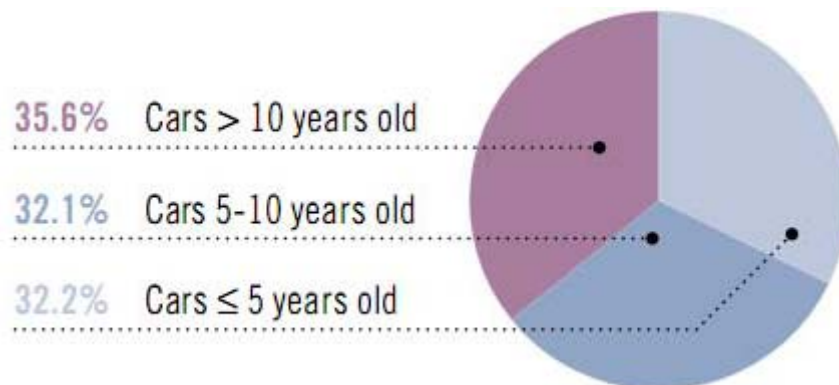
**Figure 15:** Typical life-time of a car model with start in production in 2018 compared with a four years period until sunset date.

The period to introduce changes decreases rapidly after type-approval by a certified body (Directives 2005/64/EC and 2009/1/EC). As shown in **Figure 15**, the period until sunset date (2013-

2017) could appear in early stages of life-cycle but could generally appear at any stage of the minimum 22 year life-time of a car model, even during the spare part period when changes are no longer possible.

### 5.2.3. Past model service parts - general considerations

The EU passenger car fleet (**Figure 16**) consists of about 224 million vehicles. Approximately 36% of these are older than 10 years (approx. 80 million cars).



**Figure 16:** EU passenger car fleet (share in % by age in 2010). Note: Information from 12 EU member states where information was available.

The majority of European cars are removed from the fleet after 13-15 years. This underlines the importance of an efficient supply of past model service parts beyond the end of serial production. Beside service consideration, national warranty obligations must be fulfilled. Therefore, a minimum of ten years availability of spare parts must be guaranteed (e.g. Germany: Civil law code §242). Commonly, past model service parts are even provided for vehicles that have been out of production for more than 20 years.

### 5.2.4. Past model service parts - requirements for alternative metallic chrome coating

As mentioned, the interrelation of components in vehicles is highly complex and subject of thorough testing within the development phase of vehicles. Therefore, a 1:1 substitution of metallic chrome coatings applied by electroplating with chromium trioxide is not possible. Substance substitution may cause change of functional geometry, thermal durability and lead to unexpected impacts on related parts. To ensure that possible alternatives are interchangeable with original spare parts, a completely new type-approval is necessary. This may lead to major disadvantages, which are discussed in the following.

At the end of a serial production, the tooling and bill of design for car model parts is transferred from a large to a smaller supplier (usually a small or medium size enterprise (SME)) to ensure sufficient spare part supply. These SMEs are able to produce the desired amount of past model service parts, using the original method. The limiting factor is that in most cases they do not have the know-how and capacity to perform costly and highly technically demanding re-development and re-validation procedures. Complete testing of all related components may be necessary to exclude unexpected impacts and to ensure functionality and safety in the field. Additionally, validation processes must be based on the original vehicle, which may not be available in many cases.

Another point to be mentioned is the relatively small number of spare parts being produced. Compared to the high financial input needed for validation of alternatives, an enormous increase of price per item would be the consequence.

The possibility of producing and stockpiling a sufficient amount of spare parts before sunset date should be discussed. However, this alternative may have some obvious drawbacks such as negative impacts on functionality due to chemical aging, waste of resources if spare parts are not needed for past model services, as well as high demand of stockpiling capacities.

In conclusion, the aforementioned arguments clearly show the need of metallic chrome coating from chromium trioxide electroplating in past model service part production.

## 6. IDENTIFICATION OF POSSIBLE ALTERNATIVES

### 6.1. Description of efforts made to identify possible alternatives

To prepare the authorisation of chromium trioxide, the industry consortium CTAC (Chromium Trioxide Authorisation Consortium) of 150+ members was launched in 2012.

The aim of CTAC was to efficiently gather and analyse all necessary information for the three pillars of the authorisation dossier (CSR, AoA, SEA).

#### 6.1.1. Research and development

As stated during the internal CTAC consultation, much effort on alternatives for the etching with chromium trioxide as well as for the electroplating with chromium trioxide has been made and is still ongoing. R&D is generally performed by specific companies by testing different plated products in feasibility studies. The unique functionalities of Cr(VI) as component in chromium trioxide, (explained in detail in section 3.3) make it an ideal and not easy to replace substance where superior requirements with regard for example to aesthetics/colour, corrosion and chemical resistance or abrasion resistance demanding conditions have to be fulfilled, especially where controlled etching is required. It is very difficult to find a single alternative which replaces all the multi-functionality of Cr(VI) simultaneously.

#### FuSchiDec

Many companies in Germany organized themselves in the FuSchiDec (**F**unktionale **S**chichten mit **D**ekorativem **C**harakter) group. This comprises the major sanitary companies, and also companies from the white goods, consumer, and shop outfitting sectors. The FuSchiDec experts quantitatively evaluated a broad range of alternatives with regard to their technical and economic feasibility considering promising alternatives, such as Cr(III) electroplating or based on Physical Vapour Deposition (PVD).

#### FGK & ZVO

With regard to the **automotive sector**, the most commonly used substrate is plastic. Therefore, in Germany, a group of 12 companies (platers of plastic for the automotive industry), organized in the FGK (Fachverband Galvanisierte Kunststoffe, [www.f-g-k.org/index.php](http://www.f-g-k.org/index.php)) and ZVO (Zentralverband Oberflächentechnik, <http://www.zvo.org/>) is involved in large R&D efforts. These are focussed on the technical feasibility and improvement of metallic chrome coatings from Cr(III) electrolytes, as these are considered one of the most promising alternatives to chromium trioxide electroplating, especially since this alternative would be applicable on all types of substrates.

Two comparative studies with extensive laboratory and field tests of different metallic chrome coating from Cr(III) electrolytes (**with and without a Cr(VI) based post-treatment passivation**) derived from different electrolytes - tested versus chrome coatings from chromium trioxide - have been performed. In 2012, the study has been performed with more than 530 coated plastic patterns (thereof 230 in field tests and about 300 in lab tests) and in 2013/2014 12 different metallic chrome coatings from different Cr(III) electrolytes (thereof eight sulphate based and four chloride based electrolytes from a total of seven different suppliers) have been tested. The results are described and evaluated in chapter 7.

#### Fraunhofer IST

The Fraunhofer IST research institute has applied for an R&D project on the future use of **electroplated plastic parts**, to be funded by the AiF (Arbeitsgemeinschaft industrieller



Forschungsvereinigungen) and BMBF (Federal Ministry of Education and Research). The project is scheduled with a three year timeframe. The decision on the approval of this R&D project is currently outstanding.

Indeed, on the basis of the aforementioned unique properties and diverse functionalities, where alternatives have to be identified and implemented in all processes (etching of plastics and electroplating), the identification and implementation of completely chromium trioxide free alternatives, also with regard to the extensive and promising research and innovative technologies already made, no one-to-one solutions are currently expected and the implementation of a completely chromium trioxide free process is not expected before at least 7 years after sunset date.

### 6.1.2. Data searches

For the analysis of alternatives, extensive literature and test reports were provided by the technical experts of CTAC. Furthermore, searches for publically available documents were conducted to ensure that all potential alternate processes to chromium trioxide based etching and electroplating applications were considered in the data analysis.

In addition to databases for scientific literature, the following programmes were intensively consulted: Toxics Use Reduction Institute, Massachusetts, US ([www.turi.org/](http://www.turi.org/)). Searches for safety data sheets (SDS) for chromium trioxide containing and chrome-free applications were conducted.

Based on these data, primary scoping led to the development of a generic questionnaire containing potential alternatives to chromium trioxide based processes. To complete the picture, additional alternate processes identified by CTAC consortium members were included in the initial list of alternatives, which can be found in Appendix 1.

### 6.1.3. Consultations

This questionnaire was provided to all CTAC consortium members to get an overview of experience with the alternatives, and completeness and prioritisation of critical parameters for their specific processes and the minimum technical requirements per use.

During this survey, additional alternatives were identified and included in the aforementioned initial list.

To verify data and get more detailed quantitative information, more focused technical questionnaires were sent out and discussed with the CTAC consortium members. Moreover, site visits to selected companies were carried out which were carefully chosen to adequately represent the different uses, industry sectors, countries and the size of companies. Discussions with the technical experts, followed by a final data analysis, led to the formation of a list of alternatives divided into 3 categories, according to their potential to be suitable for the specific use.

In summary, the categorized table of alternatives listed below is the outcome of extensive literature and in house research, and consultations with technical experts in the field of surface treatment.

## 6.2. List of possible alternatives

Within the following section, the most promising alternatives are discussed. For a better overview of the different processes, the assessment is made for the electroplating step (**Table 5**) and the pre-treatment step (**Table 6**) separately. However, etching is a pre-treatment and not a stand-alone process. Etching is necessary to prepare the surface for the subsequent electroplating. However, the

most important key functionalities with regard to the high-quality final product are related to the chromium trioxide based electroplating step.

According to their relevance, the potential electroplating alternatives are classified as Category 1 (focused in the dossier, relevant R&D on these substances ongoing) or Category 2 (clear technical limitations, may only be suitable for niche applications but not as general alternative). Category 3 alternatives, which are not applicable for the here defined use, are summarised in **Appendix 1**.

**Table 5:** List of plating alternatives categorised.

Category	Alternative	Part of Process Chain
Category 1 alternatives	Trivalent chromium plating	Bright/matt plating Black chrome plating
	PVD based processes: Lacquer + PVD + Lacquer and PVD metal	Bright/matt plating Black chrome plating
Category 2 alternatives	Satin & black anodized aluminium	Bright/matt plating Black chrome plating
	Chromium free electroplating: multi-component coating systems (Cu, Sn, Zn, Ni, Co), gold and platinum electroplating, zinc electroplating	Bright/matt plating Black chrome plating (Zn electroplating)
	Wet lacquering	Bright/matt plating Black chrome plating
	CVD: Chemical Vapour Deposition	Bright/matt plating
	DLC: Diamond Like Carbon	Bright/matt plating
	Electroless Nickel plating	Bright/matt plating Black chrome plating
	Powder Coating (Pulverlack)	Bright/matt plating Black chrome plating
	Stainless steel (alternative substrate)	Not only plating process, but overall process chain would be replaced

**Table 6:** List of etching pre-treatment alternatives categorised.

Category	Alternative	Part of Process Chain
Category 1 alternatives	Mineral acid based etching solutions	Etching of plastics
	Potassium permanganate based etching solution	Etching of plastics
Category 2 alternatives	Polyamide	Alternative substrate / etching of plastics

The CTAC consortium members are themselves involved in the evaluation and development process of alternatives and these are tested with the same testing procedures developed to test the quality of the metallic chrome coating. The alternatives must withstand the company/sector specific requirements regarding the different tested key functionalities. During the course of the transition to an alternative, the test procedures have to be adapted to the respective alternative coating.

### 7. SUITABILITY AND AVAILABILITY OF POSSIBLE ALTERNATIVES

To assess the feasibility of the alternatives, colour coded summary tables are included in the document.

The colours are as follows:

- Red: not sufficient - the parameters/assessment criteria do not fulfil the requirements of the respective sector.
- Green: sufficient - the parameters/assessment criteria do fulfil the requirements of the respective sector.
- Yellow: - the respective parameters/assessment criteria fulfil some requirements for some but not all applications/sectors (only used for the assessment of the technical feasibility).
- Grey: the respective parameters is not assessed for the sector or substrate.

The alternative assessments each comprise a non-exhaustive overview of general information on substances used within the alternatives and alternative processes, as well as the risk to human health and environment. These tables are provided in Appendix 2.

#### CATEGORY 1 ALTERNATIVES

The alternatives assessed in this section are considered the most promising, where considerable R&D efforts are carried out within the sectors. They either show technical limitations when it comes to the demanding requirements of all the sectors, (such as corrosion performance, chemical resistance and limitations of the aesthetic appearance) and/or have economical disadvantages at the current stage. However, some of these possible alternatives may already be used in certain industry sectors for special applications / special parts but not as a general alternative of a process step in chromium trioxide based electroplating process chains.

##### 7.1. Electroplating alternatives

###### 7.1.1. ALTERNATIVE 1: Trivalent chromium electroplating

###### 7.1.1.1 Substance ID and properties / process description

Electroplating with trivalent chromium electrolytes forms a coherent metallic chrome coating on the part to be plated by using the substrate (the part to be plated) as cathode and an inert, often graphite anode to induce an electrical current. The substrate is immersed in Cr(III) plating solution (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 the electroplating process, the dissolved Cr(III) cations are reduced to metallic chrome and build up the coating (electrodeposition).

Cr(III) electroplating is based on the same principle as chromium trioxide electroplating and can be conducted with electroplating bath equipment appropriate for chromium trioxide plating. However, there are major differences; for example in the chemical composition of the bath, the operating parameters (TURI, 2006), and the need for additional ancillary equipment (e.g. ion exchangers).

The composition of the Cr(III) electrolyte depends on the surface treatment and the application which is to be replaced. For functional chrome plating with decorative character, two types are most commonly used: sulphate based and chloride based Cr(III) solutions. The chromium (III) sulphate based metallic chrome coating is characterized by a lighter shade (similar to a functional chrome

coating with decorative character using chromium trioxide as electrolyte) and a better performance in nickel leaching tests (nickel is typically used as underplate on all substrates coated). In contrast, the chromium (III) chloride based metallic chrome coating deposits faster, can be coated in a lighter or a darker shade (compared to the functional chrome coating with decorative character from a chromium trioxide electrolyte) and performs better in sodium chloride induced corrosion tests (Blittersdorf, 2013).

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 2.1.1.

### 7.1.1.2 Technical feasibility

#### **General assessment**

The transition from chromium trioxide based electroplating to Cr(III) based electroplating is technically the closest drop-in alternative, as generally similar equipment with wet-in-wet bath technology can be used for both electroplating processes. Nevertheless, as stated during the internal consultation, the transition from chromium trioxide to Cr(III) 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.

In the following evaluation of the technical feasibility of Cr(III) based coatings, a reference to passivation after electroplating is found in several passages. This passivation is a post-treatment which is used by some companies to enhance the properties of the Cr(III) based coating. The passivation step can be performed totally Cr free, but also Cr(VI) based passivation procedures are tested and in place.

*Substrate compatibility:* Trivalent chromium plating is generally applicable to all commonly used substrates, such as for example die cast brass and copper as well as 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. Nevertheless, 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 (Blittersdorf, 2013). 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. As described above, even the smallest quantities of impurity can lead to this effect. It was stated during the internal consultation that at present it is not possible to adequately maintain process conditions that prevent the yellowish shade. In addition, 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). The longer the same plating solution is used, the more impurities are accumulated that may affect the final colour of the product. This fact makes a uniform appearance of all products plated during the lifetime use of a plating solution challenging. Besides the yellowish colour, trivalent chrome plated products from different platers are not of the exact same colour. Different trivalent chromium coated parts assembled together (for example in the interior of a car or for bathroom installations), will show a slightly different colour and will not match exactly. As stated during the internal consultation, the yellowish colour may also occur for example after longer transport times of plated parts, even if the products left the facility coated with an adequate colour. This issue depends on corrosion and a number of other factors. Furthermore, the yellowish colour also occurs during normal usage (aging of the surface) of the plated products (for example bathroom or interior automotive applications), with the effect that in case of refurbishment or repair, new parts would not match the established inventory.

### **Sector specific assessment: sanitary**

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.

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 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:* The corrosion resistance was tested, for example, by salt spray tests (NSST, AAST and CASS according to EN ISO 9227) and Kesternich tests according to EN ISO 6988, DIN 50018. The tests showed that the passivated surfaces did not show a significantly improved corrosion resistance compared to the non-passivated Cr(III) coated products and the performance of the different Cr(III) electrolyte based metallic chrome coatings was highly variable. 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 (independently if passivated or not) 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 is 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 was tested in company specific taber abrasion tests, and the metallic chrome coating from a Cr(III) electrolyte (independently if passivated or not) 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. Other test results revealed that the Cr(III) coated surface was scratched after <50 cycles (while requirements are around 300 cycles without scratches/damages). In summary, the abrasion resistance of metallic chrome coatings from a Cr(III) electrolyte depends on the electrolyte solution the coating was generated in, and is generally lower compared to metallic chrome coating from a chromium trioxide electrolyte. The overall sanitary requirements on abrasion resistance are not met.

*Adhesion:* The adhesive properties of Cr(III) based metal coatings on different kind of substrates (metals, alloys and plastic) were tested. In cross-cut tests, the adhesive properties in general sufficiently fulfilled the sanitary requirements. Some flaking of the coating has been determined, but this damage is stated not to be 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 has been observed on all tested samples and is clearly not tolerable. The final consumer may combine sanitary parts of 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 parts or upon bathroom refurbishment. Thus the aesthetic appearance of Cr(III) plated parts does not currently fulfil the sanitary requirements.

*Conclusions sanitary 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 metallic chrome coatings from a Cr(III) electrolyte 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. 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. The corrosion resistance and chemical resistance of the tested Cr(III) electrolyte based metallic chrome coatings (independently 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 sanitary requirements on abrasion resistance are not met, while the adhesive properties of metallic chrome coatings from a Cr(III) electrolyte were determined to be similar to metallic chrome coatings from chromium trioxide electroplating meeting the sanitary requirements.

Substrate compatibility	Corrosion resistance	Chemical resistance	Wear / abrasion resistance	Adhesion	Aesthetics
	varying	varying			

### **Sector specific assessment: automotive**

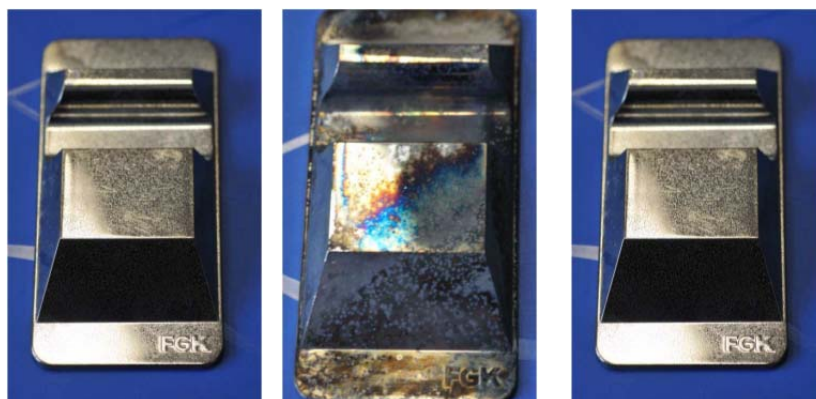
As stated during the consultation, trivalent chrome electroplating is one of the most promising alternatives to chromium trioxide electroplating and copious information has been provided. The technical performance of different types of substrates focused on plastics as the most commonly used substrate within the automotive sector, but also on metal substrates. For automotive interior and exterior applications, the coating of highest importance is a conventional (silvery-bluish)

metallic chrome coating, while black chrome coatings on plastic substrate are (niche) applications for special automotive exteriors.

As stated during the consultation, significant efforts on Cr(III) have been made and company specific feasibility studies of different plated products are performed.

A first comparative study with extensive laboratory and field tests of different metallic chrome coatings from Cr(III) electrolytes (with and without a Cr(VI) based post-treatment passivation) derived from different electrolytes – tested versus metallic chrome coatings from chromium trioxide – has been performed in 2012 and more than 530 coated plastic patterns have been tested (thereof 230 in field tests and about 300 in lab tests).

**Figure 17** depicts three Cr(III) coated samples after different lab tests (CASS, NSS, Ni leaching, from left to right) and shows the clear failure (corrosion of the surface, damaged surface) of the respective test requirements.



**Figure 17:** Examples of Cr(III) coated pattern after different laboratory tests (CASS, NSS, Ni leaching, from left to right). Data source: Prestel, 2013.

A second comparative study was performed between autumn 2013 and spring 2014. In this second study, 12 different chrome coatings, of which eight were sulphate based and four chloride based Cr(III) electrolytes, have been tested from seven different suppliers of the electrolytes. One major difference to the first study was that no Cr(VI) containing passivation post-treatments were accepted. Most of the suppliers provided new and optimized chemicals. The main focus of the test was the colour (aesthetic appearance) of the coatings, its corrosion resistance (tested in CASS and NSS tests according to EN ISO 9227), and the overall coating performance with respect to layer thickness, nickel leaching and climate / temperature change resistance. In this second trial, a total of 3000 plastic patterns provided with different types of metallic chrome coatings from Cr(III) and Cr(VI) electrolytes (chromium trioxide) were compared. Thereof 2400 patterns were examined in laboratory and the remaining 600 were mounted on a total of 72 cars and 10 trucks. The test patterns were applied to the front, the back and in the lateral area of the vehicles. The cars and trucks were used throughout the winter period and examined in spring. As a result of the field test, and presumably due to the rather mild winter 2013/2014, only few major failures of the patterns were determined. On average, the coated patterns from Cr(III) electroplating performed slightly worse than the coated patterns from chromium trioxide electroplating. It is striking that the amount of smut on all Cr(III) coated patterns after the field tests was higher than the patterns coated with chromium trioxide electroplating.

As a result of both comparative studies, none of the tested coatings from Cr(III) electrolytes are able to meet the requirements of the automotive sector at the current time.

*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 Cr(III) based or chloride Cr(III) 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 Cr(III) based metallic chrome coatings is better compared to chloride Cr(III) based coatings, while the corrosion resistance to CaCl<sub>2</sub> (tested for example in Russian Mud tests) is better for chromium (III) chloride based than for chromium (III) sulphate based metallic chrome coatings.

According to the provided information, the corrosion resistance of metallic chrome coatings from Cr(III) electrolytes is generally lower compared to metallic chrome coatings from chromium trioxide electroplating and generally does not fulfil the automotive requirements (for example exterior 480 h NSST or up to 96 h CASS according to EN ISO 9227). When testing a metallic chrome coating from a Cr(III) electrolyte with a subsequent Cr(VI) passivation, the combination performs better and may be adequate for the respective requirements. So far, only a few of these systems are stated to perform close to a conventional chromium trioxide derived metallic chrome coating (that is without subsequent passivation). Following the already performed R&D in recent years, a slight improvement of the corrosion resistance of trivalent chromium based metallic chrome coatings may have been determined, however the performance is still not sufficient. At the current stage of development, the performance depends on the respective type of electrolyte and resulting metallic chrome coating. Based on the information provided in the consultation, the corrosion resistance does not currently fulfil the requirements of the automotive sector.

*Chemical resistance:* As stated during the consultation, the chemical resistance of metallic chrome coating from Cr(III) electrolytes is generally lower, and first lab results indicate a lower chemical resistance for example against wheel rim cleaners, pancreatin or tree resins. However, the performance is dependent on the respective trivalent chromium electrolyte and its resulting type of metallic chrome coating. Based on the information provided in the consultation, the chemical resistance does currently not fulfil the requirements of the automotive sector.

*Wear resistance / abrasion resistance:* It was stated during the consultation that the abrasion resistance of metallic chrome coatings produced from Cr(III) electrolytes is generally lower than metallic chrome coatings produced by chromium trioxide electroplating. This could potentially result in a slightly reduced hardness of the metallic chrome coating from a Cr(III) electrolyte (about 1000 HV compared to 1200 HV for metallic chrome coatings from chromium trioxide based electroplating). Lab tests indicate that lower wear resistance leads to scratches and a worse performance in car wash tests. However, the performance is dependent on the respective electrolyte and resulting type of metallic chrome coating from the respective Cr(III) electrolyte. In general, the abrasion resistance does currently not fulfil the requirements of all the automotive supplier CTAC consortium members.

*Nickel leaching:* Potential nickel leaching (from the nickel underplate) can occur during use of trivalent chromium coated products, especially from coatings without additional Cr(VI) based passivation. This is due to differences in the corrosion resistance between chromium trioxide and Cr(III) based coatings and is dependent on the type of Cr(III) electrolyte used. The Ni leaching test according to EN 1811 (threshold of 30 µg/cm<sup>2</sup>/day) generally showed that chloride Cr(III) electrolyte based metallic chrome coatings performed worse than the sulphate Cr(III) electrolyte based coatings and those from chromium trioxide electroplating processes. In general, potential nickel leaching from the underplate is inappropriate for automotive applications.

*Aesthetics:* As mentioned above, the exact colour of the coating from Cr(III) electrolytes differs and is a result of the electrolytic plating solution. All Cr(III) coatings showed a significantly darker



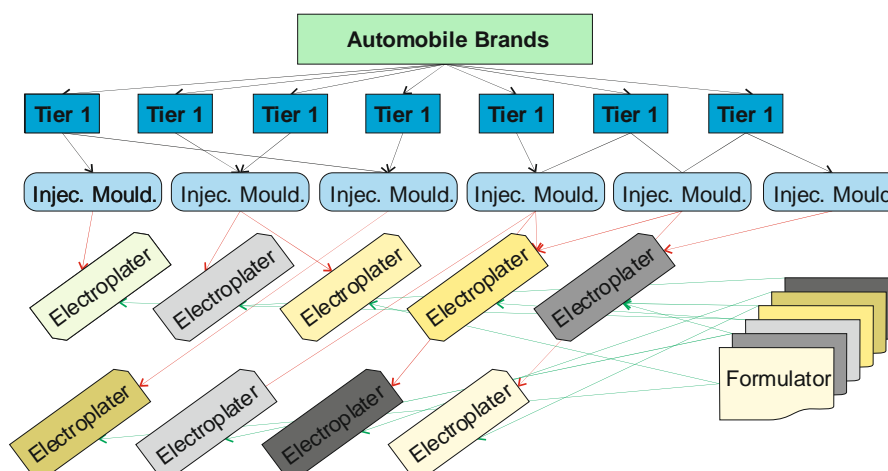
colour at the end of the test compared to the starting colour (Prestel, 2014). Specifically, chromium (III) chloride plating solutions result in a slightly darker chrome coating, while the coatings from a chromium (III) sulphate based plating solutions are slightly lighter. Impurities in the sensitive bath chemistry can also cause a yellowish/brownish colour of the trivalent chromium based coatings.

In **Figure 18**, trivalent chromium coated parts are shown to highlight the range of colour shades which can occur with this alternative.



**Figure 18:** Pattern coated with different trivalent chromium based electrolytes showing the different shades of colour. Data source: BMW, 2014.

The long-time colour stability of coatings from Cr(III) electrolytes was examined in field tests on numerous different samples. The test results showed that the coatings from Cr(III) electrolytes became gradually darker, while the coatings from a chromium trioxide electroplating did 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 result in a colour mismatch (**Figure 19**).



**Figure 19:** Automotive supply chain visualizing exemplarily the colour issue with trivalent chromium coated parts. Data source: BMW, 2014, adapted.

*Conclusion automotive sector:* In conclusion, trivalent chromium based metallic chrome coatings do not fulfil all requirements at the current stage of development.

Although some Cr(III) coated products have recently been used by a few automobile manufacturers, these products require Cr(VI) during production 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 entire automotive sector. The colour of the coating is slightly brownish and also variable between suppliers causing severe colour-match issues. Furthermore, field tests revealed a darkening effect of the coating during normal use. In general, the performance of the coating is highly dependent on the respectively used electrolyte (chromium (III) sulphate or chromium (III) chloride based) and the resulting type of metallic chrome coating. In general, further key functionalities, such as corrosion resistance, chemical resistance, abrasion resistance and nickel leaching do not fulfil all the requirements of the whole automotive sector at the current stage, and a completely chromium trioxide-free alternative cannot be widely implemented in the near future. As stated during the consultation, **black chrome** coatings from trivalent chromium electrolytes have a dark grey appearance which is used for niche applications on exterior automotive parts. These coatings are considered not to fulfil the high demands of general exterior automotive applications and are only used for special decorative purposes.

Substrate compatibility	Corrosion resistance	Chemical resistance	Wear / abrasion resistance	Nickel leaching	Aesthetics
	varying	varying			

### **Sector specific assessment: cosmetics**

As stated during the consultation, trivalent chromium based coatings are the most focused upon alternative to metallic chrome coatings from chromium trioxide electroplating within the cosmetics sector.

*Corrosion resistance:* The surface structure of a metallic chrome coating from a Cr(III) electrolyte with respect to micro cracks and micro porosity depends on the thickness of the coated layer and is generally different to a chrome coating from chromium trioxide electroplating. The difference between these factors results in a corrosion resistance which is generally lower for Cr(III) coated products than for chromium trioxide coated products. Therefore, metallic chrome coatings from Cr(III) electrolytes are not suitable to fulfil the corrosion requirements of the cosmetic sector at the current time.

*Nickel leaching:* Due to the lower corrosion resistance of the coating, potential for an increased nickel leaching from the underplate may occur and it cannot safely be guaranteed that the coated products are not toxic and do not cause allergic effects. This is an important factor for consumer safety especially for coated products in direct and continuous contact with skin.

*Aesthetics:* As different Cr(III) electrolytes provide different shades of colour and issues with the colour stability of Cr(III), the final aesthetic appearance of Cr(III) coated cosmetic products is different to the coating applied by chromium trioxide based electroplating, and is considered not to be sufficient for the aesthetic requirements of the cosmetic sector.

*Conclusion cosmetics sector:* The aesthetic appearance of metallic chrome coating from Cr(III) electrolytes is slightly yellowish/brownish and does not guarantee colour stability over time, which is a major drawback of these coatings for cosmetic purposes. Additionally, the corrosion resistance of metallic chrome coating from Cr(III) electrolytes is lower when compared to metallic chrome coatings from chromium trioxide plating. Prevention of Ni leaching from the underplates cannot be

guaranteed. In summary, metallic chrome coating from Cr(III) electrolytes are (at the current stage of development) technically not feasible as an alternative to chrome coatings from chromium trioxide electroplating.

Substrate compatibility	Corrosion resistance	Nickel leaching	Aesthetics

### **Sector specific assessment: white goods**

*General assessment:* The work of the FuSchiDec group showed that many requirements and tests to be performed for white goods products are similar to the sanitary industry. Thus the results of the sanitary sector could derivate to the white goods sector. However, there are some differences. For example, in the case of chemical resistance, the concentration of chemicals used in tests is higher than in the sanitary sector.

*Corrosion resistance:* In general, the corrosion resistance of all tested samples from different Cr(III) electrolytes was significantly lower when compared to the coatings applied by chromium trioxide electroplating. As shown by the FuSchiDec group, the tested coating from Cr(III) electrolytes showed corrosion after 200 h, not meeting the minimum requirements of products for the white goods sector of 240 h. In conclusion, the corrosion resistance does not fulfil the overall white goods requirements.

*Chemical resistance:* Tested chemicals were for example, chlorine bleach, hydrogen peroxide, acetic acid and caustic soda. The test results clearly showed that the chemical resistance does not fulfil the requirements of the white goods sector. The samples tested with chlorine bleach, hydrogen peroxide and acetic acid were very strongly attacked. The Cr(III) samples tested with chlorine bleach were even penetrated to the copper underlayer. The samples tested with hydrogen peroxide showed a strongly attacked surface with oily and iridescent appearance. The failure of the samples with acetic acid is especially critical, as this is the basis of the most commonly used household cleaning agents. For caustic soda, the results vary and depend upon the electrolyte the coating is made of. However, no sufficient performance for all tested coatings was determined. In general, metallic chrome coatings from Cr(III) electrolytes clearly do not meet the chemical resistance requirements of the white goods sector.

*Wear resistance / abrasion resistance:* The data of the sanitary sector concludes that the coatings from Cr(III) electrolytes did not pass the requirements of the white good sector in the taber abrasion test. Abrasion resistance requirements of the white goods sector are therefore also not met.

*Aesthetics:* As different Cr(III) electrolytes provide different shades of colour to the coating and there are issues with the colour stability of Cr(III) based coatings, the final aesthetic appearance of Cr(III) coated products for the white goods sector is different to metallic chrome coatings from chromium trioxide electroplating, and is generally not considered to be sufficient for the aesthetic requirements of the white goods sector.

*Conclusions white goods sector:* Besides the aesthetic issues with trivalent chrome coated surface at the current stage of R&D not meeting the aesthetic requirements of the sector, corrosion resistance, abrasion resistance and the chemical resistance of the tested Cr(III) coated samples are at the current stage of R&D clearly not meeting the requirements of the white goods sector. As stated during the internal and external CTAC consultation, further R&D and evaluation of metallic chrome coating from Cr(III) electrolytes for the purposes of the white goods applications is ongoing and planned.

Substrate compatibility	Corrosion resistance	Chemical resistance	Wear / abrasion resistance	Aesthetics

### **Sector specific assessment: general engineering**

The uses of black chrome layers with chromium trioxide electroplating applied on metal substrates in the **general engineering** sector are due to its very low reflective properties derived by the black colour, being electrical conductive and being of high quality and aesthetic.

*Electrical conductivity:* The coatings applied by a trivalent black chrome electrolyte do provide the required electrical conductivity.

*Reflective behaviour / absorption capacity:* Trivalent black chrome coated surfaces do not have a dark black colour, but rather a dark grey to anthracite shade. For this reason, the capacity of the surface to absorb the light for the applications in the general engineering sector is not sufficient and as a consequence, the surface has a certain reflectivity.

*Conclusion general engineering sector:* As stated during the consultation, no black chrome electrolyte is commercially available at present to fulfil the requirements of black coated surfaces for the purposes of the general engineering sector; a commercially available trivalent black chrome electrolyte is available for only decorative applications (without any functionality). Trivalent black chrome coatings are not a technically feasible alternative to black chrome plating. The key functionalities of black chrome plating (resulting from a deep black colour), such as low reflective properties resulting from a high absorption capacity, are clearly not fulfilled.

Substrate compatibility	Electrical conductivity	Reflective behaviour	Absorption capacity

### **Sector specific assessment: furniture**

Test results on the technical performance of trivalent chromium coatings on steel substrate for furniture applications were provided during the consultation. As corrosion resistance is the most important key functionality for products used within the furniture sector, no detailed quantitative information on other key functionalities was available.

*Corrosion resistance:* The metallic chrome coating from Cr(III) electrolytes with subsequent chromium free passivation was tested according to company specific requirements (3 cycles of each 24 h according to EN ISO 6270-2 followed by a fourth cycle of 24 h NSST according to EN ISO 9227). As a result, the coating was found not to meet company specific requirements due to severe corrosion of the product.

*Nickel leaching:* Due to the lower corrosion resistance of the coating, potentially increased Ni leaching from the underplate may occur, and it is not safely guaranteed that the coated products are not toxic and do not cause allergic reactions. This is a very important factor for coated products in contact with food (e.g. kitchen interior).

*Aesthetics:* As different Cr(III) electrolytes provide different shades of colour and issues with the colour stability of Cr(III), the final aesthetic appearance of Cr(III) coated products for furniture applications is different to metallic chrome coatings from a chromium trioxide electrolyte and is therefore not considered to be sufficient for the aesthetic requirements of the furniture sector.

*Conclusions furniture sector:* The aesthetic and corrosion requirements for products used in the furniture sector are not met by metallic chrome coating from Cr(III) electrolytes and this alternative is therefore not technically feasible at the current time.

Substrate compatibility	Corrosion resistance	Nickel leaching	Aesthetics

### 7.1.1.3 Economic feasibility

Against the background of significant technical failure of trivalent chromium plating, no quantitative analysis of economic feasibility was conducted. However, the cost for trivalent chromium electroplating depends on numerous different factors and these are presented in a qualitative to semi-quantitative way below.

First indications were made stating that the operational costs using a Cr(III) process are up to 30 % higher than chromium trioxide electroplating. Despite the clear difficult process conditions as stated in 7.1.1.2, there are a number of benefits comparing Cr(III) with chromium trioxide electroplating (NEWMOA, 2003). With regard to *air emissions*, the trivalent chromium process releases less chromium mist into the air due to a higher cathode efficiency than chromium trioxide plating. In addition, this mist is much less toxic compared to the chromium trioxide electroplating. This generally reduces the air pollution treatment measures and requirements. As the typical Cr(III) plating bath has a lower chromium concentration, there is less total chromium in the *wastewater* stream. In addition, since the wastewater contains Cr(III) cations, no reduction step from Cr(VI) to Cr(III) is necessary (which also eliminates the use of potential hazardous or harmful reducing agents). By the use of Cr(III) electroplating, approximately thirty times less sludge is produced, for example because the anode is not decomposed. This results in reduced costs for handling and disposal of *hazardous waste*. However, as organic complexing agents and stabilizers are used in the course of trivalent chrome electroplating, these substances will likely interfere with the wastewater treatment and *additional wastewater treatment measures*, such as oxidative destruction of the organic components and depuration of boron (in case of boron based additives), would be required. Another problem concerning air quality may occur; if the treated wastewater from the Cr(III) electroplating is alkalized up to pH 9, as due to the ammonium concentration, ammonia can be formed, which can endanger the *safety of workers*. All the necessary measures will, in contrast to the described cost reduction, lead to increased costs for wastewater treatment (running costs and investment costs for systems engineering). As a result, there are no costs benefits from the transition of chromium trioxide to a Cr(III) electrolyte with respect to wastewater treatment. Furthermore, higher costs for the used chemicals (trivalent chromium based solutions are more expensive than chromium trioxide plating solutions) and the used anodes should be taken into account. In addition, large analytical efforts have to be made to maintain the quality of the electrolyte and to minimize quality loss caused by impurities in the bath. It was, for example, stated during the consultation that a chromium trioxide electrolyte requires 2 hours analytical control per **week**, while the Cr(III) plating baths requires 2 h analytical control per **day**. Furthermore, ancillary equipment, such as ion exchangers for the removal of impurities, need to be added as well as numerous additional baths for adequate rinsing (more rinsing is required to minimize the entrance of impurities to the bath process). For plastic substrates, additional rinsing and baths are required. It also should be noted that in most plating shops there would be no additional free space to implement these essential rinsing baths in the existing production line. The plating process is strictly serial, and the spin-off of these additional baths adjacent to the line is not possible, as the parts are moved automatically by a transportation system which can only move along the galvanic baths. Another point is that in most



plating shops the galvanic line fits the production building closely (i.e. the line fills the building), therefore it would be difficult to expand the production line within the existing building.

Some of the above described economical drawbacks may be covered to some extent by economic benefits of Cr(III) electroplating. The lower current density of the Cr(III) plating process is less energy consuming and results in reduced energy costs. As the throwing power of trivalent chromium plating is generally better, more parts can be placed on the racks resulting in a higher production rate and throughput of parts. In general, Cr(III) electroplating may be economical feasible compared to chromium trioxide electroplating. However, especially for smaller jobplaters, significant investment is needed if the additional bathes do not fit in the building.

With regard to the currently applied Cr(VI) passivation on Cr(III) coatings, this process based on two separate steps is less economically feasible compared to the chromium trioxide based process.

#### **7.1.1.4 Reduction of overall risk due to transition to the alternative**

As the alternative is not technically feasible, only classification and labelling information of substances and products reported during the consultation were reviewed for comparison of the hazard profile. Based on the available information on the substances used within this alternative (see Appendix 2.1.1), chromium (III) chloride would be the worst case with a classification as Skin Irrit. 2, Eye Irrit. 2, Acute Tox. In general, the trivalent electroplating processes are less toxic than chromium trioxide plating due to the oxidation state of the chromium. Cr(III) solutions do not pose serious air emission issues, but still pose the problems of disposal of stripping solutions (depending on the type of stripping solution) and exposure of staff to chrome dust during grinding. In addition, there is a certain risk of Cr(VI) being generated during the plating process. This is why appropriate security precaution and process management has to be adopted to prevent the formation of Cr(VI). The bath chemistry typically also comprises a high concentration of boric acid, which is a SVHC substance (toxic for reproduction) included on the candidate list and currently on the 6<sup>th</sup> recommendation for inclusion in Annex XIV. Despite these facts, the transition from chromium trioxide to trivalent chromium constitutes a shift to less hazardous substances, however as at least one the used alternative substances is itself classified for mutagenicity and carcinogenicity, any replacements will need to be carefully evaluated on a case by case basis.

#### **7.1.1.5 Availability**

The Cr(III) electroplating techniques, as well as different kinds of Cr(III) electrolytes are commercially available. Although some Cr(III) coated products have been recently accepted by some automobile manufacturers, these products are not produced completely Cr(VI) free **and** are not fulfilling all manufacturers' requirements to cover the entire industry sector, especially under the required large scale production aspects with available capacities in Europe,. Furthermore, no long-term field experience on the behaviour of parts for all interior and exterior uses is available at the current stage. Due to the high requirements of customers in relation to the quality and functionality of the coated products, and their long term behaviour, these parts are not considered to be qualitatively comparable for equivalent application within the broad range of use in the automotive sector at the current stage. The automotive sector supplies a global market which requires exterior parts to withstand demanding requirements for example regarding corrosion, sunlight resistance, and/or temperature resistance. In addition to the demanding requirements that are not fulfilled at the current stage, capacities in Europe to cover the industry sector under large scale production are currently not available.

As stated during the consultation, much effort has been expended on Cr(III) and R&D is still ongoing. As presented above, comparative studies with extensive laboratory and field tests have been performed by the FGK and ZVO on the technical feasibility and improvement of metallic chrome coating from Cr(III) electrolytes. In conclusion of these comparative studies, none of the tested metallic chrome coatings from Cr(III) electrolytes meet the requirements of the automotive sector at the current stage.

Cr(III) electrolytically coated parts for sanitary purposes are available on the market, but as stated during the consultation, these products do not fulfil the sector's and customers' high quality requirements. 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 industry.

Following the R&D performed in the last couple of years, metallic chrome coatings from Cr(III) electrolytes have improved, but further development and testing is necessary to produce marketable Cr(III) coated products. For products that are already on the market, such as automotive exterior applications, only limited data on the longevity and durability of the products has been obtained so far. Further tests and improvement on the quality of the trivalent chrome plated products is necessary. This is especially the case for longevity and durability, colour stability and key functionalities such as corrosion resistance, chemical resistance and abrasion resistance. After having managed technological feasibility, the Cr(III) alternative coatings require sector specific approval; for example, with regard to the automotive sector by the OEMs, and within the sanitary sector coating the systems need to pass the legal requirements for drinking water safety. Only after having passed the sector specific approval procedures, the sectors can start to transition from chromium trioxide electroplating to Cr(III) electroplating. At the current stage, it is not likely that Cr(III) based electroplating can be industrially used as a general alternative to chromium trioxide electroplating within required capacities within 7 years after the sunset date.

Considering trivalent chrome electroplating as a future technical and general economically feasible alternative to chromium trioxide electroplating, the etching of plastics as pre-treatment still relies on the use of chromium trioxide. At the current stage, etching of plastics is far from being a technically feasible alternative without the use of chromium trioxide. Given that a chromium trioxide electroplating alternative might be available earlier than a chromium trioxide free etching of plastics alternative, the need to use chromium trioxide still exists. At the current stage of the development of chromium trioxide free etching solutions, it is not likely that a technically feasible alternative for the etching of plastics without chromium trioxide will become applicable within 10 years after the sunset date.

### **7.1.1.6 Conclusion on suitability and availability for trivalent chromium electroplating**

At the current stage of development, trivalent chrome electroplating is not a technically feasible alternative to chromium trioxide electroplating, and coatings from Cr(III) electrolytes do not sufficiently fulfill all the sector specific requirements for the main applications, for example regarding aesthetics, corrosion resistance, chemical resistance or abrasion resistance.

Despite these facts, some Cr(III) coated products have been recently used for sanitary and automotive applications, but do not fulfil the high quality sector specific requirements for the main applications, and no long term performance has been investigated so far. In conclusion, intensive R&D on the technical feasibility of Cr(III) based coatings is necessary and on-going. However, it is not expected that Cr(III) based electroplating can be industrially used as a general alternative to chromium trioxide electroplating at required capacities within 7 years after the sunset date. Additionally, no complete chromium trioxide free process chain will be available for an even longer

time, as the development of an alternative for chromium trioxide etching of plastic is at a lower level of maturity than the alternatives for the subsequent plating process.

### **7.1.2. ALTERNATIVE 2: PVD based processes - lacquer + PVD + lacquer and PVD metal**

#### **7.1.2.1 Substance ID and properties / process description**

Physical Vapour Deposition (PVD) is the general name for a variety of vacuum processes. The PVD process starts with placing the coating material in solid (or rarely in a liquid) form in a vacuum or low pressure plasma environment. The coating material is vaporized by an electric arc or electron beam (Turi, 2006) and deposited, atom by atom, onto the surface of the material to be coated 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.

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 depositing film with energetic particles. The energetic particles may be the same material as the depositing 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 (TURI, 2006).

*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 (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 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 of between 20 and 30 minutes. With regard to plastic substrates, the coating takes longer as a result of a reduced coating temperature. The temperature reduction is necessary due to the lower melting point of the substrate. To achieve the same thickness of the coating, the coating time must be increased. In general, the throughput of parts depends on the size of the vacuum chamber and the geometry of the parts.

PVD layers can be deposited either as a single layer or by multi-layer deposition, with up to 2000 (very thin) single layers. The typical thickness of PVD coatings lies between 0.2 and 15 µm, with values at the lower range for decorative coatings with functional purposes.

The following PVD based sector specific processes are discussed in this Category 1 alternative below:

- **PVD metal:** vacuum based deposition of a metal coating/layer
  - o PVD chrome: vacuum based deposition of a chrome coating,



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

Some typical **PVD** coatings, which can either be applied as stand-alone **PVD metal** or as 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 7** (Buettner, undated). The CrN creates the **PVD chrome** layer, while the TiAlN is responsible for **PVD aluminium**.

**Table 7:** Characteristic properties of some exemplarily PVD coatings (Buettner, undated).

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

In regard to **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 an UV-lacquer. With regard to the two-layer systems, most typically an UV lacquer is 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.

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 2.1.2. This overview is focused on selected substances for the PVD process and not on the (potential) content of potentially used lacquers (due to the large variety). Nevertheless, certain types of lacquers may contain potentially harmful substances.

#### 7.1.2.2 Technical feasibility - PVD metal

PVD based processes are assessed as a potential alternative for conventional chromium trioxide electroplating. With regard to PVD metal, prior to the application of a **PVD metal** coating, an initial supporting layer is necessary - especially on brass, different kinds of die cast 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 and among others, typically used metal substrates are die cast, brass, copper and aluminium. Plastic substrates are coated by 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 is the most common failure in PVD coating (Legg, 2003). 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. Therefore, as a consequence, PVD layers are optimally applied with a thickness of about 1-3 µm (in rare cases about 15 µm).

*Corrosion resistance:* PVD nitride coatings are reported to be essentially inert and do not corrode easily. However, they do not provide as much corrosion resistance in comparison to thicker metallic chrome coatings. Especially once 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 as used gases and gas composition, coating time, and 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. It has to be noted that a supporting layer has to be applied prior to the application of a PVD metal coating, as 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 is increased.

### **Sector specific assessment: sanitary**

It was stated during the internal consultation that large R&D efforts have already been conducted and are still ongoing on the technical feasibility of PVD and PVD based processes. Numerous test results of **PVD metal** on different substrates were provided for review by different sanitary companies. 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 clearly 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 is tested with chemical cleaning agents and is further discussed in the section “chemical resistance” below. 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 substrate. Compared to a metallic chrome coating from chromium trioxide, which generally provides a very high corrosion resistance in all cases, this is clearly a negative property of PVD coatings. In conclusion, the corrosion resistance of PVD based coatings is considered not yet

to meet the overall sanitary sector requirements due to technical issues. Efforts are necessary to overcome these.

*Chemical resistance:* Comparative tests were performed between chromium trioxide electrolyte based metallic chrome coating (with a thickness of the metallic chrome layer of 0.5  $\mu\text{m}$ ) and metallic chrome layers applied by **PVD chrome** (with 0.5 and 0.25  $\mu\text{m}$  coating thickness). These tests are performed with a thinner thickness than usual, because PVD chrome was applied as top coating on metallic chrome coating. The test results showed that the strongest corrosion was found for the 0.5  $\mu\text{m}$  PVD chrome coating. It 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 in the 7 days continuous immersion test in vinegar essence. The 0.25  $\mu\text{m}$  PVD chrome coating showed less damage compared to the 0.5  $\mu\text{m}$  PVD. Only slight corrosion at the edges was determined for PVD chrome 0.25  $\mu\text{m}$  after both tests: the 14 days daily spraying with household cleaning agents and after 7 days of continuous immersion test in vinegar essence. Comparatively, tested electroplated chrome coatings with a thickness of 0.5  $\mu\text{m}$  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  $\mu\text{m}$ . In general, the chemical resistance of these coatings was found not to be dependent on the PVD coating thickness. As the application of a PVD chrome layer is technically much more difficult compared to an electroplated chrome coating process, the process parameters highly influence the performance of the final coating. By using the correct parameters, it is possible that PVD coatings can meet the requirements for corrosion and abrasion resistance.

Besides PVD chrome coatings, other kinds of metal coatings for different aesthetic purposes can be applied by PVD technique, amongst others bronze, gold or dark chrome (surfaces for special applications). The test results provided on these kinds of **PVD metal** coatings indicate problems with corrosion and chemical resistance, potentially resulting from issues with the applied layer thickness of the coating.

Coatings tested with different test methods showed that the chemical resistance of PVD based coatings is highly dependent on the kind of coating and the coating system (including the potentially supporting layer). Large technical efforts are necessary to achieve a chemical resistant coating as required by the sanitary sector. Compared to a metallic chrome coating using chromium trioxide electroplating, which generally provides a very high chemical resistance across all different coating types, this is clearly a negative point of PVD coatings. In conclusion, the chemical resistance of PVD based coatings is considered as not yet meeting the overall requirements of the sanitary sector due to technical issues.

*Wear / abrasion resistance:* Test results provided on **PVD metal** coatings also reveal 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 from chromium trioxide electroplating showed that the PVD chrome 0.5  $\mu\text{m}$  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  $\mu\text{m}$  coating.

As shown by the different results for the different tested coatings, the abrasion resistance of PVD based coatings is highly dependent on the kind of coating and coating system applied. Large technical efforts, for example, on the optimal layer thickness or research for the optimal balance between layer thickness and internal stress are required to provide an abrasion resistant coating as required by the sanitary sector. Compared to a metallic chrome coating from chromium trioxide,

which generally provides a very high abrasion resistance in all cases, this is clearly a negative property of PVD coatings. In conclusion, the abrasion resistance of PVD based coatings is considered as not meeting the overall requirements of the sanitary sector due to technical issues at the current time.

*Temperature change resistance / heat resistance:* **PVD metal** coatings (without lacquer) were found generally to be in accordance with company specific requirements (for example 300 cycles of 80°C to 20°C without significant defects). In general, temperature change resistance is - again - dependent on the PVD coating, which is a clear disadvantage compared to a metallic chrome coating from chromium trioxide. Currently the temperature change resistance of PVD based coatings is considered as not meeting the overall requirements of the sanitary sector.

*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 metallic chrome coatings from a chromium trioxide plating solution. As stated during the consultation, PVD chrome provides an aesthetic and brightness comparable to chromium trioxide electroplated metallic chrome coatings.

In general, due to the different kinds of metal which can be used for a PVD coating, PVD chrome is considered the most promising PVD based process with regard to aesthetic appearance. All other kinds of PVD based coatings are not of the same aesthetic appearance. Some have, for example, a golden appearance which is not comparable to the silvery-bluish chrome coating, or a lacquer finish not providing the required brightness and are therefore neither comparable nor competitive to bright metallic chrome coatings from chromium trioxide based electroplating. In addition, the coated surface does not have the same metal feeling as metallic chrome coatings applied by chromium trioxide electroplating have. Although a metal coating is applied by the PVD method, the coated layer thickness is too thin to create the required metal feeling.

*Conclusion 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
	Depending on deposited metal			Depending on deposited metal	Depending on deposited metal

### **Sector specific assessment: automotive**

For automotive interior and exterior applications, the coating of highest importance is a conventional (silvery-bluish) chrome coating, while black chrome coatings on plastic substrate are used as special applications for exterior automotive uses (and the price is customer and quantity related). The vast majority of coatings are applied on plastic substrate. As stated during the consultation, PVD metal coatings have been tested for automotive applications, but were generally

found not to be sufficient. PVD aluminium is a special PVD metal coating applied by aluminium metallizing and has been evaluated as a special coating for special exterior applications. In general, the most focused PVD based alternative is a lacquer + PVD system, which is discussed separately in chapter 7.1.2.3.

*Corrosion resistance:* No quantitative data is available as R&D is not focused on these PVD based alternatives. However, the corrosion resistance of **PVD metal** coatings strongly depends on a number of factors, such as the type of base material, adequate pre-treatments, the type of coating and also differs with the type of deposited metal. Corrosion resistance can be considered to be adequate in some cases, unless stone chip resistance is required on top (for example for exterior parts). The corrosion resistance of **PVD aluminium** coatings does not fulfil overall automotive requirements, especially not for exterior parts.

*Chemical resistance:* No quantitative values are available, but the chemical resistance is also dependent on the exact kind of coating, as well as the chemicals used. In this regard, the performance of the coating is similar to painted coatings, whose chemical resistance are generally lower than for metallic chrome coatings. As stated during the consultation, the chemical resistance of **PVD aluminium** coatings was found to be sufficient, but only if varnish was deposited on the surface (which is not desired due to aesthetic reasons).

*Wear resistance / abrasion resistance:* No quantitative values are available, but the wear resistance is also dependent on the exact kind of coating. **PVD aluminium** coatings were stated to have a lower abrasion resistance and do not fulfil the automotive sector requirements.

*Adhesion:* The adhesive properties of **PVD aluminium** coatings to the substrate are lower than for coatings applied by chromium trioxide electroplating and do not fulfil the automotive sector requirements.

*Aesthetics:* It was stated during the consultation that the use of a **PVD metal** coating directly applied on the substrate is - from an aesthetic point of view - not a comparative alternative to the general appearance created by a metallic chrome coating from chromium trioxide. In general, the colour of **PVD metal** coatings is highly characterized by the deposited metal. For example, **PVD aluminium** coatings only creates an aluminium colour and are therefore not considered a suitable alternative for decorative applications within the automotive sector. In addition, the metal feeling of these kind of 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 requirements.

*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 to substrate	Aesthetics
	Depending on deposited metal	Depending on deposited metal and topcoat			Depending on deposited metal

### Sector specific assessment: store construction

*General Assessment:* With regard to products used for the store construction sector, PVD metal as an alternative to electroplating with chromium trioxide was assessed. The alternative was found to be potentially technically feasible, but with major limitations regarding the economic feasibility (see chapter 7.1.2.4).

### 7.1.2.3 Technical feasibility - lacquer + PVD systems

#### **General assessment:**

*Substrate compatibility:* A number of different substrates (metal as well as plastic) can be applied with a lacquer + PVD system, however these kinds of alternative are more focused on plastic substrates. The lacquer + PVD systems can be applied on plastic ABS substrates without the etching pre-treatment.

*Corrosion resistance:* With regard to a three-layer **lacquer + PVD + lacquer** system, 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:* In the case of a three-layer **lacquer + PVD + lacquer** system with a final lacquer, the wear resistance of these coatings is clearly lower compared to a metallic chrome coating, as no lacquer is 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, and considering a PVD chrome layer, the aesthetic is determined to be sufficient, however due to the very thin PVD coating there is no metal feeling.

#### **Sector specific assessment: sanitary**

It was stated during the consultation that large 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 by different sanitary companies and information was provided regarding **lacquer + PVD** systems.

*Corrosion resistance:* In general, the corrosion resistance of PVD based coatings is highly dependent on the kind of coating and coating system and inconsistent data is available at the current stage of development. According to publicly available data (Wüko, 2007), a commercial **lacquer + PVD + lacquer** system is able to withstand 240 h CASS exposure, and tests conducted on a **lacquer + PVD + lacquer** coating applied on plastic substrate (ABS) showed that the coating passed 300 h in NSS and 96 in CASS test according to DIN 9227, thus meeting company specific requirements. However, sanitary sector companies stated that the corrosion resistance of **lacquer + PVD + lacquer** coatings were found not to withstand salt spray exposure according to EN 248 resulting with flaking of the coating, especially at the edges. With regard to a two-layer **lacquer + PVD** system, it was stated during the consultation that these coatings failed the corrosion requirements at the current stage of development. As a consequence, further R&D is necessary to reach suitable and repeatable corrosion resistance for these kinds of coatings. Compared to a metallic chrome coating electroplated using chromium trioxide as electrolyte, which generally provides a very high corrosion resistance in all cases, this is clearly a negative property of lacquer + PVD systems.

*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 the reason for the varying test results. No final overall conclusion can be made, but inconsistent performance is clearly not sufficient and processes with consistent and reproducible performance need to be developed.

*Wear / abrasion resistance:* The abrasion resistance of different **lacquer + PVD + lacquer** coatings was tested by different companies in taber abrasion tests. A test performed on one kind of **lacquer + PVD + lacquer** system resulted in the total abrasion of the coating at the end of the test (1000 cycles, company specific requirement). Another test with an improved version of this kind of system showed a better abrasion resistance but with significant scratches, and still clearly failed the company specific requirement of 1000 cycles. No information on the respective improvement measures of the coating system is available, but in general the abrasion resistance for the improved system was also insufficient for sanitary sector requirements.

Another kind of **lacquer + PVD + lacquer** coating system also clearly failed the abrasion resistance requirements, as the coating was fully destroyed after <10 abrasion cycles (company specific requirement is 300 cycles). The major problem of all **lacquer + PVD + lacquer** coating systems is that the final lacquer layers are generally not as hard as metallic chrome coatings by chromium trioxide electroplating, and the lower hardness is the reason for the overall failure of the abrasion resistance tests. As stated during the consultation, two-layer **lacquer + PVD** based coating systems failed the abrasion requirements of the sanitary sector at the current stage of development. In conclusion, the abrasion resistance **lacquer + PVD systems** do not meet the overall sanitary sector requirements due to technical issues at the current stage of development and efforts are necessary to overcome these.

*Temperature change resistance / heat resistance:* The temperature change resistance of, for example, a **lacquer + PVD + lacquer** coating on ABS was found not to meet the company specific requirements, as the coating was completely milky at the end of the 300 cycle test. In general, the temperature change resistance is dependent on the **lacquer + PVD + lacquer** coating. Compared to a metallic chrome coating from chromium trioxide, which general provides a high temperature change resistance for all different kinds of process types, this is clearly a disadvantage of PVD coatings. In conclusion, the temperature change resistance of PVD based coatings is not considered to meet the overall sanitary sector requirements at the current stage.

*Drinking water compliance:* In case of an **UV lacquer** used for the **lacquer + PVD** coating system, it is considered that – based on the technical application procedure - UV lacquers are not limited to the outside of the product to be coated, but may also be diffused to the inner geometry (inner waterways). Therefore, and due to the necessary curing of the UV lacquers, residues of non-cured particles can remain in inner geometries. As UV lacquers are known to contain substances where an approval for materials in contact with drinking water is not likely to be granted, , using these UV lacquers will either not be possible, or highly technical design is required, or expensive process technology would be required to prevent the migration of UV-lacquer residuals to the inner waterways. As a consequence, it is not likely that a lacquer + PVD alternative with UV lacquers can be used for materials in contact with drinking water.

*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, it was stated during the consultation 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 the metal feeling is missing.

*Conclusion sanitary sector:* **Lacquer + PVD + lacquer** systems are currently no technically feasible alternatives to metallic chrome coatings from chromium trioxide electroplating, but they are one of the most promising potential alternatives. From an aesthetic point of view, these coatings are not as good as metallic chrome coatings applied by electroplating using chromium trioxide electrolyte. While the performance of the coatings regarding corrosion resistance and chemical resistance is highly dependent on the respective coating system and the applied PVD metal, the abrasion resistance of lacquer systems do not sufficiently fulfil sanitary sector requirements. In addition, further R&D is necessary on the temperature change resistance of these kinds of coatings.

Substrate compatibility	Corrosion resistance	Chemical resistance	Wear / abrasion resistance	Temperature change / heat resistance	Drinking water compliance	Aesthetics
	Depending on the deposited metal	Depending on the deposited metal			Not for UV lacquers	

### Sector specific assessment: automotive

For automotive interior and exterior applications, the coating of highest importance is a conventional (silvery-bluish) chrome coating, while black chrome coatings on plastic substrate are special applications for exterior automotive uses. It was stated during the consultation that large 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. Especially in regard to mechanical loads caused by stone chip, the corrosion resistance of lacquer + PVD + lacquer systems with PVD aluminium as intermediate layer is not sufficient for exterior automotive requirements.

*Chemical resistance:* It was stated during the consultation that the chemical resistance of lacquer + PVD + lacquer systems is similar to stand-alone painting/lacquering (which is generally lower than for metallic chrome coatings from chromium trioxide). 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 given the early stage of development.

*Wear resistance / abrasion resistance:* With regard to abrasion resistance, **lacquer + PVD + lacquer** systems are stated to provide a similar abrasion resistance as stand-alone painting/lacquering, which are both much lower compared to metallic chrome coatings coated by using chromium trioxide electrolyte. Test results show a totally abraded surface after 1000 cycles in taber abrasion test according to DIN ISO 20566 (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:* As stated during the consultation, tests are ongoing on the adhesion of **lacquer + PVD + lacquer** systems. Currently, the adhesive



properties of this kind of coating system are not sufficient for some OEM. 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. In summary, the adhesion of **lacquer + PVD + lacquer** coatings for automotive applications does not fulfil the sector specific requirements at the current stage of development.

*Weather proof:* 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. During the consultation, R&D was stated to be ongoing. At the current stage, some systems, **especially UV-lacquer** systems, show a delamination of the lacquer after UV exposure.

*Others:* As stated during the consultation, the **lacquer + PVD + lacquer** coatings have an additional drawback, as 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. Due to the application technique, selective multi-component electroplating is not possible however.

*Aesthetics:* In general, the colour of **lacquer + PVD + lacquer** based coatings is highly characterized by the deposited metal. As stated during the consultation, the typical appearance of coated surfaces have a characteristic wavy surface and show an orange peel effect instead of the bright and silvery-bluish appearance of a metallic chrome coating applied by chromium trioxide plating and as such do not meet OEM requirements. In addition, the metal feeling of this kind of coating is not available and therefore not fulfilling the customer's requirements.

*Conclusions automotive sector:* The **lacquer + PVD + lacquer** technique is the most favoured PVD based alternative within the automotive sector, but is technically not feasible as an alternative to chrome electroplating at the current stage. The R&D on this alternative is still at an early stage and therefore not all key functionalities have been quantitatively evaluated to the full extent. Nevertheless, effects of the lacquer on the aesthetic appearance, together with a missing metal feeling, do not fulfil the high aesthetic requirements of the automotive sector. Corrosion resistance and chemical resistance are dependent on the kind of metal deposited as well as the topcoat lacquer used. Due to the lower hardness of lacquers, the abrasion resistance of **lacquer + PVD + lacquer** coatings is clearly lower compared to metallic chrome coatings from chromium trioxide electrolyte, and therefore clearly does not fulfil the automotive sector requirements. At the current stage of development, the adhesive properties of **lacquer + PVD + lacquer** coatings are also insufficient; for example, resulting in a delamination of the topcoat lacquer after UV exposure.

Substrate compatibility	Corrosion resistance	Chemical resistance	Wear / abrasion resistance	Adhesion	Weather proof	Aesthetics
	Depending on deposited metal	Depending on deposited metal			Not for UV lacquers	

#### **Sector specific assessment: cosmetics sector:**

*General Assessment:* From a general point of view, **lacquer + PVD + lacquer** would be a possible alternative to metallic chrome coated products for the cosmetics sector.

*Chemical resistance:* The lacquer + PVD + lacquer coatings do not sufficiently fulfil the requirements of chemical resistance; for example, against certain fragrance fluids and therefore not all kinds of coatings are compatible with all kind of fillings.

*Wear / abrasion resistance:* As stated during the consultation, the abrasion resistance of lacquer + PVD + lacquer coatings meets the sector specific requirements.

*Aesthetics:* Due to the process technique, no metal touch effect and no aspect foil effect (“mirror-like effect”) is provided to the coated product. As consumers widely require these characteristics, an alternative not providing these characteristics is not suitable. Moreover, it is not possible to produce cups with selective metallization.

*Conclusions cosmetics sector:* At the current stage of development, lacquer + PVD systems are not a technically feasible alternative to coatings from chromium trioxide based electroplating, as the aesthetic appearance of the coating and the chemical resistance do not fulfil the requirements of the cosmetics sector.

Substrate compatibility	Chemical resistance	Wear / abrasion resistance	Aesthetics

### **Sector specific assessment: white goods**

*General assessment:* The requirements of the white goods sector regarding a high-aesthetic appearance and a high-qualitative coating are comparable to sanitary sector requirements. For example, with regard to chemical resistance, they are even more demanding, as the tested and potentially used chemical agents for white goods parts are even more aggressive. Therefore, in a first test trial, testing was only performed on the chemical resistance of lacquer + PVD coating systems, while the technical conclusions regarding the other key functionalities can be drawn equivalent to the sanitary sector.

*Corrosion resistance:* The corrosion resistance of lacquer + PVD alternatives was already stated by the sanitary sector to be inconsistent at the current stage of development. Further development is necessary to reach suitable and repeatable corrosion resistance. Compared to a metallic chrome coating from chromium trioxide which generally provides a very high corrosion resistance in all cases, this is clearly a negative property of lacquer + PVD systems.

*Chemical resistance:* The chemical resistance of the **lacquer + PVD** coating was tested for the purpose of the white goods sector with chlorine bleach, hydrogen peroxide, acetic acid and caustic soda. The samples tested with chlorine bleach, hydrogen peroxide and caustic soda were very strongly attacked. The sample parts tested with chlorine bleach were even penetrated to the zinc die-casting substrate and the complete coating system was removed. The samples tested with hydrogen peroxide were also penetrated to the zinc die-casting substrate, but the coating system was only partially removed. For acetic acid only a minimal attack was found. However, this already has to be considered critical, as acetic acid is the basis of the most commonly used household cleaning agents. In general, the chemical resistance of the tested lacquer + PVD coating was clearly found not to meet the requirements of the white goods sector.

*Wear / abrasion resistance:* The negative results in similar and comparable tests of the sanitary sector implicate that the performance of these coating systems are also insufficient for the white goods sector.

*Aesthetics:* According to product information of one commercially available two-layer lacquer + PVD system applying a UV lacquer and a PVD chrome layer, this coating provides a bright chrome-like appearance. Nevertheless, it was stated during the consultation that the aesthetics and brightness of these coatings is not as good as a metallic chrome coating applied by chromium

trioxide electroplating. The colour was found to be grey and the colour changed over time (colour stability, colour match). In addition, no adequate metal feeling is provided.

*Conclusions white Goods sector:* The aesthetics requirements of the tested lacquer + PVD coating were found not to fulfil the high requirements and additionally not to provide the metal touch, which is a customer requirement. This is especially critical, as the white goods parts with a metallic chrome coating are supplied to a premium sector. The requirements for corrosion resistance can potentially be reached, depending on the kind of coating, but for other key functionalities such as chemical resistance and abrasion resistance, large technical efforts are necessary to develop a coating system able to meet the overall white goods sector requirements. As a consequence, lacquer + PVD systems are a promising alternative but at the current stage of development, they are not considered to be a technically feasible alternative to functional chrome plating with decorative character using chromium trioxide.

Substrate compatibility	Corrosion resistance	Chemical resistance	Wear / abrasion resistance	Aesthetics
	Depending on deposited metal			

#### 7.1.2.4 Economic feasibility

Against the background of significant technical failure of PVD based processes, no detailed quantitative analysis of economic feasibility was conducted. Indications were made stating 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. In all cases, very high investments for setting up a PVD based production line at an adequate size to guarantee the sufficient throughput of parts would be necessary. Further factors are that the coating costs for PVD metal are significantly higher, because no wet-in-wet coating is possible, and at the current stage full automation is not possible. Additionally, due to the complexity of PVD based systems, maintenance is very high.

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

In the case of transition from chromium trioxide electroplating to a PVD based alternative, the installation of completely new production lines is required, as the PVD based process cannot be performed in the same installations. In addition, technical knowledge of the operating staff is required. As stated during the consultation, compared to a classical electroplating line at least two PVD coating lines would be necessary to realize the same through-put of parts. The cost for the installation of one PVD coating line is estimated to be about 1 million Euros, resulting in investment costs (only for the PVD coating) of at least 2 million Euros. These high investment costs on the PVD technique do not yet cover costs for the set-up of adequate lacquer coating lines when changing to a lacquer + PVD + lacquer alternative, and further investment costs of at least 1 million Euro can be considered for this part.

In addition to investment costs, the vacuum chamber must have a sufficient size for the respective parts (for example front grills, trim stripes, etc.) 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, a line of sight process, is not suitable for complex geometries and large 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.

#### 7.1.2.5 Reduction of overall risk due to transition to the alternative

As the alternative is not technically feasible, only classification and labelling information of substances and products reported during the consultation were reviewed for comparison of the hazard profile. Based on the available information on the substances used within this alternative (see Appendix 2.1.2), titanium nitride would be the worst case with a classification as Flam. Sol. 2, Skin Irrit. 2 and Eye Irrit. 2. As such, transition from chromium trioxide - which is a non-threshold carcinogen - to one of these substances would constitute a shift to less hazardous substances.

#### 7.1.2.6 Availability

Different PVD based processes have been tested within the different sectors and R&D is still ongoing, as PVD based alternatives are one of the most promising alternatives to chromium trioxide electroplating at the current stage of development.

A long-term R&D project on the technical feasibility and development of **lacquer + PVD + lacquer** coatings was performed by a company within the sanitary sector. The project conducted more than 25 test trials and it was shown that lacquer + PVD + lacquer is a partly technically feasible alternative to metallic chrome coatings from chromium trioxide as electrolyte on a small pilot scale. As stated during the consultation, the existing technical issues on converting the process to large-scaling and e.g. aesthetics, corrosion resistance, chemical resistance and abrasion resistance, have to be further investigated by a prototype plant. Due to the high investment costs for this, further development is halted at the moment. The possibility of using the current lacquer coatings for applications in contact with drinking water has not yet been evaluated and may not be solved at all. If the lacquer is not permitted by the authorities, in cured or uncured condition, for parts in contact with drinking water, highly technical designs, or cost expensive process technology would be needed to cover the entire inner waterways against coating.

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 the long-term performance) of the coatings is ongoing. In addition, R&D and development of these kind of coatings for future use in exterior automotive applications is ongoing. As stated during the consultation, no sufficient capacities are available on the market for the broad application of lacquer + PVD + lacquer systems (with either applying a chrome or aluminium coating). The transition to this alternative would demand the set-up of new production lines across the market, which would result in high investment costs. Within the automotive sector, it was stated that the use of a **lacquer + PVD + lacquer** coating is limited to simple parts with small geometries and only for interior applications.

A R&D project "Flexicoat" on the extended usage of PVD based technology as alternative to electroplating processes to improve the characteristics of the final product was launched in March 2007 by a group of companies across the EU (from Spain, Netherlands, Italy, France, and UK). The duration of the project was 36 months. The result was a PVD prototype, potentially able to create decorative coatings in a short time (90 seconds), that required low application temperatures (up to 150°C) based on a cathodic arc or sputtering technology. No further details were available. However, these process temperatures are clearly too high to be applicable on plastic substrates.

Further technological development of PVD based processes, and especially of the lacquer + PVD + lacquer systems, is necessary before a coating system may become technically comparable to

metallic chrome coatings applied using chromium trioxide as electrolyte. It was stated during the consultation that at least 2 years of intensive R&D are necessary for this step. The coating process then requires sector specific approval. This approval would be given by the OEM for the automotive sector, while coating systems intended for sanitary sector use need to pass legal requirements for drinking water safety. Finally, and only after passing the sector specific approval procedure, the sectors could start to increase the required production capacity. In total, it is not likely that lacquer + PVD + lacquer system could be industrially used as a general alternative to functional plating using chromium trioxide electroplating within 7 years after the sunset date.

### 7.1.2.7 Conclusion on suitability and availability for PVD based processes

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.

At the current stage, the most promising PVD based alternative for all kinds of applications and sectors is a **lacquer + PVD + lacquer** system. However, at this stage of development this alternative system is not a technically feasible alternative to chrome 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 aesthetic appearance and the abrasion resistance due to the rather low hardness of the lacquer topcoat. In addition, other key functionalities such as corrosion resistance or chemical resistance are either not yet fulfilling the company specific requirements or the R&D is still ongoing to quantitatively evaluate these criteria.

In addition to the technical failure, 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 have to be coated. 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).

## CATEGORY 2 ALTERNATIVES

The alternatives assessed in this section have clear technical limitations and may only be suitable for niche applications but not as general alternatives to functional chrome plating with decorative character. In most cases, they showed clear technical limitations when it comes to the demanding requirements of the different sectors.

### 7.1.3. ALTERNATIVE 3: Satin & black anodized aluminium

#### 7.1.3.1 Substance ID and properties / process description

In this analysis of alternative, the anodizing treatment creating a **satin anodized aluminium** is assessed in general as well as anodized aluminium with a post-treatment creating a **black anodized aluminium**.

In general, 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 although the only commercial application is the

treatment of aluminium to create alumina ( $\text{Al}_2\text{O}_3$ ) on the surface (RPA Report, 2005). Therefore, the paragraphs below refer to aluminium and its alloys as substrate.

Anodization of aluminium changes the microscopic texture of the surface and changes the crystal structure of the metal near the surface. Anodizing is performed in an acidic bath containing an electrolytic acidic solution. Different kinds of acids can be used for anodizing, for example sulphuric acid or phosphoric acid. The temperature of the anodizing process / electrolyte is typically between 38 and 42°C and typical tank sizes are between 500 to 5000 litres (RPA Report, 2005). The parts to be treated form the anode electrode of an electrical circuit. The respective cathode is inert. The electric current can be varied during the anodizing process step. This leads to oxidation of the base metal at the anode with the formation of aluminium oxides on the surface.

The oxide layer partly grows into the substrate and partly grows onto the surface. There is a differentiation between “**normal anodizing**” and “**hard anodizing**”. In the course of hard anodizing, approximately **50%** of the oxide layer grows **into the substrate**, while approximately **65%** of the oxide layer grows into the substrate during normal anodizing (www.werkstoffoberflaeche.de). The total oxide thickness after anodizing is between 3 and 60 µm, while the thickness after hard anodizing is up to 300 µm (Feßmann and Orth, 2002).

Anodized aluminium surfaces are harder than the base substrate but have low to moderate wear resistance that can be improved with increasing thickness or by applying suitable sealing substances. Anodic films are generally much stronger and more adherent than most types of paint and metal plating, but are also more brittle. This makes them less likely to crack and peel from aging and wear, but more susceptible to cracking from thermal stress. Anodized surfaces show a certain porosity and need to be sealed or top coated either with thick porous coatings (that can absorb dyes), or with thin transparent coatings (that add interference effects to reflected light). Common examples are picture frames, car-body parts, door-knobs and other building fixtures, bathroom fixtures and racks, sporting goods, e.g. baseball bats. **A number of different colours are possible.**

**Black anodizing** is the subsequent colouring treatment (top coating) of an anodic surface and can be conducted using different methods such as Black dyeing (BD), Inorganic colouring (IC), or Electrolytic colouring (EC). For **BD**, the anodised specimens are immersed for 15 minutes in an organic black dye solution at values of between 4.5 to 5.5 pH, and at temperatures between 70 and 80°C. **IC** is a two-step process immersing the anodized specimens initially in a cobalt acetate ( $\text{Co}(\text{C}_2\text{H}_3\text{O}_3)_2$ ) solution and in a second step in an ammonium sulphide ( $\text{NH}_4)_2\text{S}$  solution, each immersion step lasting 15 minutes at temperatures between 20 to 30°C (Franco et al, 2012). According to Franco et al (2012), the black colour is the result of an inorganic reaction between the remaining acid (from the previous anodizing step) in the pores forming black cobalt sulphide ( $\text{CoS}$ ). **EC** is an electro-deposition technique where metallic salts are deposited within the anodic porous layer. The anodised specimens are electrolytically coloured by using an electrolyte comprising sulphuric acid, stannous chloride, and phenol sulphonic acid at highly acidic pH values and temperatures between 20 and 30°C, with a voltage of around 20 V (AC) for 15 minutes.

A non-exhaustive overview on general information on substances used within this alternative and the risk to human health and the environment is provided in Appendix 2.1.3.

### 7.1.3.2 Technical feasibility

Anodized aluminium is not an alternative for metallic chrome coatings applied by electroplating with chromium trioxide (neither bright/matt nor black), but was evaluated as an **alternative substrate** potentially replacing the whole electroplating process step. Pre-treatments and post-

treatments may still be required/necessary when using anodized aluminium. With regard to the overall appearance, either a satin anodized aluminium or a black anodized aluminium is discussed below (no bright appearance is possible, in comparison for example with bright chrome electroplating).

### **General assessment**

*Substrate compatibility:* 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.

*Aesthetics:* Satin anodized aluminium 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. Obviously, a black anodized surface is also no alternative to a metallic chrome coating from an aesthetic point of view, but instead, the black anodized surface may offer functionalities related to black chrome plating.

### **Sector specific assessment: sanitary**

As stated during the consultation, satin anodized aluminium parts are used in the sanitary sector, for example as construction parts (mixers and taps) for shower systems. These parts are not used to replace metallic chrome coated construction parts or parts coming directly in contact with drinking water (country specific drinking water regulations need to be observed). This use is a niche application only and the parts are purchased and not produced by the sector itself.

Test reports for a number of different satin anodized aluminium parts (without colouring top coat) were provided by various companies within the sanitary sector during the consultation phase. The reports generally showed that the overall requirements of the sanitary sector clearly cannot be met. It has to be noted that all tested key functionalities have to be fulfilled by an alternative to be considered technically feasible by the sanitary sector.

*Corrosion resistance:* The corrosion resistance of satin anodized aluminium was tested in numerous extensive salt spray tests ("normal" SST and CASS) and most of the tested anodized aluminium parts failed company specific test requirements (for example 300 h SST) due to severe corrosion. However, the behaviour of the tested parts is highly dependent on the kind of aluminium alloy used in the test. For single aluminium alloys (for example AlMg<sub>3</sub>) the company specific salt spray test with 300 h exposure and 4 h CASS exposure were met. In summary, the corrosion resistance of satin anodized aluminium is considered as being generally insufficient, as most of the tested parts failed the corrosion requirements.

*Chemical resistance:* The chemical resistance of satin anodized aluminium was tested in different cleaning agent spray tests (for example daily spraying for 14 days with vinegar essence and other commercially available cleaning agents). According to the provided test reports, all tested samples failed. The cleaning agent continuous immersion test (for example 14 days continuous immersion in vinegar essence) performed for various samples showed discrepancies on different kinds of aluminium alloys used. While the performance of anodized AlMg<sub>3</sub> was found to be satisfactory, other companies stated that the major failure of anodized aluminium samples was revealed during the continuous immersion test. In variable test procedures of spraying and immersion, the aluminium alloys behave differently under the test conditions. Anodized aluminium is generally highly susceptible to strong alkaline and strong acidic media resulting in a poor chemical resistance (either spray test or immersion test) and clearly does not meet the minimum requirements of the sanitary sector.



*Others:* The test results provided showed that company specific requirements on temperature cycle tests (for example 500 cycles, 80°C / 20°C) and water immersion tests can be met by AlMg<sub>3</sub>. However, other companies clearly stated that apart from corrosion and chemical resistance, no other tests on key functionalities (such as wear/abrasion resistance, adhesion, hardness, sunlight resistance or temperature change resistance) were performed at all due to the major failure on chemical resistance.

*Conclusion sanitary sector:* In summary, satin anodized aluminium is technically not a feasible alternative. It is no alternative for plastic substrates, as the anodizing process is metal (aluminium) specific. The satin/matt appearance of the anodized aluminium is not comparable to the bright silvery optic of chrome coated products and generally does not fulfil the aesthetic requirements of the sanitary sector. The general corrosion resistance of anodized aluminium was not satisfactory as most alloys clearly failed the requirements. Anodized aluminium is generally highly susceptible to strong alkaline and strong acidic media resulting in poor chemical resistance.

### **Sector specific assessment: automotive**

Black anodized aluminium is already on the market as material for the cladding of the centre pillar instead of ABS. This is an interior automotive part where a non-chrome optic may be suitable and where the requirements regarding other key functionalities, such as corrosion resistance, are lower. As stated during the consultation, typical black anodized aluminium in the automotive industry is produced using electrolytic Sn colouring (EC).

*Corrosion resistance:* Generally, both satin as well as black anodized aluminium show high sensitivity to road salt corrosion given their high susceptibility to acidic media. In case of surfaces already scratched, the corrosion requirements for exterior automotive applications are not met, while the corrosion resistance was stated to be acceptable for unscratched surfaces.

*Chemical resistance:* Satin anodized aluminium generally does not perform as well in chemical resistance as metallic chrome coated products, only being resistant up to a pH value of around 12.5, while there is no pH limitation of metallic chrome coated products using chromium trioxide electrolyte.

*Wear resistance / abrasion resistance:* As stated during the consultation phase, anodized aluminium (satin and black) is generally less scratch resistant than chromium trioxide coated products, but was stated to be acceptable for some OEMs when tested in car wash tests (exterior automotive requirement). In general, both satin and black anodized aluminium is a hard layer but shows poor stone chip resistance (exterior automotive requirement), because stone chips can damage the outer oxide layer by striking through it.

*Others:* Given the generally porous nature of an anodized aluminium surface, it shows an excellent adhesion behaviour for subsequent layers/coatings, but this is not a functionality of high importance.

*Conclusion automotive sector:* Although anodized aluminium parts may be used for automotive applications, this is not for the same purpose as chrome coated parts. In summary, satin anodized aluminium is technically not a feasible alternative. It is no alternative for plastic substrates, as the anodizing process is metal (aluminium) substrate specific. The satin/matt appearance of satin anodized aluminium is not comparable to the bright silvery optic of the chrome coated product and generally does not fulfil the aesthetic requirements. The hardness of the layer is not sufficient to protect the parts from stone chip, and the corrosion resistance was stated to be insufficient for scratched parts. In addition, the chemical resistance is limited to pH values of around 12.5.



### **Sector specific assessment: general engineering**

As stated during the consultation phase, **black anodizing** was tested as an alternative to black chrome plating for general engineering applications, but was found to be insufficient.

The main applications of black chrome layers in the general engineering sector are due to its very low reflective properties derived by the black colour **and** being electrically conductive at the same time. In contrast, black anodized surfaces do not show any electrical conductivity. Therefore, they cannot replace the functionality as required.

*Conclusion general engineering sector:* Black anodizing is technically not a feasible alternative to black chrome plating which is used for example in optical applications (photo, laser, solar technology). Satin anodized aluminium is not an alternative for any other consumer goods product, as the major key functionality of aesthetics clearly cannot be met by the satin (non-bright) surface.

#### **7.1.3.3 Economic feasibility**

Against the background of significant technical failure of satin and black anodized aluminium, no detailed analysis of economic feasibility was conducted.

The anodizing process is significantly different from the conventional electroplating process. Shifting production from electroplating to anodizing would mean the construction of a completely new process line comprising new bath equipment, new technical installations and new energy supply. Additionally, the costs for the chemicals were stated to be 2 to 3 times higher than for chromium trioxide plated products. Finally, as the bath temperatures are slightly higher than for the chromium trioxide process, the energy costs are also higher (up to 20%).

The main application of anodized aluminium lies within the aerospace sector (not part of this dossier). As stated during the consultation, parts are up to 100% more expensive than chromium trioxide coated parts.

#### **7.1.3.4 Reduction of overall risk due to transition to the alternative**

As the alternative is not technically feasible, only classification and labelling information of substances and products reported during the consultation were reviewed for comparison of the hazard profile. Based on the available information on the substances used within this alternative (see Appendix 2.1.3), cobalt di(acetate) for black anodizing would be the worst case with a classification as Muta.2, Carc. 1B, Repr. 1B. Skin Sens.1, Resp. Sens 1, Aquatic Acute 1 and Aquatic Chronic 1. Cobalt di(acetate) is a SVHC and included on the Candidate list according to REACH Annex XV for being carcinogenic and toxic for reproduction. Therefore, the use of cobalt di(acetate) for black anodizing as alternative to black chrome plating may become time limited by potentially transferring cobalt di(acetate) to the REACH authorization (Annex XIV). The use of cobalt di(acetate) instead of chromium trioxide is not a significant improvement regarding the reduction of overall risk.

Besides this substance, a transition from chromium trioxide - which is a non-threshold carcinogen - to one of these other substances would constitute a shift to less hazardous substances. However, as at least one of the used alternative substances is itself classified for mutagenicity and carcinogenicity, any replacements will need to be carefully evaluated on a case by case basis.

### 7.1.3.5 Availability

Anodized aluminium parts, satin as well as black ones, are commercially available e.g. for specific applications in the sanitary and automotive sector and can be purchased on demand.

In summary, satin and black anodized aluminium has been investigated and found not to be technically equivalent to metallic chrome coatings due to the insufficient aesthetic appearance and the failure on corrosion, chemical resistance, and sufficient electrical conductivity requirements. Due to the absence of the technical and economic feasibility of the process, no anodizing production is known to be currently set up within the sectors analysed. It is questionable if these systems will qualify for further R&D efforts within the discussed sectors, since other alternatives are much more promising.

### 7.1.3.6 Conclusion on suitability and availability for satin & black anodized aluminium

In summary, satin anodized aluminium is clearly technically inappropriate as a substrate alternative to replace the electroplating process step. It is not possible as an alternative to plastic substrates, as the anodizing process is metal (aluminium) substrate specific. The satin/matt appearance of satin anodized aluminium is not comparable to the bright silvery optic of the chrome coated product and generally does not fulfil the aesthetic requirements. In addition, the chemical resistance as well as the hardness of the coating do not fulfil the respective requirements to adequately protect the surface. Black anodizing is technically not feasible as an alternative to black chrome plating for the purposes of the general engineering sector, as the required electrical conductivity of the surface is not fulfilled.

As a consequence of the performed investigations on the technical properties of anodized aluminium, it is questionable if these alternatives will be further developed within the framework of the required applications in this use group, as more promising alternatives are currently under R&D.

Technical feasibility	Economic feasibility	Risk reduction	Availability
		Co compound: SVHC	Not a general alternative

## 7.1.4. ALTERNATIVE 4: Chromium free electroplating (zinc electroplating, multi-component coating system of copper, tin, zinc, nickel, cobalt; gold and platinum electroplating)

### 7.1.4.1 Substance ID and properties / process description

Electroplating is a process based on the principle of electrolysis. It forms a coherent metal coating on the part to be plated (substrate with already plated intermediate layers) by using the substrate as a cathode and an anode (type of anode depends on the distinct electroplating) and inducing an electrical current. The substrate is immersed in the electrolytic plating solution, which contains dissolved metal salts specifying the metal layer and additives (electrolyte). During the electroplating process, the dissolved metals are reduced and build up the coating (electrodeposition). Electroplating may enhance the corrosion resistance as well as the wear and abrasion resistance of the substrate.

For the purposes of functional chrome plating with decorative character, the following chromium trioxide-free electroplating processes were evaluated:

- Multi-component electroplating systems combining copper, tin zinc and/or nickel and/or cobalt,

- Gold and platinum electroplating,
- Zinc electroplating.

With regard to the **multi-component coating system of Cu, Sn and Zn**, tin is used due to its good corrosion resistance (Zhang, 1998). A number of commercially available **copper-tin-zinc electroplating solutions** are on the market for a number of different applications such as costume jewellery (piercings), clothing accessories (zippers), and high-frequency process techniques (screws). These alloys are composed of 50 to 55 wt% copper, 25 to 40 wt% tin and 10 to 20 wt% zinc - for example as sulphates. The resulting coatings can reach a layer thickness of maximum 10 µm with a hardness of about 600 HV [tested with a force of 0.5 N] (Umicore, 2013).

Further multi-component coating systems combine **tin and nickel**, with around 65% tin and 35% nickel in the solution, applicable on copper and copper alloys, nickel, silver and steel substrates (www.dico-sued.com) or **nickel, tin and copper**, or are based on cobalt, such as for example **tin-cobalt** and **nickel-cobalt-tin**.

In addition, further chrome-free electroplating processes such as **gold and platinum electroplating** are commercially available. However these are niche applications without broad commercial and market relevance and a special look. Typical gold plating electrolytes are based on potassiumdicyanoaurat(I), and typical platinum plating electrolytes are based on diamminodinitritoplatin(II).

A number of different zinc electroplating types are commercially available and known. With regard to the decorative purpose to be fulfilled, only the **acid zinc type** may be of interest (www.zink-nickel-kft.com) providing at least a limited levelling effect to the surface for a final bright appearance of the coating. For acid zinc type electroplating, aqueous soluble zinc salts, such as zinc sulphate, zinc chloride or zinc acetate can be used (Martin, 1979) with sodium hydroxide or potassium hydroxide as conducting salts. The further zinc electroplating types are alkaline zinc and cyanide zinc, which are not relevant for the applied use. The temperature of the **zinc electroplating** bath is about 60°C (Umicore, 2013) and the plated layer thickness is in the range between 10 and 20 µm, but also layers reaching up to a thickness of 50 µm are possible. The adhesion properties of zinc electroplated coatings are stated to be higher compared to the adhesion of lacquers on steel and comparable to hot-dip galvanizing (www.galvaswiss.ch). The hardness of these layers was stated to reach around 200 HV, but the zinc coatings are not resistant against acids and bases (www.galvaswiss.ch).

A non-exhaustive overview on general information on substances used within this alternative and the risk to human health and the environment is provided in Appendix 2.1.4.

#### 7.1.4.2 Technical feasibility

**Multi-component coating systems** comprising copper, tin, zinc and/or nickel and/or cobalt as well as **gold and platinum coatings** were assessed as potential alternatives for metallic chrome coatings from chromium trioxide based plating, while Zn coatings were assessed as potential alternatives for black chrome coatings applied by chromium trioxide based electroplating.

#### General assessment

As stated in the process description, different **multi-component coating systems comprising copper, tin, zinc and/or nickel and/or cobalt** are possible, for example copper-tin and copper-tin-zinc (also known as “white bronze”) or copper-nickel-tin. The basis of all multi-component coating systems is generally copper. The copper layer cannot be used as stand-alone coating, as it does not provide adequate corrosion protection, and further subsequent protection is needed.

*Substrate compatibility:* In general, the different chromium trioxide free electroplating processes are applicable on a number of different metal substrates such as die cast and brass as well as on plastic substrate.

### **Sector specific assessment: sanitary**

*Corrosion resistance:* The major problem with the **multi-layer coating systems** (independent of which combination chosen) is insufficient corrosion resistance. As stated during the consultation by various companies, the tested multi-layer systems comprehensively failed company specific corrosion resistance requirements due to severe corrosion of the coating. Corrosion results in a shorter lifetime of the plated product. The corrosion resistance of **gold and platinum coatings** is lower than for a metallic chrome coating applied using chromium trioxide electrolyte since the layer has very fine pores (no sealed surface) caused by the potential difference of the coating to the solid. Test results provided by the sanitary sector for electrolytic applied platinum layers (tested in a salt spray test performed according to EN 248), showed significant to severe corrosion and failed company specific requirements for corrosion resistance. The purchasers of these kind of coatings only sell these kind of coatings due to the special look and not for functionality such as superior corrosion resistance.

*Chemical resistance:* **Multi-layer coating systems** as well as **gold and platinum coatings** are susceptible to acidic media and do not fulfil the overall requirements of chemical resistance for standard applications in the sanitary sector (due to very fine pores in the coating caused by the potential difference between the coating and the solid).

As stated during the consultation and given the chemical properties of **gold and platinum**, the hardness of these coatings is much lower compared to coatings from chromium trioxide as electrolyte. According to information provided by the sanitary sector, the hardness of electrolytically applied gold layers is between 200 and 290 HV.

*Wear resistance / abrasion resistance:* The low hardness of the **multi-component coating systems** as well as **gold and platinum coatings** result in a low wear and abrasion resistance of the coatings. Test results provided by the sanitary sector on electrolytically applied gold layers showed abrasive damages on the surfaces after 2000 cycles in the taber abrasion test performed according to company specific test criteria. In addition, after a longer storage time of newly gold plated products, these showed numerous small scratches on the surface.

*Aesthetics:* The appearance of **multi-component coating systems** is generally comparable with metallic chrome coated products. However, the very bright appearance and the typical silvery-bluish shade cannot be achieved. In addition, technical difficulties of the multi-layer plating process can lead to a red colouring of the tin layer affecting the final appearance. As key functionalities such as corrosion resistance, and chemical resistance do not fulfil the requirements of the sanitary sector, resulting corrosion would highly affect the aesthetic of the products leading to an unacceptable surface.

As stated during the consultation, different kinds of **zinc coatings** (for example applied by zinc electroplating) are available. Certain zinc coatings are not applicable as decorative coating as an alternative to conventional chrome coatings due to their dark greyish/black appearance. They may be sufficient when only functional aspects (for example hot-dip galvanised steel) are required, but this is generally not the purpose of the functional chrome plating with decorative character as discussed for the applied use. Other kinds of zinc coatings are available which look like bright chrome, but these kinds of coatings are not corrosion resistant.

**Gold or platinum coatings** as an alternative to chromium trioxide derived metallic chrome coatings are already on the market. Gold and platinum coatings are niche applications for special

market purposes and from an aesthetic point of view not comparable to chrome coatings due to the light yellowish to red, and respectively grey to yellowish colours.

*Conclusion sanitary sector:* **Multi-component coating systems** based on copper, tin, zinc and/or nickel and/or cobalt are not technically feasible as alternatives to chromium trioxide electroplating. The coating has a low hardness, resulting in low wear and abrasion resistance. Given that these coatings have poor chemical and corrosion resistance, the lifetime of the product and the long-term aesthetic of the product are not satisfactory for the sanitary sector. **Gold and platinum coatings** are a niche application for special demands and not an alternative to the broad market of metallic chrome coatings. Given the limited availability (limited resource) of **gold and platinum** these coatings are very expensive. Furthermore, the hardness, abrasion and corrosion resistance is lower than the coatings applied by chromium trioxide electroplating resulting in a limited lifetime of the product. Overall these coatings do not fulfil the requirements for broad commercial applications within the sanitary sector.

### **Sector specific assessment: automotive**

**Zinc coatings** are generally not feasible technically for interior or exterior automotive applications as the aesthetic appearance of the coatings is insufficient. They are only seen as a potential application for specific automotive interior applications, for example headrest rods (parts which are generally not touched by customers) and therefore have not been evaluated in more detail. **Gold and platinum coatings** are niche application for special aesthetic interior automotive applications. They are based outside the regular commercial automotive sector and are chosen due to their aesthetic performance and not due to their functionality. Compared to a metallic chrome coating applied by chromium trioxide based electroplating, gold and platinum coatings are much more expensive given the limited raw material. The general (broad) requirements for corrosion resistance, hardness and abrasion resistance of the automotive sector cannot be fulfilled by such coatings.

*Corrosion resistance / chemical resistance / wear resistance / abrasion resistance:* As stated during the consultation, the corrosion resistance of **multi-component coating systems** is lower compared to coatings applied using electroplating techniques with chromium trioxide and does not fulfill the requirements of the automotive sector.

*Aesthetics:* **Multi-component coating systems** were stated not to be suitable as an alternative within the automotive sector as the coating is not stable (corrosion), resulting in a rainbow effect (refraction of light).

*Conclusion automotive sector:* Zinc coatings are not technically feasible as an overall replacement for metallic chrome coatings from chromium trioxide electrolyte, as the aesthetic appearance is not sufficient. Gold and platinum coatings are only high price niche applications and not an overall replacement to metallic chrome coatings applied by electroplating with chromium trioxide. Multi-component coating systems are not technically feasible to replace metallic chrome coatings from chromium trioxide, as the key functionalities of corrosion resistance, chemical resistance, abrasion resistance and hardness do not fulfill the requirements of the automotive sector.

### **Sector specific assessment: general engineering**

As stated during the consultation phase, a **zinc coating** with a subsequent black passivation (to enhance the absorption capacity) was tested as alternative to **black chrome plating** for the purposes of the general engineering sector and was found to be insufficient.

Given the metallic nature of the coating, the electrical conductivity is likely to be sufficient. However, as stated during the internal consultation, customers generally reject this alternative surface, as the reflective properties (one of the key functionality of black chrome plating) and the abrasion resistance are not sufficient and the zinc coating is susceptible to corrosion. The dark

colour of the zinc coatings is not considered to be sufficiently black and does not sufficiently absorb the light.

*Conclusion general engineering sector:* Zinc coating with subsequent black passivation is not a technically feasible alternative to black chrome plating, as the reflective properties (one of the key functionalities of black chrome plating for the use in optical applications such as photo, laser and solar technology) are not fulfilled. In addition, the abrasion resistance of the coating is not sufficient.

#### 7.1.4.3 Economic feasibility

Against the background of the significant technical failure of the evaluated alternative, no detailed analysis of economic feasibility was conducted. During the consultation phase it was indicated that the costs for the **multi-component coating systems** are higher because of the chemicals used and the higher analytical effort required (dependent on the distinct chosen components). With regard to **black passivated zinc coatings**, the installation and process costs were stated to be lower than for metallic chrome coatings from chromium trioxide electrolyte. From an apparent point of view, **gold and platinum coatings** are more expensive given the higher costs for the plating solutions due to their more limited natural availability (limited resource) and global price fluctuations of noble metals. Besides gold and platinum coatings, a transition from a chromium trioxide based electroplating process to a chrome free electroplating process would not result in a total shift of the overall production line (it remains a wet-in-wet electroplating process).

#### 7.1.4.4 Reduction of overall risk due to transition to the alternative

As the alternative is not technically feasible, only classification and labelling information of substances and products reported during the consultation were reviewed for comparison of the hazard profile. Based on the available information on the substances used within this alternative (see Appendix 2.1.4), nickel sulphate would be the worst case with a classification Muta. 2, Carc. 1A, Repr. 1B, Acute Tox. 4, Skin Irrit. 2, Skin Sens. 1, Resp. Sens. 1, STOT RE 1, Aquatic Acute 1 and Aquatic Chronic 1. Nickel sulphate is not yet included on the Candidate list or the Authorisation list according to REACH Annex XIV, nor included in the Community Rolling Action Plan (CoRAP), indicating substances for evaluation by the EU Member States in the next three years. However, based on the classification of nickel sulphate as carcinogenic, mutagenic and toxic to reproduction, its use is likely to be subject to further evaluation under the REACH authorization process.

Besides this substance, transition from chromium trioxide – which is a non-threshold carcinogen – to one of the other substances would constitute a shift to less hazardous substances. However as at least one of the used alternative substances is itself classified for mutagenicity and carcinogenicity, any replacements will need to be carefully evaluated on a case by case basis.

#### 7.1.4.5 Availability

All above evaluated chromium free electroplating solutions are commercially available and already on the market for their distinct applications. As stated during the consultation, R&D is planned for the automotive sector on electroplated zinc alloys for interior automotive parts used in areas not touched by consumers. However, it is not a general alternative.

#### 7.1.4.6 Conclusion on suitability and availability for chromium free electroplating

The aesthetic appearance created by the chromium free coatings are not comparable to the bright silvery-bluish appearance of the metallic chrome coating produced by chromium trioxide based electroplating. Gold and platinum coatings however, provide a special aesthetic for niche market applications (and the resulting reduced lifetime of the product may not be the criteria of highest importance compared to the exclusive aesthetic appearance).

In summary, chromium free electroplating processes are not technically feasible as a general alternative to chrome plating, as the requirements of the sectors in relation to corrosion resistance, chemical resistance and hardness are, in general, not fulfilled. The alternative coatings are found to result in an unaesthetic surface and a limited lifetime of the plated product.

With regard to black powder coatings as alternative to black chrome plating, the alternative was found not to be technically sufficient as it does not fulfil the requirements of the sectors (e.g. for electrical conductivity and low reflectivity).

Technical feasibility	Economic feasibility	Risk reduction	Availability
		Ni compounds: CMR	Not a general alternative

#### 7.1.5. ALTERNATIVE 5: Wet lacquering/ colour painting

##### 7.1.5.1 Substance ID and properties / process description

Wet lacquers are liquid coating materials that can be applied either as clear (transparent) lacquer ("Klarlack") or as coloured lacquer ("Farblack"). According to the Kunststoff Institut Lüdenscheid ([www.kunststoff-institut.de](http://www.kunststoff-institut.de)), lacquers can be classified:

- According to the number of components: one- or two-component-lacquers (1K or 2K),
- According to the kind of paint used: water-based lacquers (that also contain a certain amount of solvent) and solvent-based lacquers (low, medium and high-solid),
- According to the kind of drying procedure; and
- As UV-lacquers: either solvent-free (= 100% solid) or solvent-based.

In general, the main components of wet lacquers are bonding agents (organic polymers such as alkyd resin, acrylate or polyester resin), **solvents** (such as alcohols or ketones), **additives** (such as rheology additives e.g. polyurethane, **surface tension additives** (e.g. polydimethylsiloxan), **antioxidants** (e.g. cyclohexanoneoxime), and **fillers** (such as soot or talcum). For coloured lacquers, **colouring pigments** (such as titanium dioxide, ferrous oxide, or other pigments) are added ([www.kunststoff-institut.de](http://www.kunststoff-institut.de)).

Non-UV wet lacquers cure by evaporation of the solvents during the drying process. The formation of the lacquer film can occur either by a physical agglomeration or by chemical networking during the evaporation/drying process. Typical drying temperatures for wet lacquered plastic substrates do not exceed 80°C, while wet lacquered metal substrates dry when exposed to a temperature of up to 250°C.

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 ([www.kunststoff-institut.de](http://www.kunststoff-institut.de)). UV-lacquers have a broad application range and are commonly used in the printing industry.

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 2.1.5.

### **7.1.5.2 Technical feasibility**

Wet lacquering is assessed as a potential alternative for bright/matt metallic chrome coatings from chromium trioxide based electroplating and black chrome electroplating with chromium trioxide.

#### **General assessment**

*Substrate compatibility:* In general, wet lacquering is applicable on plastic substrates as well as on a number of different metal substrates such as different kinds of die cast and brass.

*Corrosion resistance:* According to a company providing wet lacquer applications (e.g. to parts for the automotive industry (www.benseler.de)), wet lacquer applied **on top** of a conversion coating is able to withstand at least 240 h in NSSC according to EN ISO 9227. Further information is taken from a technical datasheet for a black coloured wet lacquer, which is stated to be applicable for use on automotive parts, construction steel and parts used in furniture construction (Brillux, 2013). According to this datasheet, 480 h corrosion resistance in NSSC according to EN ISO 9227 can be reached. Cross-cut tests are stated to reach GT0 to GT1. After 500 h fast weathering test according to EN ISO 11507, a remaining gloss of >50% can be achieved. It has to be noted that all these parameters can be only achieved if an adequate lacquer top coating (“Decklack”) is applied on top of the wet lacquering and results may vary depending on the lacquer used.

*Temperature change resistance / heat resistance:* Wet lacquers are typically applied with thicknesses up to 80 µm and show a temperature resistance in the range between -35°C and 180°C. Special lacquers for parts exposed to high-temperatures are able to withstand temperatures of up to 600°C. (www.benseler.de).

*Aesthetics:* Wet lacquers create coloured surfaces (white, black, green, blue, yellow, etc.) but cannot create a bright and silvery-bluish coating as metallic chrome coatings applied by chromium trioxide based electroplating do. The aesthetic of wet lacquered parts is clearly neither comparable, nor equivalent to metallic chrome coatings from chromium trioxide as electrolyte, as an orange peel effect always occurs on the surface.

#### **Sector specific assessment: sanitary**

Intensive R&D activities target the performance of wet lacquered products in the sanitary sector. Numerous test reports for a number of different wet lacquered parts (different kind of tested lacquers) were provided by companies within the sanitary sector during the consultation phase. A limited number of wet lacquered sanitary installations (for example white or black coloured) are available on the market. These are consciously purchased by consumers for a preferred look, taking into account the lower functionalities (hardness, abrasion).

The market acceptance of non-chrome coated products is very low. Its market share is less than 1% Europe-wide whereas chrome-coated sanitary products cover more than 99% of the European sanitary market.

*Corrosion resistance:* Corrosion resistance of lacquers depends on the thickness of the lacquer layer. As stated during consultation, lacquers with a certain layer thickness are able to provide at least a corrosion resistance equal to metallic chrome coatings from chromium trioxide as electrolyte, while thin lacquer layers do not offer sufficient corrosion protection.



The test reports provided revealed only limited information on tested corrosion protection. The few results available showed that tested wet lacquers either fulfil, or slightly fail the company specific test requirements. The main defects were surface defects after 200 h salt spray exposure according to EN 248. However, the different tests are not comparable as the tested lacquers are of different origin and of layer thicknesses. It is considered therefore that there are wet lacquers on the market which meet basic corrosion requirements, but do not correspond to the overall requirements of the sanitary sector.

*Chemical resistance:* The test reports provided show numerous tests on chemical resistance of different kinds of wet lacquer coatings. All tested lacquers clearly failed the cleaning agent continuous immersion test and show discolouration (after 7 spraying days) and blistering (after 14 spraying days) when tested with vinegar essence. In further tests on household cleaning agents the coatings withstand continuous immersion tests as well as cleaning agent spray tests. A drop test to test soap and cleaner effects on the lacquered surfaces reveal a strong discolouration after treatment with sodium hydroxide, clearly failing this test. In general, the chemical resistance of wet lacquers is not sufficient to fulfil the requirements of the sanitary sector. It has to be noted that metallic chrome coatings coated by electroplating with chromium trioxide are much easier to clean compared to lacquered surfaces.

*Wear resistance / abrasion resistance:* The tested abrasion resistance of different wet lacquers showed that the surface was completely abraded within less than 10 test cycles (in contrast to the required 300 cycles) or resulted in very strong degradation after 1000 cycles (company specific requirement). In addition, further abrasion tests performed after testing the chemical resistance of the surfaces resulted in a completely abraded coating. The abrasion resistance of wet lacquered substrates therefore does not fulfil the requirements of the sanitary sector.

*Hardness:* The above described failure of the abrasion resistance test of wet lacquers is caused by the low hardness of the coating. Thus standards for hardness in the sanitary sector are not met.

*Others:* A number of tests for other key functionalities of the lacquer coating, for example sun tests for UV resistance (exposure by 650 W/m<sup>2</sup> for 588 h), temperature change tests for temperature change resistance (for example 300 cycles from 80°C to 20°C) and cross-cut tests for adhesive properties (for example reaching GT0 before and after temperature change test), have been performed and in general are able to meet the sanitary sector requirements.

*Aesthetics:* The overall appearance of wet lacquered parts is not comparable to the brilliant and silvery-bluish surfaces created by electroplating with chromium trioxide. The transfer from metallic chrome coating to wet lacquering would mean a complete change in aesthetic.

Currently wet lacquering has no sufficient market acceptance. Coloured parts were last used in the sanitary sector in the 1970s and 1980s (for example green, blue, and yellow sanitary installations), and since the early 1990s changed to today's bright chrome appearance. As stated during the consultation, the market relevance of sanitary chrome coatings is also country specific. However, more than 99% of the sanitary parts sold in the EU are equipped with a metal chrome coating. The chrome appearance is considered to be timeless in comparison to coloured coatings; it is less affected by seasonal variations, and sanitary parts of different vendors are highly compatible with each other (best price-performance ratio). In addition, a certain colour tone of different sanitary installations may change from one manufacturer to another, as such the combined installation of products from different manufacturers might not be possible from an aesthetic point of view.

*Conclusion sanitary sector:* Wet lacquered substrates are not technically able to meet the requirements of the sanitary sector to be considered an alternative to metallic chrome coatings applied by chromium trioxide based electroplating. The overall appearance of wet lacquered parts is

not comparable to the brilliant and silvery-bluish surfaces and a certain “orange peel” always affects the surface. The very low market acceptance is, among other factors, also due to a lower ability to clean the coatings compared to coatings from chromium trioxide as electrolyte. Lacquered coatings are consciously purchased by consumers for a preferred look, taking into account the lower functionalities (hardness, abrasion, cleanability).

When transferring from a metallic chrome coating to wet lacquering as alternative, the transfer would result in a complete change in aesthetics and would not have sufficient market and consumer acceptance. Wet lacquers that are available today are able to meet basic corrosion requirements, but do not answer the overall requirements of the sanitary sector. All tested lacquers clearly failed the cleaning agent continuous immersion test, showing discolorations and blistering. The lacquers’ abrasion resistance does not fulfil the requirements of the sanitary sector given the low hardness of the coatings. All these performance failures against the sector requirements also lead to a reduced lifetime of the product. Further key functionalities, such as temperature change resistance, adhesive properties, and UV resistance meet the sanitary sector requirements. However, the delivery of these functionalities is not crucial for the overall assessment for the use of this alternative in the sanitary sector given the clear failure of the other main requirements.

### **Sector specific assessment: automotive**

Wet lacquered parts for interior automotive applications are available on the market. These wet lacquered parts are not an alternative for all interior automotive applications and thus are neither intended nor able to replace the decorative functionality of chrome coated parts. Also, they are not considered to be an alternative for chrome plated exterior automotive applications. Bright chrome coated parts in the interior and exterior of an automotive are of high quality and part of the corporate design of the respective car manufacturer brand on the global market.

*Corrosion resistance:* It was stated during the consultation phase that the corrosion resistance of wet lacquered substrates depends on the respective lacquer system and can reach adequate results meeting the automotive sector requirements (for interior parts) but might also be much lower in comparison to metallic chrome coatings electroplated using chromium trioxide electrolyte.

*Chemical resistance:* The chemical resistance of wet lacquered parts depends on the respective lacquer system, but may satisfy requirements for interior automotive applications. The chemical resistance for exterior automotive applications needs further evaluation. While the metallic chrome coatings from chromium trioxide electrolyte are chemically inert in contact with various chemicals, the chemical resistance of wet lacquered substrates highly depends on the kind of wet lacquer applied, especially in contact with organic chemicals.

*Wear resistance / abrasion resistance:* Abrasion resistance depends on the lacquer system chosen, but is generally lower than metallic chrome coatings, and does not fulfil the automotive requirements with regard to maximum abrasion. The hardness of wet lacquered substrates was stated to be much lower compared to metallic chrome coats applied by chromium trioxide based electroplating, and does not meet the automotive sector requirements. Insufficient hardness results in a reduced and deficient abrasion resistance.

*Others:* As stated during the consultation, the adhesive properties of the wet lacquer coating depend on the lacquer system, the layer thickness, and the substrate chosen. Adhesion might be sufficient to meet automotive requirements, but could be lower compared to metallic chrome coatings applied by electroplating with chromium trioxide. This depends mainly on the paint system. Both, sunlight resistance and temperature change resistance performance are subject to ongoing R&D. So far requirements can be met, but strongly depend on the lacquer system chosen.

*Aesthetics:* The overall appearance of wet lacquered parts is not comparable to the brilliant and silvery-bluish metallic chrome layer used in the automotive industry. As stated during the consultation phase, the maximum brilliance to be achieved with wet lacquers is 400 to 500 UB (UB = unité de brilliance) compared to a minimum required brilliance of 600 UB for metallic chrome coatings applied using chromium trioxide based electroplating. As such, wet lacquering may be a possible substitution to satin chrome optics, but not for bright chrome optics. In addition, the possible orange peel effect of wet lacquers can adversely affect the aesthetic surface of the coating.

In the case of selective painting of complex geometries (for example painting of small knobs), the application of the lacquer is difficult with potential overlap of painted areas that might result in reduced quality and durability of the coating.

*Conclusion automotive sector:* Based on the information provided, wet lacquering is not considered to be a technically feasible alternative to bright metallic chrome coatings applied using chromium trioxide based electroplating. The aesthetic requirements regarding a silvery-bluish bright surface are not fulfilled. Wet lacquered coatings may be used for interior automotive applications, in locations where the aesthetic criteria are less relevant. For exterior applications abrasion resistance and corrosion resistance need improvement. In general wet lacquering does not fulfil the high requirements of the automotive sector.

### **Sector specific assessment: general engineering**

It was stated during the consultation phase that a **black coloured coating** applied as wet lacquering for the purposes of the general engineering sector is not comparable to a **black chrome coating**.

Coatings achieved with wet lacquering do not offer electrical conductivity and are less reflective (both key functionalities of black chrome plating) in comparison to black chrome plating. In addition, the temperature resistance of wet lacquered substrates is not sufficient for consumer goods applications (for example in photo, laser and solar technology). Even special lacquers for high-temperature applications cannot achieve a temperature resistance of  $> 750^{\circ}\text{C}$  as required for these applications. Finally, the layer applied to form the alternative coating is too thick for the intended use.

*Conclusion General Engineering sector:* Black coloured wet lacquers are not technically feasible alternatives to black chrome plating. Apart from other parameters, the key functionalities of black chrome plating such as low reflective properties and electrical conductivity are not fulfilled.

### **7.1.5.3 Economic feasibility**

Wet lacquered substrates significantly failed in technical tests, so no detailed analysis on the economic feasibility of this alternative was conducted. Some indications were made stating that the operational costs for wet lacquering are at least 30% higher compared to chromium trioxide based electroplating due to increased demand on maintenance of the process equipment.

For wet UV lacquers even higher costs than for other wet lacquers occur, as more material is required for the comparatively thick coatings, and the machines need special UV radiation-proof equipment. Additionally, the energy costs for UV radiation are higher compared to conventional drying methods ([www.veredelungslexikon.htwk-leipzig.de/de/veredeln-durch-beschichten/lackieren/uv-lack/](http://www.veredelungslexikon.htwk-leipzig.de/de/veredeln-durch-beschichten/lackieren/uv-lack/)).

#### 7.1.5.4 Reduction of overall risk due to transition to the alternative

As the alternative is not technically feasible, only classification and labelling information of substances and products reported during the consultation were reviewed for comparison of the hazard profile. Based on the available information on the substances used within this alternative (see Appendix 2.1.5), polyurethane 4-methyl-m-phenylene diisocyanate would be the worst case with a classification as Carc.2, Skin irrit. 2, Skin sens. 1, Eye irrit. 2, Acute Tox. 2, Resp. Sens.1, STOT SE 3 and Aquatic chronic 3. A second worst case process uses titanium dioxide as colouring pigment, classified as Carc.2 and Acute Tox. 4. Both substances are classified as carcinogenic but yet not further evaluated under REACH.

Despite the risks of these two substances, a transition from chromium trioxide - which is a non-threshold carcinogen - to one of the two above mentioned substances used for the production of wet lacquers would constitute a shift to less hazardous substances. However as at least one of the alternate substances is itself classified for mutagenicity and carcinogenicity, any replacements will need to be carefully evaluated on a case by case basis.

#### 7.1.5.5 Availability

Wet lacquers and wet lacquered substrates are available on the market for a broad range of applications, including within the industry sectors evaluated. However, the aesthetic appearance of these products is neither comparable nor competitive with chrome coated products. It was stated during the consultation that R&D is ongoing for use in the automotive sector. Wet lacquering could improve the technical functionality of applications where bright chrome optic is not required. For applications of functional chrome plating with decorative character, other alternatives are more promising.

#### 7.1.5.6 Conclusion on suitability and availability for wet lacquering / colour painting

In summary, wet lacquers are not technically feasible as an alternative to metallic chrome coatings, as the requirements of the sectors regarding the aesthetic appearance are not fulfilled. Other key functionalities are met by wet lacquer coatings and it may be an alternative for applications without the demand for a chrome optic. As stated during the consultation, R&D is ongoing in the automotive sector to improve the technical functionality of wet lacquering for applications with a non-bright chrome optic. For applications of functional chrome plating with decorative character, other alternatives are more promising. Black powder coatings as an alternative to black chrome plating were found to be technically insufficient and did not fulfil requirements for electrical conductivity and low reflectivity.

Technical feasibility	Economic feasibility	Risk reduction	Availability
			Not a general alternative

### 7.1.6. ALTERNATIVE 6: CVD - Chemical vapour deposition

#### 7.1.6.1 Substance ID and properties / process description

Chemical vapour deposition (CVD) is a process similar to PVD, but uses gases that, combined on a hot surface, form a hard coating (TURI, 2006). TURI (2006) presents the following variations of CVD processes:

- Atmospheric CVD: conducted at atmospheric pressure and high temperature,

- Low pressure CVD: at sub-atmospheric pressure and high temperature and
- Plasma enhanced CVD: at lower temperatures with heat generated by electrical plasma.

Typical CVD coatings include single-layer titanium carbide TiC coatings or multi-layer CVD systems combining either a first TiC layer with a subsequent titanium nitride TiN layer, or the same two layers in reverse order, depending on the product specific requirements.

CVD coatings are typically applied with a total layer thickness between 7 and 10 µm (www.eifeler.com). The process temperature ranges between 800 and 1000°C. CVD and coatings have good adhesion behaviour. Different coating types are discussed in more detail below.

**Titanium carbide (TiC)** as a coating material is of metallic grey colour. The hardness of the coating is between 3,500 to 4,500 HV. The layer thickness of up to 9 µm is higher than PVD application of the same coating materials. The coating is resistant to temperatures of maximum 300°C. Possible applications of TiC coatings include tools for iron processing.

The use of **titanium carbide/titanium nitride** results in a golden coloured coating. The coating hardness is between 2400 and 3000 HV and is temperature resistant up to 500°C. The layer thickness is in the range between 6 and 10 µm. The automotive industry uses this coating for the processing of galvanized plates.

**Titanium nitride/ titanium carbide (TiN/TiC)** has a metallic grey colour. The hardness of the coating from this material is between 2700 and 3300 HV. A layer thickness of up to 9 µm is possible. The coating is temperature resistant to 450°C. Applications for TiN/TiC coatings include tools for iron processing.

The surface of CVD coated parts is rough and microporous which limits the application spectrum.

A non-exhaustive overview on general information on substances used within this alternative and the risk to human health and the environment is provided in Appendix 2.1.6.

### 7.1.6.2 Technical feasibility

Chemical vapour deposition is assessed as a potential alternative to metallic chrome coatings from chromium trioxide based electroplating.

#### General assessment

*Substrate compatibility:* The typical process temperature for the application of a coating by CVD is between 200 and 500°C.

ABS - the most commonly used substrate in the sanitary and automotive sector - melts at a temperature of about 105°. This mismatch of melting point and process temperature makes CVD **an alternative that is generally not technically feasible to replace chromium trioxide plating on plastic**. However, CVD is a suitable alternative for application on numerous different kinds of metal substrates. A special process is available which creates a black CVD coating on top of a metallic chrome coating from chromium trioxide as electrolyte on plastic parts and is used as a special application for the automotive (exterior) sector. However, this application relies on an initial chrome coating and is not a stand-alone process and is therefore not considered to be an alternative for chromium trioxide based electroplating.

*Aesthetics:* The nature of the coating applied in a CVD process depends on the kind of metal used in the vacuum process step. This metal determines the colour and the properties of the final coating.

**Sector specific assessment: sanitary**

The application of metal coating on metal substrates by CVD as an alternative to metallic chrome electroplated coatings was tested for the sanitary sector. Some test reports for different kinds of CVD coatings - where the coatings were not further specified - were provided during the consultation.

*Substrate compatibility:* CVD coatings are not applicable for plastic substrates, due to the high process temperatures (between 200 and 500°C) compared to the melting point of the ABS plastic substrate (105°C). Within the sanitary sector, plastic substrates are of great importance for applications like shower heads, but of less importance in other areas. A limiting factor of the CVD technique is 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.

*Chemical resistance:* 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 continuous immersion tests (for example immersed for 4 and 7 days in household chemicals). The results of both tests clearly show that CVD coatings do not sufficiently meet the company specific requirements on chemical resistance.

*Temperature change resistance:* Depending on the kind of CVD coating applied, the company specific requirements on temperature change resistance (300 cycles) were either met or clearly failed. This is due to the fact that not all CVD coatings feature the same temperature change resistance. This is clearly a negative aspect compared to metallic chrome coatings applied by electroplating with chromium trioxide, which show a good temperature change performance.

*Wear resistance / abrasion resistance:* As stated during the consultation, the abrasion resistance of CVD coatings is better than the one of metallic chrome coatings deposited using chromium trioxide electrolyte, due to the higher hardness of the coating. CVD coatings are applied on parts later used as tools.

*Others:* The adhesion of the coating on the substrate was tested in cross-cut tests that were performed before and after temperature change tests and met the company specific requirements (GT0).

*Aesthetics:* A CVD coating does not necessarily offer a bright surface. A bright underplate has to be applied which is responsible for a bright appearance of the CVD surface. The colour of the surface then is determined by the kind of metal deposited on the substrate.

*Conclusion sanitary sector:* CVD coatings do not meet the requirements of technical feasibility to be considered an alternative to bright metallic chrome coatings from chromium trioxide. One constraint is the high process temperature of CVD coatings that cannot be applied on plastic substrates due to their low melting point. This makes CVD a limited alternative for only specific kinds of substrates. Another constraint is that the CVD coatings on metals substrates do not meet the requirements of chemical resistance. Other parameters, such as temperature change resistance, may meet the requirements for some uses, but not all kinds of CVD coatings pass this test successfully. Metallic chrome coatings from chromium trioxide based electroplating fulfill all requirements, whereas CVD coatings failed to perform in a number of areas.

**Sector specific assessment: automotive**

It was stated during the consultation that so far no evaluation of decorative parts with an alternative CVD coating has been performed for the automotive sector.

*Substrate compatibility:* The vast majority of metallic chrome coated parts within the automotive sector are based on plastic substrate due its low weight compared to metal as substrate. This contributes to a lower overall weight of the assembled car, and results in lower fuel consumption and less CO<sub>2</sub> emissions. CVD coating is not technically feasible as an alternative to the chromium trioxide based electroplating on plastic substrates due to the high process temperatures (between 200 and 500°C) compared to the melting point of plastic substrates e.g. of ABS at 105°C, as the substrate would either be heavily distorted or even melt. The CVD coating technique is also limited by the *geometry* of the parts to be coated; complex geometric parts and parts with small internal diameters are especially difficult to handle.

*Conclusion automotive sector:* CVD coatings are technically not feasible as an alternative to metallic chrome coatings applied by chromium trioxide based electroplating, as the high process temperatures are not compatible with the low melting point of plastic substrate, which is the substrate most commonly used within the automotive sector. Due to this major technical failure, no further evaluation has been undertaken for use within the automotive sector.

### **7.1.6.3 Economic feasibility**

In view of the significant technical failure of CVD coatings, no detailed analysis of economic feasibility was conducted. Indications were made stating that the costs for CVD coatings are at least twice the costs of conventional chromium trioxide plated parts.

CVD coatings are applied via a vacuum chamber, all parts to be coated (independent of size, geometry and amount) need to pass within the vacuum chamber. At the current stage of development, 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.

### **7.1.6.4 Reduction of overall risk due to transition to the alternative**

As the alternative is not technically feasible, only classification and labelling information of substances and products reported during the consultation were reviewed for comparison of the hazard profile. Based on the available information on the substances used within this alternative (see Appendix 2.1.6), titanium nitride would be the worst case with a classification as Flam. Sol. 2, Skin Irrit. 2 and Eye Irrit. 2. Titanium nitride is not further evaluated under REACH. As such, transition from chromium trioxide - which is a non-threshold carcinogen - to one of these substances would constitute a shift to less hazardous substances.

### **7.1.6.5 Availability**

The CVD technique is limited to smaller parts to be coated without complex geometries and without small internal diameters to be coated. The CVD technique and CVD coated parts (for example machining tools, shims, etc.) are already commercially available on the market. In general, CVD is not available on plastic substrates due to the high process temperatures in comparison to the low melting point of the plastic substrate.

In the absence of technical and economic feasibility, it is not likely that this alternative will be part of further R&D for the adaptation of the process technology, especially as other alternatives are more promising.

### 7.1.6.6 Conclusion on suitability and availability for CVD

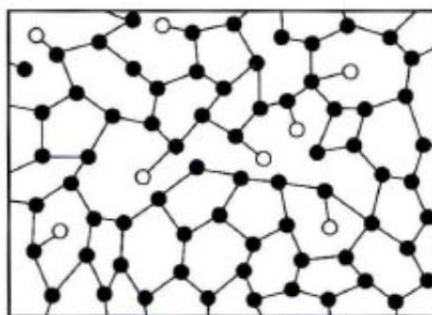
CVD coatings are neither technically nor economically feasible as alternative to metallic chrome coatings applied by chromium trioxide based electroplating. In general, CVD layers cannot be applied on plastic substrates due to the high process temperatures. This makes CVD a very limited alternative for only some kinds of substrates and applications. The use of a CVD based application leads to high costs per part and is not suitable for high volume production (limited size of vacuum chamber, limited throughput of parts). In addition, the process technique is not successful when coating parts with complex geometries or small internal diameters. The CVD coatings tested applied on metal substrates did not meet the requirements of the industry sectors, such as for chemical resistance. In the absence of technical and economic feasibility and in the presence of more promising alternatives, it is not likely that this alternative will be part of further R&D.

Technical feasibility	Economic feasibility	Risk reduction	Availability

### 7.1.7. ALTERNATIVE 7: DLC - Diamond like carbon

#### 7.1.7.1 Substance ID and properties / process description

Diamond Like Carbon (DLC) is an amorphous carbon layer with “diamond-like” properties such as extreme high hardness, good wear and chemical resistance (Engemann, 2010). DLC has an amorphous structure where different foreign atoms, such as hydrogen, silicon, and fluorine, can be integrated in the network structure as shown in **Figure 20**.



**Figure 20:** Schematic illustration of a highly cross-linked, hard amorphous DLC structure (2D view from above) with a foreign atoms/hydrogen proportion between 15 and 25% (carbon atoms: black, foreign atoms/hydrogen: white). Data source: Engemann, 2010.

Variations of the coating can be achieved when hydrogen is added to the coating process. The hydrogen in the coating process bonds with the carbon, resulting in a softer polymeric network. In contrast, non-hydrogenated DLC has a very rigid network (Grill, 1999).

DLC layers are applied under vacuum conditions with two graphite electrodes that initiate an electric arc in-between. The application of DLC coatings is performed using a vacuum technique, either CVD or PVD. One graphite electrode acts as a cathode, the other one as an anode. The temperatures transform the graphite to a plasma phase. The energy of the light arc places the plasma corona between the anode and the cathode. The parts to be coated (substrate) are placed below the plasma corona. The carbon condenses as a thin DLC layer on the substrate. An additional pulsed bias current is applied to transfer the carbon from the plasma to the substrate.



The colour of the coating is dark grey to anthracite. The typical thickness of DLC coatings ranges between 2 µm and 4 µm and provides a hardness of 2000 to 3000 HV (Poco, 2013). Some DLC processes achieve a hardness of up to 9000 HV (www.kohlenstoffschichten.de). The typical coating temperature is about 150°C (Poco, 2013).

DLC coatings are commonly used for various applications, such as machining tools or for coating of mould components.

A non-exhaustive overview on general information on substances used within this alternative and the risk to human health and the environment is provided in Appendix 2.1.7.

### 7.1.7.2 Technical feasibility

DLC coatings are assessed as a potential alternative for metallic chrome coatings from chromium trioxide based electroplating.

#### **General assessment**

*Substrate compatibility:* The process temperatures during application of a DLC coating are typically about 150°C. When applying a DLC coating on plastic substrate, for example on ABS with a melting temperature of 105°C, the plastic would melt. Therefore DLC is **not generally a technically feasible alternative to chromium trioxide plating on plastic**. DLC can be an alternative for coatings on different kinds of metal substrates.

*Aesthetics:* Given the nature of the DLC coating, it has a dark grey to anthracite appearance, which is neither compatible nor comparative to the bright silvery-bluish appearance of a metallic chrome coating applied by using chromium trioxide electroplating. Another limiting factor of DLC coating is for parts with complex geometries or with small internal diameters.

#### **Sector specific assessment: sanitary**

*General assessment:* As stated during the consultation, DLC layers were tested and found not to be sufficient for the purpose of functional chrome plating with decorative character. DLC layers are not a stand-alone coating for decorative purposes, but can be used as an additional functional layer applied on top of a metallic chrome coating from chromium trioxide based electroplating, for example as coating on ceramic disks. A number of different tests on the general functionality of DLC layers were provided during the consultation by various companies of the sanitary sector for various DLC coated samples. It has to be noted that the test results are DLC coating specific (matt, bright, and applied on top of a metallic chrome coating from chromium trioxide) and are therefore not comparable.

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.

*Corrosion resistance:* In general, the corrosion resistance of tested DLC coatings fulfils company specific requirements. For example, DLC coating applied on top of an electrolytically applied metallic chrome coating with chromium trioxide as electrolyte withstands the company specified required 300 h salt spray exposure tested according to EN ISO 9227.

*Chemical 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 are not able to fulfil the requirements of chemical resistance which would be required to pass all test procedures for withstanding household chemicals. As an example, a DLC coating applied on brass and a DLC coating applied on tin die cast were both completely corroded after a 7 day continuous immersion test with vinegar essence, while the same parts withstand a 14 days continuous immersion test in a commercially available cleaning product. With regard to cleaning agent spray tests, DLC coatings were completely corroded after 14 days of daily spraying with commercially available products. In general, most DLC coatings do not fulfil the sanitary sector requirements regarding chemical resistance. The issue is less with the chemical resistance of the coating itself, but with the adhesion of the coating to the substrate. If the coating is not bonded tightly enough to the substrate, this highly affects the overall performance of the product.

*Wear resistance / abrasion resistance:* The abrasion resistance of most tested DLC coatings withstand the company specific test requirements, for example more than 300 abrasion cycles or more than 10000 cycles. This is due to the high hardness of the coating that ranges typically between 2000 and 3000 HV.

*Aesthetics:* A DLC coating does not necessarily lead to a bright surface. A bright underplate has to be used which is responsible for the bright appearance of the DLC surface. Nevertheless, the final colour is determined by the DLC layer and is dark grey to anthracite.

*Conclusion sanitary sector:* DLC coatings are not a technically feasible alternative to metallic chrome coatings applied by electroplating, as 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. In addition, the chemical resistance of the tested DLC coatings did not fulfil the requirements of the sanitary sector. Although the corrosion resistance test and the abrasion resistance test of DLC coatings generally met the sanitary requirements (due to the high hardness of DLC coating), the main functionalities of a functional chrome plating with decorative character are not fulfilled.

### **Sector specific assessment: automotive**

It was stated during the consultation that DLC coatings are not an alternative for decorative automotive applications, but can be used, for example, as high performance coatings in engine applications.

*Substrate compatibility:* The vast majority of metallic chrome coated parts within the automotive sector are based on plastic substrate due to their very low weight compared to metal substrates, which provides a lower overall weight of the assembled car, which in turn means less fuel consumption and CO<sub>2</sub> emissions. DLC coatings are generally not a technically feasible alternative to metallic chrome electroplated parts due to the higher process temperatures (normally around 150°C). Compared to the melting point of plastic substrates (for example ABS at 105°C), as such the substrate would be either heavily distorted or even melt. A limiting factor of the DLC technique is also the *geometry* of the parts to be coated. Complex geometric parts and parts with small internal diameters are especially difficult to handle as already stated for the sanitary sector.

*Abrasion resistance:* Due to the extreme hardness of the DLC coatings (typically in the range of 2000 to 3000 HV), the coatings have a high abrasion resistance.

*Aesthetics:* The dark grey to anthracite coloured DLC coating is not an alternative to a bright chrome decorative coating. Only very few selected applications could be covered by DLC coating.

*Conclusion automotive sector:* DLC coatings are not a technically feasible alternative to metallic chrome coatings applied by electroplating with chromium trioxide as electrolyte. 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.

### **7.1.7.3 Economic feasibility**

Owing to the significant technical failure of DLC coatings, no detailed analysis of economic feasibility was conducted. Indications were made stating that the costs for DLC coatings are up to 150% above costs of conventional chromium trioxide plated parts.

The DLC layer is applied via a vacuum chamber and, as such, all parts to be coated (independent of size, geometry and amount) need to pass through the vacuum chamber. Currently, vacuum chambers neither have the size nor is the process able to realize the turnover as required by the industry sectors analysed for their products. DLC coating is difficult to apply on complex geometric parts, especially with small internal diameters to be coated. In case of transition to DLC, high investment costs would be required for the realisation of a DLC line that is able to coat parts of different sizes with adequate throughput.

### **7.1.7.4 Reduction of overall risk due to transition to the alternative**

As the alternative is not technically feasible, only classification and labelling information of substances and products reported during the consultation were reviewed for comparison of the hazard profile. Based on the available information on the substances used within this alternative (see Appendix 2.1.7), graphite would be the worst case with a classification as Eye Irrit. 2 and STOT SE 2. As such, transition from chromium trioxide - which is a non-threshold carcinogen - to one of these substances would constitute a shift to less hazardous substances.

### **7.1.7.5 Availability**

The DLC technique and DLC coated parts (for example for machining tools, mould components and engine applications) are already commercially available on the market. In general, DLC is not applicable on plastic substrates due to the high process temperature compared to the low melting point of plastic substrates. DLC coatings were tested by the industry sectors analysed and found not to be sufficient for the purpose of functional plating with a decorative character.

In the absence of technical and economic feasibility, it is not likely that this alternative will be part of further R&D as alternative for chromium trioxide, especially as other alternatives are much more promising.

### **7.1.7.6 Conclusion on suitability and availability for DLC**

In conclusion, DLC coatings are neither technically nor economically feasible as an alternative for metallic chrome coatings applied by chromium trioxide based electroplating for the purpose of functional chrome plating with decorative character. Although the technique and DLC coated products are commercially available and have been tested by the industry sectors analysed, DLC coatings do not fulfil the aesthetic functionality of providing a high decorative and bright shiny surface. Furthermore, the key functionality of chemical resistance was not sufficiently fulfilled, and DLC coatings are not applicable on plastic substrates due to coating temperatures that are above the melting point of plastic substrates. DLC coatings are not a general alternative that would be applicable on all kind of substrates.

Technical feasibility	Economic feasibility	Risk reduction	Availability

### 7.1.8. ALTERNATIVE 8: Electroless nickel plating

#### 7.1.8.1 Substance ID and properties / process description

Nickel (Ni) coatings can be applied on substrates by two different techniques, either using electroless nickel plating, or using nickel electroplating. The process discussed in this section is electroless nickel plating (EN) that, in contrast to nickel electroplating, is conducted without electric current to deposit the nickel layer.

**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. The most commonly used electroless nickel plating process produces a nickel coating with phosphor (Ni-P). Another version that is less common uses nickel-boron (Ni-B) coating and will not be discussed further in this context.

Electroless nickel plating is performed by dipping the parts to be coated in an electrolytic aqueous solution containing the nickel source (for example nickel sulphate), reducing agent (for example sodium hypophosphite, borohydrite) and complexing agent (for example carboxylic acids or amines). The process depends on the presence of the reducing agent, which reduces the metallic ions in the electroless plating solution to form a coating. The complexing agent is necessary to increase the phosphite solubility of the reducing agent and to regulate the reaction rate.

The phosphorous containing electroless nickel processes are characterized according to the phosphorous concentration of the coating: **low phosphorous** coatings have between 2 - 5 % phosphor, **medium phosphorous** coatings range between 8 - 10 % phosphor, and **high phosphorous** coatings range between 11-14 % phosphor. The process can be adapted to the purpose of the coating. A phosphor concentration of about 10 % provides good corrosion resistance while a lower phosphor concentration offers a better wear resistance to the coating (holzapfel-group.com). In general, electroless nickel coatings are resistant against most organic and inorganic media except strong oxidising agents. Another way to improve the properties of the coating is the incorporation of additive particles (such as silicon carbide, diamond, polytetrafluoroethylene (PTFE), or tungsten carbide) into the Ni layer to form composite coatings. By controlling the amount of phosphor additives, various coating properties can be modified.

According to the technical data sheet derived from [www.spitzke-hartchrom.de](http://www.spitzke-hartchrom.de), the EN coating is carried out uniformly on the substrate without constructing edges. The coating process temperature is between 90 and 95°C. The usual thickness of the layers is about 2 µm to 50 µm but a higher thickness of up to 200 µm or more can be produced. The typical hardness of the coating is about 500 - 550 HV [tested with a force of 0.3 N], but with thermal post-treatment the hardness can be increased to about 900 - 1000 HV ([www.spitzke-hartchrom.de](http://www.spitzke-hartchrom.de)).

During the electroless nickel plating process, hydrogen can be produced which can cause embrittlement of the coating. For substrates with a risk of being affected by this, a thermal pre-treatment can be applied to reduce the risk of embrittlement ([www.spitzke-hartchrom.de](http://www.spitzke-hartchrom.de)).

Typical products equipped with electroless nickel coatings include functional automotive parts, such as brake cylinders. Injected moulded products for machining and processing are also often coated using electroless nickel coatings. In general, electroless nickel coatings are applied because of functional advantages and not for decorative purposes.

A non-exhaustive overview on general information on substances used within this alternative and the risk to human health and the environment is provided in Appendix 2.1.8.

### 7.1.8.2 Technical feasibility

Electroless nickel plating was assessed as a potential alternative for chromium trioxide based electroplating and black chrome electroplating with chromium trioxide.

#### **General assessment**

The hypophosphite based electroless nickel plating process is of broad commercial use due to low process costs, simple process control, and good corrosion resistance (once an adequate coating thickness is applied). Thin electroless nickel layers are used to pre-treat plastic substrates for further metal electroplating to enhance their electrical conductivity.

*Substrate compatibility:* It was stated during the consultation that electroless nickel plating is available for a broad range of substrates, including tin die cast, brass, steel and different kinds of plastic substrates (after suitable etching pre-treatment and activation processes).

*Corrosion resistance:* **Table 8** summarizes the corrosion resistance of electroless nickel coatings with a high content of phosphor. The data shows that high phosphorous electroless nickel layers can meet sector specific requirements (as for example 300 to 500 h in NSST (sanitary) or 480 h in NSST (automotive)) but only if a rather 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.

**Table 8:** Corrosion resistance of highly phosphorous electroless nickel coatings ([www.spitzke-hartchrom.de](http://www.spitzke-hartchrom.de)).

Thickness [µm]	10-25	25-50	> 50
NSST EN ISO 9227 [hours]	240 h	> 800 h	> 1500 h
AASST EN ISO 9227 [hours]	200 h	800 h	> 1000 h
Kesternich-Test (0.2 l SO <sub>2</sub> ) [cycles]	4	10	12

*Others:* The hardness of electroless nickel coatings is typically in the range of 500 to 550 HV, compared to 800 - 1200 HV for electroplated chrome. The hardness of the coating can be increased to reach up to 750 HV by varying the phosphorous content of the final coating. With a heat post-treatment, the hardness can be increased further to reach around 950 HV.

*Aesthetics:* The aesthetic appearance of an electroless nickel coating is neither comparable nor competitive to a bright chrome coating. The colour of EN layers are not silvery-bluish and do not resemble the brightness of the chrome coating **Figure 12**. Electroless nickel layers are neither intended, nor used, as a final coating for decorative applications.

#### **Sector specific assessment: sanitary**

According to the information provided during the consultation, electroless nickel coatings have been tested for the sanitary sector as an alternative to chrome coatings but found to be insufficient.

*Corrosion resistance:* The corrosion resistance of electroless nickel coatings is highly dependent on the kind of plating solution. According to the information and test reports provided during the consultation from companies within the sanitary sector, the corrosion resistance of electroless nickel coatings clearly does not meet the requirements. For example, for an electroless sulphamate nickel plating on different kind of substrates (brass, plastic and zinc die cast), salt spray tests showed verdigris (initial corrosion) after 72 h and, as such, failed to meet the company specific corrosion requirements of 300 h salt spray exposure. However, a variation of electroless nickel process containing a high amount of phosphor may be able to provide sufficient corrosion protection if applied with a layer thickness of at least  $> 25 \mu\text{m}$ . Again, this makes electroless nickel plating neither adequate, nor competitive to, chrome coating with a thin thickness of 0.2 to  $2 \mu\text{m}$ .

*Chemical resistance:* Following the test results provided, none of the nickel plated products was able to meet all company specific requirements for chemical resistance. Electroless nickel coated zinc die cast products failed the continuous immersion test in vinegar essence as well as spray testing that included 14 days of daily spraying with a commercially available product. Additionally, other company specific tests on electroless nickel plated products (such as the continuous immersion test) failed showing severe corrosion. In general, the chemical resistance of electroless nickel plated products is not sufficient and does not meet all sanitary sector requirements.

*Nickel leaching:* The maximum nickel concentration in drinking water is regulated by law. A nickel layer as final coating for sanitary parts that are in contact with drinking water is clearly not able to meet the requirements for drinking water quality. Nickel leaching is also legally limited for consumer goods; parts with a final nickel coating would certainly exceed the legal threshold.

*Aesthetics:* The bright silvery-bluish appearance which is required for functional chrome plating with decorative character cannot be reached with an electroless nickel layer. However, as stated during the consultation, bright electroless nickel layers with a clear lacquer topcoat have been used in series production in the 1990s. These have been taken off the market due to severe issues with corrosion protection. Besides corrosion and chemical resistance issues, insufficient durability, and a lack of long-term aesthetic appearance, reduced brightness, and a slightly yellowish appearance do not fulfil the requirements for aesthetic appearance for sanitary use. In addition, electroless nickel layers do not have any levelling effect, meaning that any unevenness of the substrate (for example resulting from the moulding or die casting process) will still be apparent after coating.

*Conclusions sanitary sector:* Electroless nickel coatings are not technically feasible as an alternative to conventional metallic chrome coating applied by chromium trioxide based electroplating. The aesthetic requirements of the sanitary sector are clearly not met. The corrosion resistance may be able to meet the sanitary requirements, but only if a final coating with a high thickness is applied. The corrosion resistance of the electroless nickel coated parts does not fulfil the requirements of the sector. A nickel layer applied as final coating would exceed the nickel threshold values according to drinking water and construction products legislation for parts in contact with drinking water or for consumer goods.

### **Sector specific assessment: automotive**

According to information provided during the consultation, electroless nickel layers have been tested for application in the automotive sector as an alternative to chrome coatings but found to be insufficient.

*Corrosion resistance:* As stated during the consultation phase, the corrosion resistance of electroless nickel coatings does not meet the automotive requirement. Electroless nickel coated parts did not pass the (company specific) 48 h CASS test.

*Chemical resistance:* It was stated during the consultation that the chemical resistance of electroless nickel coatings is sufficient and meets the overall automotive requirements.

*Wear resistance / abrasion resistance:* The abrasion resistance of electroless nickel layers was stated to be sufficient for automotive applications given the hardness of the coatings.

*Nickel leaching:* The nickel leaching of consumer goods is regulated by law. The threshold is certainly not met if a final nickel coating is used.

*Aesthetics:* The bright silvery-bluish appearance which is required for the functional chrome plating with decorative character cannot be reached with an electroless nickel layer. The electroless nickel coating is only a functional, not a decorative finish. The electroless nickel coatings may be slightly affected by corrosion, resulting in a reduced brightness and a yellowish appearance of the surface. This creates a colour match problem with other metallic surfaces, and makes it incompatible with numerous other parts that are assembled for one car.

*Conclusion automotive sector:* Electroless nickel coatings are not technically feasible as an alternative to conventional coatings applied by electroplating with chromium trioxide. The aesthetic requirements of the automotive sector are clearly not fulfilled. The corrosion resistance does not meet the automotive requirements. Finally, nickel coatings as a final coating are not able to meet the legal requirements regarding nickel leaching from plated products.

### **Sector specific assessment: general engineering**

It was stated during the consultation that black electroless nickel coating **with subsequent black passivation** was the most focused alternative to black chrome plating for the purposes of the general engineering sector, but the final product was not accepted by consumers. At the current stage, no technical feasible chromium trioxide free alternative fulfilling the key functionalities of the general engineering sector is known to being available.

*Corrosion resistance:* As stated during the consultation, the corrosion resistance of the tested black electroless nickel coatings was found to be sufficiently high for the application purpose.

*Wear resistance / abrasion resistance:* The black electroless nickel coating does not provide the required abrasion resistance which black chrome applications do provide.

*Conclusion general engineering sector:* Black electroless nickel coatings with subsequent passivation are not a technically feasible alternative to black chrome plating, as reflective properties (a key functionality of black chrome plating for the use in optical applications such as photo, laser and solar technology) is not fulfilled. In addition, the abrasion resistance of electroless nickel coatings is not sufficient. Given the metallic nature of the coating, the electrical conductivity is likely to be sufficient, but this is not relevant given the failures for other functionalities.

### **Sector specific assessment: store construction**

As stated during the consultation, electroless nickel coatings with incorporated PTFE particles are assessed as an alternative on steel substrates for store construction applications. The most focused key functionality of the store construction sector is abrasion resistance of the coating.

*Wear / abrasion resistance:* The very high sliding properties of the PTFE particles enclosed in the surface of the product are responsible for a good abrasion resistance of the coating.

*Nickel leaching:* With regard to nickel migration from the product potentially affecting consumers, the respective nickel thresholds certainly cannot be met by parts with a final nickel coating. However, this issue was not evaluated due to the failure of the economic feasibility of this special alternative for this sector.

*Conclusions store construction sector:* Electroless nickel coating with incorporated PTFE particles show a good abrasion resistance and can be a technically possible alternative to chromium trioxide plated metallic chrome coatings. However, the technical feasibility is not the major criterion for this application, given the major limitations with the economic feasibility (see 7.1.8.3).

#### **7.1.8.3 Economic feasibility**

Against the background of significant technical failure of electroless nickel coated substrates, no detailed analysis of economic feasibility was conducted. Indications were made stating that the costs for electroless nickel coating are higher compared to costs of conventional chromium trioxide plated metallic chrome parts. The cost difference is associated with the increased layer thickness that, in turn, is related to higher chemical and energy requirements, a longer plating time that results in a lower throughput of products in the coating process, and higher technical process efforts (for example for water treatment during electroless nickel plating). In general, the transition from a coating applied using a chromium trioxide based electroplating to electroless nickel technique would not mean a total shift in production, as all bath applications could be reworked (by changing tank material, protecting current, etc.) to fit the alternative process.

With regard to an electroless nickel coating with incorporated **PTFE** particles, for the purposes of the store construction sector, the coating is between 4 to 5 times more expensive compared to electroplating with chromium trioxide. This are clear economical disadvantages for the coating of steel within the store construction sector.

#### **7.1.8.4 Reduction of overall risk due to transition to the alternative**

As the alternative is not technically feasible, only classification and labelling information of substances and products reported during the consultation were reviewed for comparison of the hazard profile. Based on the available information on the substances used within this alternative (see Appendix 2.1.8), nickel sulphate would be the worst case with a classification as Muta. 2, Carc. 1A, Repr. 1B, Acute Tox. 4, Skin Irrit. 2, Skin Sens. 1, Resp. Sens. 1, STOT RE 1, Aquatic Acute 1 and Aquatic Chronic 1. Nickel sulphate is not yet included in the Candidate list, the Authorisation list of REACH Annex XIV, nor included in the CoRAP that indicated substances for evaluation by the EU Member States in the next three years. However, based on the classification of nickel sulphate as carcinogenic, mutagenic and toxic to reproduction, its use is likely to be subject of further evaluation under REACH.

With regard to nickel migration from the product either into drinking water (when using electroless nickel coated parts that are in contact with drinking water), or affecting consumer goods, the respective nickel thresholds certainly cannot be met by parts with a final nickel coating. Therefore, the use of electroless nickel as alternative to chromium trioxide would clearly not mean a reduction of risk for the consumer, and the use of this alternative therefore must be carefully evaluated on a case by case basis.

#### **7.1.8.5 Availability**

The electroless nickel plating technique as well as electroless nickel plated products for functional purposes (for example brake cylinders) are commercially available on the market. In addition,



electroless nickel plating is typically used as an underplate on plastic substrates prior to functional chrome plating with decorative character used by plastic plating companies within the industry sectors analysed (no stand-alone coating functionality).

Electroless nickel as alternative to functional chrome plating with decorative character was tested by the industry sectors analysed and found not to be technically feasible. Electroless nickel with PTFE is not economically feasible as alternative for the purposes of the store construction sector. In the absence of technical and economic feasibility, it is not likely that this alternative will be part of further R&D as alternative for functional chrome plating with decorative character, especially as other alternatives are much more promising.

#### 7.1.8.6 Conclusion on suitability and availability for electroless nickel plating

Electroless nickel as an alternative to functional chrome plating with decorative character was tested by the industry sectors analysed and found to be neither technically nor economically feasible. The bright silvery-bluish appearance which is required by functional chrome plating with decorative character cannot be reached with an electroless nickel layer, as this layer shows a slightly yellow appearance. Electroless nickel coatings provide a functional, but not a decorative finish. Further key functionalities such as corrosion resistance and chemical resistance were found to be insufficient to meet the respective requirements of the industry sectors. Electroless nickel with PTFE is not economically feasible as alternative for the purposes of the store construction sector.

In the absence of technical and economic feasibility, it is not likely that this alternative will be part of further R&D among CTAC member companies, especially as other alternatives are much more promising.

With regard to black powder coatings as an alternative to black chrome plating, the alternative was found to be technically insufficient as it does not fulfil the requirements for electrical conductivity and low reflectivity.

Technical feasibility	Economic feasibility	Risk reduction	Availability
	PTFE for store construction	Ni: CMR	

#### 7.1.9. ALTERNATIVE 9: Powder coating

##### 7.1.9.1 Substance ID and properties / process description

The application of powder coatings is based on the physical principle of electrostatic attraction without use of any kind of solvent. The substances used for powder coatings are organic polymers with thermosetting properties. In general, powder coatings consist of about 60% of binder inclusive networker (for example hybrid, epoxy, polyester or acrylate powder), to approximately 40 % of colouring pigments and fillers (for example kaolinite, barite or wollastonite (Oggermüller & Reiter 2014)) and 1-3 % of additives (for example polyacrylates, benzoin and waxes).

Commonly used substrates are steel, ferrous materials and galvanized ferrous materials, cast, aluminium and magnesium (www.benseler.de). The average grain size of the powder is in the range of 20-45 µm. According to Mischke (2007), finer particles (< 10 µm) would agglomerate and result in issues during the application process, while coarse particles lead to problems with levelling of the surface (Mischke, 2007).

The powder coating process comprises three process steps: pre-treatment for cleaning, the powder application, and a thermal hardening process (curing of the powder, post-treatment). The cleaning of the substrate from any kind of dirt like oil, soil, lubrication greases, metal oxides and welding scales uses various chemical cleaning methods (such as degreasing, etching or de-smutting) and mechanical cleaning methods (such as abrasive blasting, sandblasting or shot blasting) that are company specific.

There are two main commercial application techniques for powder coatings that differ in the application gun used: electrostatic / corona application and tribo-application. For electrostatic / corona powder coating, the gun gives a positive electric charge to the powder (electrostatic / corona gun), while the tribo-gun charges the powder by friction, produced by rubbing the powder particles along a Teflon layer inside the tribo gun.

After the application of the powder coating on the substrate, the coating is fixed by a thermal curing treatment. Typical curing temperatures are between 110° and 250°C, but most commonly in the range of 140° and 200°C. Special powder coatings needing an extended curing time that work with low curing temperatures of around 120°C are also on the market.

The main use of powder coatings are for general metallic substrates (35 %), household applications (21 %), architectural / façade coatings (20 %), furniture (13 %) and for finishing of automotive parts (8 %) ([www.pulver-beschichtung.org/](http://www.pulver-beschichtung.org/)).

There is a broad range of different kinds of powder coatings and in general, the details of the ingredients are not publicly available. Therefore, only groups of chemical ingredients can be described without details of their physicochemical properties, or hazard classification and labelling.

#### **7.1.9.2 Technical feasibility**

Powder coating was assessed as a potential alternative to metallic chrome coating from chromium trioxide electroplating and black chrome plating with chromium trioxide.

##### **General assessment**

*Substrate compatibility:* In general, powder coatings are applicable on a number of different metal substrates such as brass and copper. The curing temperature of the heat treatment is typically in the range between 140 and 200°C, so powder coatings are not applicable on plastic substrates. Powder coating on die castings (such as zinc, aluminium or magnesium) can reduce the strength and stiffness of these kinds of substrates (this effect typically starts at temperatures of 100°C).

A company involved in the application of powder coatings for a number of different industry sectors is commercially advertising that the corrosion requirements of the automotive sector (worldwide) are met ([www.benseler.de](http://www.benseler.de)). This company claims that corrosion and chemical resistance of powder coatings are sufficient and show no substantial alteration after contact with common fuels, brake fluids, oils and solvents, and that the cross-cut-test for the adhesion properties of powder coatings is satisfactory by reaching values of GT0 to GT1.

##### **Sector specific assessment: sanitary**

*General assessment:* Intensive R&D on powder coatings has been performed in the sanitary sector. Numerous test reports were provided for a number of different powder coated products and different powder coatings by various companies during the consultation phase. Powder coatings for sanitary purposes have been used in the past, but currently are not widely used due to unwanted effects such as migration (corrosion), brittleness, and yellowing of the coating (orange peel effect). Powder coatings have a rather low market acceptance and penetration and are consciously

purchased by the consumers for a preferred look, taking into account the lower functionalities (hardness, abrasion). The very low market acceptance is, among other factors, also due to a lower cleanability of the coatings compared to the cleanability of metallic chrome coatings from chromium trioxide.

*Corrosion resistance:* According to the test results provided, the corrosion resistance of powder coatings is dependent on the substrate and the kind of powder coating applied. A test of a powder coating applied on brass showed defects on the surface and significant migration under the coating after salt spray exposure of around 200 h according to EN ISO 9227 and failed the company specific requirements (in this case of 200 h salt spray exposure), while other powder coatings (for example applied on top of a platinum coated substrate) did meet the requirements by either showing no corrosion (after 200 h exposure) or minimal corrosion (in case of platinum, which is easier corroded). In general, the corrosion resistance of powder coatings is dependent on a number of factors. This is clearly one of the weak points of powder coatings when compared to metallic chrome coatings by chromium trioxide, which perform independently from substrate and require no technically challenging coating specification.

*Chemical resistance:* The very low market acceptance is, apart from other factors, also due to a lower cleanability of the coatings compared to chrome coatings from chromium trioxide. Powder coated surfaces were tested with different chemical agents (such as toothpaste, shampoo, nail polish remover, perfume, hair spray, and household cleaning agents). The evaluation of the provided test reports showed that powder coatings exposed to alcohol and/or solvent containing chemicals (nail polish remover, perfume) as well as to toothpaste, failed the respective tests by showing chemical corrosion of the surface. In contrast, coatings tested with household cleaning agents (for example vinegar essence and a commercially available product) using cleaning agents spray tests (14 days of daily spraying) or continuous immersion test (7 and 14 days immersion) passed the tests. In summary, the evaluation of all the provided information showed that the overall requirements of the sanitary sector for chemical resistance are clearly not met by powder coatings, and chemical resistance is not comparative with surfaces coated using chromium trioxide based electroplating.

*Wear resistance / abrasion resistance:* According to the information provided during the consultation, the abrasion resistance of powder coatings does not fulfil the sanitary sector requirements, as the coatings were completely abraded after just a few abrasive cycles (<10 cycles according to the specific company test performance). Abrasive tests by other sanitary companies were performed with a higher number of cycles and other test criteria. They generally resulted in a slight abrasion of the coating starting at 2000 cycles, which subsequently minimized the brightness of the coating and finally resulted in an overall failure of the test (minimum company specific requirement of 10000 cycles). The low abrasion resistance is due to the low hardness of the coatings.

*Adhesion:* The adhesion properties were tested via cross-cut test generally showing that the adhesion of the powder coatings to the respective substrates is sufficient and fulfil the overall sanitary sector requirements (GT0).

*Aesthetics:* The aesthetic appearance of a powder coating is not comparable with a metallic chrome coating applied by electroplating with chromium trioxide. Powder coatings do not show the bright and silvery-bluish appearance of metallic chrome coatings and thus do not fulfil the aesthetic requirements of the sanitary sector. As stated during the consultation, problems with long-term colour stability (depending on the respective coating system) may result in a yellowing of the coating.

*Conclusions sanitary sector:* Powder coatings are not a technically feasible alternative to bright metallic chrome coatings applied electroplating with chromium trioxide as electrolyte. The aesthetic appearance of the powder coated surface is not equivalent to the silvery-bluish and bright appearance of the latter. Depending on the coating system, a yellowing of the coating may develop over time. Corrosion resistance, chemical resistance and abrasion resistance of powder coatings were generally not able to meet the sanitary sector requirements. In addition, powder coatings cannot be applied on all kinds of substrates, due to the curing temperature being higher than some substrate's melting points (e.g. for plastic substrates).

#### **Sector specific assessment: automotive**

*General assessment:* As stated during the consultation, R&D has been performed within the automotive sector and is still ongoing. Powder coatings are already on the market for some motorcycle components but mostly not as an alternative for decorative parts.

*Substrate compatibility:* Powder coatings cannot be applied on plastic substrates, as the curing temperature of the powder coatings is higher than the melting point of most plastic substrates. Powder coatings are not a general alternative to chrome electroplating due to the high volume of plastic applications in the automotive industry

*Corrosion resistance:* According to the automotive sector, the tests conducted on corrosion resistance of powder coated metal substrates showed worse results in comparison with metallic chrome coatings applied by electroplating with chromium trioxide and did not fulfil the automotive sector requirements.

*Wear resistance / abrasion resistance:* As stated during the consultation, the abrasion resistance of powder coatings is generally low due to the low hardness of the coating.

*Aesthetics:* The aesthetic appearance of a powder coating is not comparable with that of metallic chrome coated parts. Powder coatings are not able to show the same bright and silvery-bluish appearance as the metallic chrome coatings and therefore do not fulfil the aesthetic requirements of the automotive sector. In addition, a yellowing of the coating may occur that finally results in an orange peel effect, depending on the coating system used.

*Conclusion automotive sector:* In conclusion, powder coatings are technically not feasible as alternative to metallic chrome coatings applied by chromium trioxide electroplating. Powder coatings are not able to show a bright and silvery-bluish appearance such as chrome coatings and therefore do not fulfil the aesthetic requirements of the automotive sector. Furthermore, the technique is not applicable on plastic substrates and does not meet the requirements of key functionalities of the automotive industry such as corrosion resistance and abrasion resistance.

### **Sector specific assessment: general engineering**

*General assessment:* As stated during the consultation, the performance of black powder coatings as an alternative to black chrome electroplating with chromium trioxide has been evaluated based on the known performance of powder coatings.

In comparison between black chrome coating and powder coating in terms of the key performance parameters, the latter do neither show any electrical conductivity (as not of metallic origin) nor the reflective property. Their absorption capability is lower compared to black chrome coatings, the temperature resistance is lower, and the applied layer thickness is higher (too high for many applications).

*Conclusion general engineering sector:* Black powder coatings are not a technically feasible alternative to black chrome plating with chromium trioxide, as the key functionalities of low reflective properties and no electrical conductive surface are not fulfilled for the requirements of the specific applications. Also, further functionalities, such as thin layer thickness and sufficient temperature resistance are not provided.

### **Sector specific assessment: store construction**

*General assessment:* Different test results on powder coated steel products used in the store construction sector were provided for review. Powder coated products are sold in a small market (less than 1% compared to the metallic chrome coated products) for customers interested in special looks, such as different colours.

For all products used in the store construction sector, the key functionality of the coating is the abrasive behaviour and therefore, all provided quantitative data is based on this parameter.

*Wear / abrasion resistance:* The abrasion resistance of a metallic chrome coating applied by electroplating with chromium trioxide as electrolyte has to withstand at least 25000 double strokes in abrasion testing with the hook of a standard clothes hanger. In comparison different kinds of powder coatings clearly showed lower abrasion resistance in the range between 1300 to 12500 double strokes, with the exact value depending on the kind of coating.

*Conclusions store construction sector:* Powder coated products for store construction are sold in a small market (less than 1%) due to special looks required by the customers, but with a clear limitation on the abrasive quality of the product. The majority of products are sold with a metallic chrome coating by chromium trioxide electroplating due to the quality and longevity of the product. The abrasion resistance of powder coatings is clearly lower compared to metallic chrome coatings, and powder coatings are not a technically feasible alternative to metallic chrome coatings from chromium trioxide as electrolyte.

### **7.1.9.3 Economic feasibility**

Against the background of significant technical failure of powder coated substrates, no detailed analysis of economic feasibility was conducted. Indications were made stating that the operational costs compared to chrome electroplating are up to 30% higher. Additionally, the through-put of coated parts is lower using powder coating due to the necessary heat-treatment of all parts, compared to the faster electroplating bath process. The transition from an electroplating process to a powder coating production would mean the set-up of a completely new production line and would require high investment costs.

#### 7.1.9.4 Reduction of overall risk due to transition to the alternative

Chromium trioxide is a non-threshold carcinogen which represents the toxicological worst case. Powder coating is considered to use only ingredients less hazardous than Cr(VI) components and therefore, the transition from chromium trioxide to powder coatings would constitute a shift to less hazardous substances. Nevertheless, it has to be considered that the application of powder coatings may generate an explosive atmosphere and special explosion prevention measures may become necessary. In case of transition, any replacement will need to be carefully evaluated on a case by case basis.

#### 7.1.9.5 Availability

Powder coatings and powder coated substrates are available on the market for a broad range of applications. However, these applications are not intended to replace parts of functional chrome plating with decorative character, as the aesthetic appearance is not comparable nor competitive.

As stated during the consultation, R&D is ongoing within the automotive sector on the development of new parts (for example for the supply of spare parts). With regard to the alternatives for application of functional chrome plating with decorative character, other alternatives are much more promising.

#### 7.1.9.6 Conclusion on suitability and availability for powder coating

Powder coatings are not a technically feasible alternative to metallic chrome coatings applied by electroplating with chromium trioxide. The technique is not applicable on plastic substrates and may also affect die cast substrates. The aesthetic appearance of the powder coated parts is neither comparable nor competitive to the bright silvery-bluish appearance of chrome coated parts. Apart from the aesthetic failure, other key functionalities, such as corrosion resistance and chemical resistance generally did not meet the sector specific requirements. Powder coatings are available on the market but less for functional applications within the discussed sectors. Powder coatings have a rather low market acceptance within the sanitary sector and are consciously purchased by customers/consumers for a preferred look taking into account the lower functionalities (hardness, abrasion). R&D was stated to be ongoing for the development of new parts (for example for the supply of spare parts). With regard to black powder coatings as an alternative to black chrome plating, the alternative was found to be technically insufficient and does not fulfil the requirements for electrical conductivity and low reflectivity.

Technical feasibility	Economic feasibility	Risk reduction	Availability
			<b>Not a general alternative</b>

### 7.1.10. ALTERNATIVE 10: Stainless steel (alternative substrate)

#### 7.1.10.1 Substance ID and properties / process description

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 (Informationsstelle Edelstahl Rostfrei, 2012).

About 30 to 40 % of the worldwide production of stainless steel is austenitic chromium-nickel-steel 1.4301 (X5CrNi 18-10). It includes a maximum of 0.07 % carbon, 17.5 - 19.5 % chromium, 8 - 10.5 % nickel and not more than 0.11% nitrogen. This kind of stainless steel provides good corrosion resistance, easy machinability, and an attractive appearance; these characteristics are why it is the most commonly used stainless steel.

The corrosion resistance of 1.4301 stainless steel is about 17.5 - 21.36 PREN (Pitting Resistance Equivalent Number). The PREN value is a measurement of the corrosion resistance of Ni containing stainless steel, tested according to ASTM G48. In general, the higher the PREN value, the higher the corrosion resistance. Stainless steels with a PREN value above 32 are considered seawater corrosion resistant. Stainless steels are generally passivated, meaning the presence of metal oxides, which create an outer shell to the substrate, protect the substrate against deeper corrosion and the steel is less affected by environmental impacts caused by air or water. Passivation is also used to strengthen and preserve the appearance of metallic surfaces. Passivation processes can be divided into **spontaneous passivation coatings** and **industrial applied passivation coatings**.

Stainless steels with a chromium content of > 3 w% have the ability to form a natural passive layer of chromium oxide preventing deeper corrosion and providing self-active corrosion inhibition properties. This natural passivation only occurs if the chromium content is high enough and if oxygen is present. Despite the natural corrosion protection of stainless steels, they are not completely insusceptible to rusting. Rusting can start at small spots on the surface where impurities or foreign material (e.g. grinding swarf) have become enclosed in the material. These spots offer access to the iron by water or oxygen, the iron is then oxidised and rusting begins.

All stainless steels need to be provided with an industrially applied passivation coating in a post-treatment process, performed in addition to the processing step.

Stainless steel would be used in the assessed industry sectors as an article and therefore no distinct hazardous classification and labelling information is provided.

### 7.1.10.2 Technical feasibility

Stainless steel is not an alternative to functional chrome plating with decorative character, but is evaluated as an alternative substrate to potentially replace the whole electroplating step. Adequate pre-treatments and post-treatments may still be required.

#### **General assessment**

*Substrate compatibility:* 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.

*Corrosion resistance:* Stainless steels are problematic when being assembled with other metal materials, resulting in severe corrosion of all parts. For example, in almost all conditions that require a high load, sliding, and wear resistant material, even stainless steels (with sufficient strength and hardness) are affected by galling (a kind of corrosion) that destroys the stainless steel surface in a rather short time period.

*Nickel leaching:* Depending on the kind of stainless steel (including the most commonly used stainless steel 1.4301) there will be a certain amount of nickel content present. Bioavailable divalent nickel ions can leach from the substrate to the skin and potentially cause allergic reactions. In general, stainless steels are proven from decades of experience to be safe for human health

(Heubner, 2009), nevertheless the respective nickel thresholds in drinking water and for consumer goods have to be met.

*Aesthetics:* Stainless steel surfaces do not provide a comparable or competitive appearance to a coated surface by chromium trioxide based electroplating. Although the general colour of stainless steel is silvery, it has a yellowish tinge and the surface is not of the same brightness (even when polished) compared to a chrome coated surface. Stainless steel surfaces are available with bright, brush and satin appearance. In general, stainless steel surfaces are not comparable or competitive with chromium trioxide electrolytically applied coatings from an aesthetic point of view.

### **Sector specific assessment: sanitary**

Stainless steel parts are commercially available on the market for example in canteen kitchens and as catering equipment (stainless steel faucets). As stated during the consultation, around 20% of parts sold within this specific sector area - a niche area of the overall sanitary market - are made of stainless steel. These parts are provided with a passivation layer which requires extra effort and cost. The overall market acceptance of stainless steel parts for broad commercial use (for example in sanitary bathroom installations), is very limited. In addition, the design of the parts is also limited.

It was stated during the consultation that R&D has been performed within the sanitary sector on the use of stainless steel, and various test results by different companies were provided.

*Corrosion resistance:* A lot of effort on the evaluation of the corrosion mechanisms of stainless steel has been made and was reported during the consultation. According to numerous test reports, the overall corrosion resistance of separate stainless steel parts was found to meet the minimum sanitary requirement of at least 300 h salt spray exposure. However, assembled parts combining a stainless steel part and other metal components (such as screw and screw-nut or shower heads assembled with different kinds of metals including stainless steel), generally showed the beginning of corrosion (rust) after only a few hours of salt spray exposure (for example 12 h or 72 h). At the end of the respective tests, these assemblies were strongly corroded and in general the overall sanitary corrosion requirement of 300 h salt spray exposure was not met. A lot of effort is required to prevent assembled parts with stainless steel from corroding, starting during the production of the stainless steel and continuing with special measures during processing and forming. A protective coating or special post-cleaning solutions were tried to eliminate the rust. In general, this is technically too complex and is labour and cost intensive compared to the coating applied by the chromium trioxide based electroplating process.

*Chemical resistance:* The chemical resistance of stainless steel was tested with different household cleaning agents during continuous immersion tests and daily spray tests. In general, stainless steel failed tests with different kinds of cleaning agents (for example: 7 days immersion in vinegar essence and Sagrotan, and 14 days of daily spraying with commercially available products). However, it passed the 7 days continuous immersion in a commercially available cleaning product and 14 days daily spraying with vinegar essence and a commercial available product. In general, the chemical resistance of stainless steel may be sufficient when exposed to some cleaning agents, but generally failed in contact with strong acids and chloride based chemicals. Therefore, the overall chemical requirements of the sanitary sector were not met by stainless steel.

*Wear resistance / abrasion resistance:* As stated during the consultation, the abrasion resistance of stainless steel is lower compared to a conventional, electrolytically applied coating using chromium trioxide as electrolyte. This is caused by a lower hardness of the stainless steel (depending on the kind of stainless steel, typically in the range between 200 and 400 HV; compared to 800 to 1200



HV for metallic chrome coatings from chromium trioxide based electroplating), therefore it does not fulfil the sanitary sector requirements and leads to a surface that is rather easily scratched.

*Others:* Different companies provided test results showing that the *temperature change resistance* of stainless steel generally meets the respective sector requirements (for example 300 cycles in temperature cycle test, or 5 cycles according to EN 248).

*Aesthetics:* Besides the fact that the aesthetic of stainless steel surfaces does not general meet the sanitary sector requirements regarding colour and brightness, stainless steel parts do not provide a long-term high-aesthetic appearance due to corrosion and scratches on the surface.

*Conclusions sanitary sector:* Stainless steel is not a technically feasible alternative to replace the overall functional chrome plating with decorative character. It is a substrate alternative for metals and not an alternative for chromium trioxide based electroplating on plastic substrates. The aesthetic appearance of stainless steel is different to the aesthetic requirements of the sanitary sector. Due to a lack of chemical and abrasion resistance a long-term high aesthetic appearance is not provided. In addition, stainless steel parts assembled with other metal parts show severe corrosion, which does not fulfil the overall sanitary sector requirements.

### **Sector specific assessment: automotive**

As stated during the consultation, R&D has been performed within the automotive sector on the use of stainless steel. Stainless steel parts are commonly used for example for front grills, door handles, trims, front hoods and covers.

*Substrate compatibility:* As a large variety of products within the automotive sector are made of plastic substrates with a chrome coating, stainless steel is not an alternative for these applications. Compared to electroplated parts, the stainless steel parts have a higher weight.

*Corrosion resistance:* The overall corrosion resistance of stainless steel parts that are in contact with other metal parts is not sufficient. Stainless steel parts are prone to local corrosion phenomena like crevice corrosion or pitting. In addition, their stone chip resistance is less than metallic chrome coatings applied by electroplating with chromium trioxide. Stone chipping easily leads to indentations followed by corrosion effects.

*Chemical resistance:* As stated during the consultation, the chemical resistance of stainless steel is lower in comparison to a chrome coating (for example in contact with acidic media) and therefore does not meet the automotive sector requirements.

*Wear resistance / abrasion resistance:* Stainless steels need to have a good formability for the parts to be made. This good formability results from a rather low hardness leading to a low abrasion resistance. A low abrasion resistance can lead to scratches (for example during car wash) and stone impacts can easily create attack points for localized corrosion. In conclusion, good formable stainless steels are not hard enough to provide sufficient abrasion resistance required for the automotive sector applications.

*Aesthetics:* Besides the non-comparable and competitive aesthetic appearance of stainless steel, problems with complex geometries (forming limitations) occur. The processing of stainless steel is technically difficult, especially with regard to small parts, and can cause a lot of waste raw material. This waste raw material could be reprocessed but only after energy-consuming treatment.

*Conclusions automotive sector:* Stainless steel as alternative substrate is neither comparable nor competitive to the bright, silvery-bluish appearance of a metallic chrome coating applied by chromium trioxide based electroplating and does not fulfil the automotive sector requirements.

Furthermore, neither the corrosion resistance (especially of stainless steel parts assembled with other metal parts) nor the chemical resistance sufficiently fulfils the automotive sector requirements. With regard to automotive sector applications, especially for exterior use, the hardness and resulting abrasion resistance is not high enough to prevent stone impacts and scratches, which could lead to local corrosion.

#### **7.1.10.3 Economic feasibility**

Against the background of the significant technical failure of stainless steel, no detailed analysis of economic feasibility was conducted. Indications were made stating that the processing (machining, sawing, etc.) of stainless steel is much more complex than, for example, the production of die castings (which are currently commonly used as metal substrates for applying a chrome coating). The production costs are stated to be 30 to 40% higher compared to a product electroplated with chromium trioxide as electrolyte. This is mainly due to the higher technical effort required and that the additional cost of an adequate post-treatment passivation is necessary. Without further technical effort and post-treatment passivation, stainless steel products cannot fulfil the high requirements of corrosion resistance and chemical resistance.

In general, maintaining two separate production lines is economically difficult (especially for smaller jobplaters).

#### **7.1.10.4 Reduction of overall risk due to transition to the alternative**

As the alternative is not technically feasible, only classification and labelling information of substances and products reported during the consultation were reviewed for comparison of hazard profile, which is presented in the following:

Stainless steel is a term that defines a diverse family of alloys, containing iron and a minimum of 10.5% of chromium or in some cases nickel ( $\geq 8\%$ ) and/or molybdenum. Nickel is the only substance of major importance in regard to the hazard classification of stainless steel in solid form. Although, stainless steels are generally considered non-hazardous to human health and the environment (and regularly applied in contact with drinking water, food contact materials and medical devices), stainless steels containing more than 10% nickel are (in accordance with CLP criteria), classified as STOT RE 1, with 1-10% as STOT RE 2 and with less than 1% Nickel they are not classified. Furthermore, stainless steel containing more than 1% of Nickel is classified as carcinogen category 2 when classified as a simple mixture.

However, no carcinogenic effects resulting from exposure to stainless steels have been reported, either in epidemiological studies or in tests with animals. In addition, the International Agency for Research on Cancer (IARC) has concluded that stainless steel implants are not classifiable as to their carcinogenicity to humans. Stainless steels containing less than 1% Ni are not classified. Since the exact composition of a possible alternative substance is not known, an assessment regarding the overall risk to human health and the environment is not possible. However, transition from chromium-trioxide, which is a non-threshold carcinogen, to stainless steel would constitute a shift to a less hazardous substance.

#### **7.1.10.5 Availability**

Stainless steel is commercially available on the market and used for different applications.

In the absence of technical feasibility and economic aspects, it is not likely that this alternative will be subject to further R&D to adapt the technology adequately for the assessed sectors, especially as other alternatives are much more promising.

#### **7.1.10.6 Conclusion on suitability and availability for stainless steel**

Stainless steel as alternative substrate is neither comparable nor competitive to the bright, silvery-bluish appearance of chrome coatings and does not fulfil the aesthetic requirements of the sectors analysed. The corrosion resistance, especially for assembled parts made of stainless steel and other metals, does not meet overall requirements and severe corrosion can be the result. Due to the lack of chemical resistance, especially in regard to acidic and chloric media, the surface corrodes easily and highly affects the aesthetic. Besides the technical failures, stainless steel has also economic disadvantages compared to chrome electroplating and is especially no alternative for the automotive sector where most parts are made of plastic substrates.

Technical feasibility	Economic feasibility	Risk reduction	Availability
	Production costs		Not a general alternative

### **7.2. Etching pre-treatments (plastic substrate only)**

#### **7.2.1. ALTERNATIVE 11: Mineral acid based etching solution**

##### **7.2.1.1 Substance ID and properties / process description**

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 the risk to human health and the environment is provided in Appendix 2.2.1.

##### **7.2.1.2 Technical feasibility**

Sulphuric acid based solutions are assessed as a potential alternative for chromium trioxide based etching pre-treatments on plastic substrates.

It was stated during the consultation that various major issues occurred with all kinds of mineral acid etching solutions as an alternative to **etching of plastics** with a chromium trioxide based solution. When using 2K- or 3K-parts (where only one part should be plated), the chromium trioxide etching solution selectively etches the ABS component – as required. The alternative is not selective for ABS (butadiene 1.3 removal) only and may also affect the other components. In addition, the alternative does not prepare the substrate for an adequate adhesion of the subsequent coating.

Generally, issues with bath maintenance (water treatment, increased bath temperature, sludge deposition) are not solved yet. However, the major concern was stated to be swelling of the plastic substrate. It was confirmed that it is not technically possible to prevent swelling of the plastic surface when using any kind of acidic replacement etching solutions, and therefore, no further R&D

on this alternative will be performed. As a consequence, all alternate acidic etching solutions are technically not suitable as an alternative to chromium trioxide based etching of plastic substrates.

As stated during the consultation, a solution of **sulphuric acid with sodium peroxydisulphate** was tested for the **etching of plastic** substrates. Only very limited information on the performance is currently available, and it is anticipated that this alternative is at very early R&D stage. However, first results revealed major problems with the adhesive properties. As this alternative also contains a mineral acid, it is likely that problems may occur with swelling of the plastic substrate as well as with a general poor stability of the peroxydisulphate solution

*Conclusions:* Mineral acid based solutions are clearly not technically suitable as an alternative to chromium trioxide based etching of plastics. A major limitation is the swelling of the plastic substrate and the non-selectiveness for ABS when using any kind of mineral acid. Consequently, it is not likely that these solutions will become technically feasible at all.

Adequate surface preparation	Adhesion to substrate	Compatibility with substrates

#### 7.2.1.3 Economic feasibility

The economic feasibility of etching with mineral acid was not assessed, as the alternative is not technically feasible and already failed the requirements at early investigation stage. However, based on the literature research and consultations there is no indication that the discussed alternative is not economically feasible. However, switching to a chromium trioxide-free etching alternative would generally necessitate the installation of additional bath equipment for rinsing processes. This is related to necessary investment costs, for example for the production of the peroxydisulphate by electrolysis.

#### 7.2.1.4 Reduction of overall risk due to transition to the alternative

As the alternative is not technically feasible, only classification and labelling information of substances and products reported during the consultation were reviewed for comparison of the hazard profile. Based on the available information on the substances used within this alternative (see Appendix 2.2.1), nitric acid would be the worst case with a classification as Ox. Liq. 3, Skin Corr. 1A, Met. Corr. 1, Skin Irrit. 2, Eye Dam. 1, STOT SE 3. As such, transition from chromium trioxide - which is a non-threshold carcinogen - to one of these substances would constitute a shift to less hazardous substances.

#### 7.2.1.5 Availability

Much R&D has been performed in recent years on a chromium trioxide free etching solution for **etching of plastics**. Following the R&D studies of Fath (2008), it was possible to reduce the concentration of chromium trioxide in the sulphuric acid based etching solution from 400 g/l to 4 g/l. In general, the lower concentration chromium trioxide etching solution produces less sludge and lower chemical consumption. Due to a lower temperature of the etching bath (of around 50°C), also less energy is required. Compared to the conventional chromium trioxide based etching solutions, the edges of the raw products (mainly die cast products) are far less smoothed and straightened and even the smallest defects of the raw product remain visible after coating. In addition, plastic substrates etched with a reduced content of chromium trioxide were strongly hygroscopic due to the very high proportion of sulphuric acid (swelling effect). In addition, the process could not be stably

operated in the production line for plastic (for none of the components, even with different injection parameters). An adequate chromium trioxide free sulphuric acid etching solution is therefore not foreseeable at the current stage of development.

It is of great importance for the final performance and quality of the coating that the pre-treatment is in line with the subsequent electroplating process. Therefore, an alternative etching pre-treatment has to be adapted to an alternative main process adequately. 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.

#### 7.2.1.6 Conclusion on suitability and availability for mineral acid based etching solution

With regard to etching of plastic substrates, mineral acid based solutions are clearly 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 ABS, when using any kind of mineral acid. It is unlikely that these solutions will become technically feasible at all.

### 7.2.2. ALTERNATIVE 12: Potassium permanganate based etching solution

#### 7.2.2.1 Substance ID and properties / process description

Potassium permanganate ( $\text{KMnO}_4$ ) 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  $\text{Mn}^{2+}$  ( $\text{MnO}$ ) giving the solution a pink colour. Under neutral conditions, permanganate is reduced to  $\text{Mn}^{4+}$  ( $\text{MnO}_2$ ), exhibiting a brownish colour to all materials that are in contact with the solution. In alkaline solutions, potassium permanganate is spontaneously reduced to  $\text{Mn}^{6+}$  ( $\text{K}_2\text{MnO}_4$ ), having a green colour.

A non-exhaustive overview on general information on substances used within this alternative and the risk to human health and the environment is provided in Appendix 2.2.2.

#### 7.2.2.2 Technical feasibility

In general, permanganate based etching is only feasible on plastic substrates (ABS).

As stated during the consultation, extensive R&D on this alternative has been performed and is still ongoing. First tests were made with a small series of experiments showing very different results.

Potassium permanganate-based etching is performed either under acidic or under alkaline conditions. While the acidic permanganate etching is performed with a bath temperature of  $69^\circ\text{C}$  and an etch time of 9 minutes, the alkaline permanganate etching is carried out with a bath temperature of  $45^\circ\text{C}$  and an etch time of 5 minutes. In both cases, a number of subsequent steps such as rinsing, hot rinsing, neutralisation, etc. are required before plating on plastics can be performed.

In **Figure 21**, plastic surfaces etched with different kind of etching solutions are shown.



**Figure 21:** Comparison of typical etched plastic surfaces (left: after chromium trioxide etching, middle: after acidic permanganate etching, right: after alkaline permanganate etching). Data source: Kunststoff Institut Lüdenscheid, 2014.

According to Ziegert (2013), 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 a reasonable stability and are environmentally friendly. However, the etching capability, especially on plastic substrates (like ABS, PC, Polyetherimide (PEI), or blends), is not very strong so 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 the adhesive properties required for the subsequent coating steps are not sufficiently provided. As shown in **Figure 21**, the etching rate is much weaker than using a chromium trioxide based etching solution. In general, only a small series of experiments with very different results have been performed. Etching key functionalities, such as the depth, form and density of the cavities were generally found to be different, but in line with the requirements (no change of the substrate's micro roughness), whereas the adhesive properties were found to be less than chromium trioxide based etching.

The inferior adhesive properties lead to extensive blistering of the functional coating with decorative character. As a consequence, the high quality requirements regarding aesthetics of the final product cannot be met for the respective industry sectors.

Permanganate etching is a wet-in-wet process, the overall technique is comparable to the chromium trioxide based process. Therefore, the alternative process was stated to be compatible with the subsequent electroplating step. Nevertheless, the racks where the etched parts are applied to, have to be protected prior to the electroplating step to avoid cross-contamination.

Given the chemical nature of permanganate solutions, the bath maintenance is much more complex. During the etching process,  $Mn^{7+}$  is reduced and  $MnO_2$  is precipitated from the etching solution, causing interferences with the etched substrate. Finally, increased costs for the disposal of high amounts of  $MnO_2$  sludge, created during the process have to be taken into account. The  $MnO_2$  deposits at the base of the etching baths highly influence the overall etching performance. Also, as the etching performance is not adequate, the quality of the final product will decrease over time. Chemical instability and disadvantages in the production and handling, as well as waste water treatment are the main issues of this system. All these technical limitations lead to the conclusion that permanganate based etching alternatives are currently not feasible for high volume production. It is also very important to mention 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.

Due to technological advances within recent years, especially in the automotive sector, one component (1K) parts made of ABS are commonly used, but also 2K or 3K parts, with non-ABS components which must not be affected by etching, are also used. In this regard, this alternative is technically feasible on 1K parts but requires to be adapted for 2K, 3K or even more-component parts in a way that the alternative solution does **NOT** affect the other components (selective etching).

In summary, permanganate based etching solutions are not technically feasible as an alternative to chromium trioxide based etching on plastics, as the adhesive properties cannot be provided as required. In addition, a number of technical issues with the permanganate chemistry severely negatively affect the etching process and its outcome. Therefore, clearly more R&D on this alternative is necessary, the alternative is at the laboratory R&D stage at some automotive OEMs.

Due to the early stage of R&D of this alternative, no long-term testing and experience with potassium permanganate etched and subsequently coated products is available. This has to be investigated by further R&D, as stated during the consultation.

Adequate surface preparation	Adhesion	Compatibility with substrates

#### **7.2.2.3 Economic feasibility**

Against the background of the significant technical failure of this alternative, no detailed analysis of economic feasibility was conducted. Indications were made that showed the permanganate based etching to be more expensive compared to chromium trioxide based etching solutions, given the large maintenance efforts and large amounts of sludge resulting in high disposal costs. Applications are limited due to extensive changes and investments needed to transition to this alternative.

#### **7.2.2.4 Reduction of overall risk due to transition to the alternative**

As the alternative is not technically feasible, only classification and labelling information of substances and products reported during the consultation were reviewed for comparison of the hazard profile. Based on the available information on the substances used within this alternative (see Appendix 2.2.2), potassium permanganate would be the worst case with a classification as Oxid Solid 2, Acute Tox. 4, Aquatic Acute 1 and Aquatic Chronic 1. As such, transition from chromium trioxide - which is a non-threshold carcinogen - to one of these substances would constitute a shift to less hazardous substances.

#### **7.2.2.5 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 consultation, further R&D is necessary to develop the alternative in a way to safely gain surfaces of high quality. R&D efforts were stated on the overall development of the alternative. Given the very early (laboratory) stage of R&D and the clear technical limitations at the current stage, it is not expected that permanganate etching will become technically feasible within 7 years after the sunset-date. In addition industrial implementation and OEM qualification procedures for certain applications and sectors would be required afterwards.

#### **7.2.2.6 Conclusion on suitability and availability for potassium permanganate based etching solution**

At the current stage, permanganate based alternatives for etching of plastic substrates is not technically feasible and has economic disadvantages. From a technical point of view, the major drawback is the clearly insufficient adhesive properties, leading to delamination and unacceptable aesthetic appearance of the final coating. Furthermore, the permanganate process leads to deposition of sludge, which causes high maintenance and costs. Further R&D is necessary to overcome the existing technical hurdles. It is not expected that the alternative can be used as a chromium trioxide etching of plastics alternative within 7-10 years after the sunset date.



### 7.2.3. ALTERNATIVE 13: Polyamide (alternative substrate)

#### 7.2.3.1 Substance ID and properties / process description

Polyamides are macromolecules which contain repeating amides. Polyamides can be of natural (in wood and silk) or of synthetic origin produced by polymerization. Three different kinds of polyamides are available, classified as

- Aliphatic polyamides, for example PA6  $[\text{NH}-(\text{CH}_2)_5-\text{CO}]_n$  and PA6.6  $[\text{NH}-(\text{CH}_2)_6-\text{NH}-\text{CO}-(\text{CH}_2)_4-\text{CO}]_n$ , commercially traded as Nylon,
- Semi aromatic polyphthalamides, for example PA 6T (hexamethylenediamine + terephthalic acid), commercially traded as Trogamid and,
- Aromatic polyamides, for example paraphenylenediamine + terephthalic acid, commercially traded as Kevlar.

The melting temperature of polyamides is generally higher compared to that of ABS. The melting temperature of PA6 is at 220°C and of PA6.6 at 260°C.

A non-exhaustive overview on general information on substances used within this alternative and the risk to human health and the environment is provided in Appendix 2.2.1.

#### 7.2.3.2 Technical feasibility

Different kinds of plastic substrates are currently evaluated as **alternative to ABS. Polyamides** are considered to be the most promising amongst other alternative substrates such as polyetheretherketone (PEEK), polyurethane or carbon fibre reinforced plastic. These alternative substrates are not an alternative to chromium trioxide based etching pre-treatment but are substrate replacements.

As stated during the consultation, the currently used polyamide is PA6. Polyamide is used for special parts, such as door handles for interior automotive applications, due to the high tensile strength of the material, and may also be used for cosmetic products due to a better resistance against fragrance perfume. However, ABS has a better mechanical strength, which is especially necessary during moulding operations with polyesters (for multi-component parts).

Using Polyamide (PA) instead of ABS would eliminate the need for a chromium trioxide based etching pre-treatment, because due to the different chemical composition of PA, surfaces can be etched without chromium trioxide (for example using sulphonation).

As stated during consultation, polyamides as alternative to ABS were tested and found to be generally sufficient. However, due to several issues using polyamide as broad substrate alternative, PA is considered only for special applications.

The major technical issue with polyamide as an alternative substrate is the production process of the raw part. The polyamide raw materials are, similar to ABS raw materials, produced by injection moulding. In the course of the polyamide raw material production, flow problems (by injection into the injection machine) cause a certain porosity of the polyamide part and an uneven surface with dislocations and waves. This leads to disadvantages in the design of the substrate and as a consequence, in design limitations for the final product.

For etching of polyamide substrates, different treatment processes and organic acids can be used. Polyamides have different mechanical, thermal and chemical properties compared to ABS and the preparation of the surface prior to plating is less critical.



The adhesive properties of polyamide surfaces for subsequent electroplated layers were found to meet the requirements by the testing automotive company. In general, the use of polyamide as alternative substrate was found to be technically compatible to the subsequent electroplating.

The major drawback of polyamide is that the raw part must be of very high quality. In contrast to conventional plastic substrates, the etching pre-treatment removes even small defects and imperfections, but with polyamide as substrate, small edges, blisters or unevenness will occur on the final surface. In that case, the aesthetic properties of the final product are not in line with the demanding requirements of the sectors.

In addition, a higher scrap rate is generated because of particle adhesion in the swelling process.

As a conclusion, polyamide as alternative substrate may only be technically feasible for a limited number of small applications (without complex geometries), but is not an overall alternative substrate for all sectors.

### **7.2.3.3 Economic feasibility**

No detailed economic assessment was made and no data is available for the production of the polyamide raw parts by injection moulding, however the use of polyamide as an alternative substrate would mean a complete redesign and rebuild of all the injection moulding tools and machines which are currently designed and built for the production of ABS or parts.

This economic data is only related to the use of polyamide for plating. However, in regard to production costs, first indications were made stating that plating on polyamide instead on ABS is 5-15 % more expensive. In addition, a higher scrap rate causes higher costs of up to 20% per part, totalling to higher costs of 25 to 35%.

### **7.2.3.4 Reduction of overall risk due to transition to the alternative**

As the alternative is not technically feasible, only classification and labelling information of substances and products reported during the consultation were reviewed for comparison of the hazard profile. The polyamide products/substrates (polymers) do not have any kind of hazard classification and labelling. As the sectors discussed in this AfA are not involved in the production of polyamide substrate on their own, the shift to polyamide substrates would constitute a shift to less hazardous substances. When assessing the production of polyamides substrates, the hazard profile of the two most commonly used monomers was reviewed. Based on the available information on the substances used within this alternative (see Appendix 2.2.3), using polyhexamethylene adipamide would be the worst case with a classification as Skin Irrit. 2, Eye Irrit. 2 and Aquatic Chronic 4. As such, transition from chromium trioxide - which is a non-threshold carcinogen - to one of these substances would also constitute a shift to less hazardous substances.

### **7.2.3.5 Availability**

Polyamides are available on the market and are commercially used in the textile industry and for special applications, such as interior door handles, in the automotive industry.

The use of polyamides as an alternative plastic substrate prior to plating was investigated and generally found to be technically suitable for small parts and for special applications due to the high tensile strength of the material, but not for complex geometries.

It was reported during the consultation, that research for alternative plastic substrates has only just begun.

### 7.2.3.6 Conclusion on suitability and availability for polyamide

As a conclusion, polyamide as an alternative substrate may only be technically feasible for a limited number of small applications (without complex geometries), but is not an overall alternative substrate for all sectors. Electroplating on polyamide is related to higher costs in the range of 25 to 35%. To date, polyamide substrates are not a suitable alternative to ABS. In addition, at the current stage, no information on the long-term behaviour of electroplated polyamides is known to be available.

Technical feasibility	Economic feasibility	Risk reduction	Availability
Special applications	Higher production costs		Not a general alternative

## 8. OVERALL CONCLUSIONS ON SUITABILITY AND AVAILABILITY OF POSSIBLE ALTERNATIVES FOR FUNCTIONAL CHROME PLATING WITH DECORATIVE CHARACTER

This Analysis of Alternatives (AoA) forms part of the Application for Authorisation (AfA) for the use of chromium trioxide electrolyte utilized in functional plating of articles with decorative character. Functional chrome plating with decorative character is a surface treatment process that involves depositing a thin layer of metallic chrome from the chromium trioxide electrolyte on the surface of a plastic or metallic component following product specific underplates. The final metallic chrome coating is free of Cr(VI). The coating provides the article with a resistant, durable, and safe finish, normally with a bright or matt silvery (occasionally black) appearance. The process is therefore specified for particular applications where this combination of performance characteristics is critical. Approximately 2000 tonnes of chromium trioxide are used in surface treatment applications within the scope of this AfA per year.

An extensive literature survey and consultation was carried out to identify and evaluate potential alternatives to chromium trioxide in functional chrome plating with decorative character. 31 potential alternatives were identified. 18 of these substances could be excluded from further consideration based on proven performance and 13 alternatives (including processes and substances) are a focus for ongoing R&D programs and were examined in further detail in this AfA.

Plating using chromium trioxide involves immersion of the component in a series of treatment baths containing chemical solutions or rinses under specific operating conditions and is the final step in the overall surface treatment process: pre-treatments and nickel or copper coatings ('underplates') are normally applied to prepare the surface prior to chromium plating. The 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) of the final treated article, and varies depending on the required functionalities of the final product and the substrate to which it is applied.

The industry sectors use functional chrome plating with decorative character with chromium trioxide (such as, but not limited to automotive, consumer goods, cosmetics, electrical devices, furniture, general engineering, lamps & light fittings, locks & fittings, sanitary, store construction, tools, wheels & castors and white goods), in order to meet the strict performance criteria necessary for regulatory compliance, public safety and customer expectations. These are described further in Chapter 5.

Functional chrome plating with decorative character has unique technical functions that confer substantial advantages over potential alternatives including corrosion resistance, chemical resistance, wear resistance / abrasion resistance, excellent health and environmental safety for finished articles (no nickel leaching), adhesion between coating and substrate, sunlight resistance / UV resistance, temperature resistance / heat resistance, overall conserving the high aesthetic coating. Additionally, black chrome coating on metal substrates is a specialized functional and decorative black metallic chrome coating used by the general engineering sector, where further key functionalities (electrical conductivity, reflection behaviour / absorption capability) are important.

The chromium trioxide based functional chrome plating with decorative character is complex and typically involves numerous steps, such as etching of plastics as pre-treatment, and several underplating steps followed by the chrome electroplating process (main process) itself. The etching of plastics 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. Compatibility and technical performance of the overall system are therefore primary considerations of fundamental importance during material specification.

This means that while the use of chromium trioxide may be specified for the final metallic chrome plating step, it cannot be entirely replaced in the process without impacting the technical performance of the final article. As of today, no complete chromium trioxide free process, providing all the required properties to the surfaces of all articles in the scope of this application, is industrially available.

### **Use of chromium trioxide functional chrome plating with decorative character in all evaluated sectors**

A key advantage of chromium electroplating is that the metallic chrome finish is completely safe to human health and the environmental, a critical requirement when specifying products relied on by the public. Furthermore, the metallic chromium layer acts to *prevent* release of or contact with substances that are specified in pre-treatment coatings or underplate as part of the complex surface treatment system, thus allowing safe use that complies with regulatory obligations. For example, nickel in some coatings may be released and available to come into contact with skin, drinking water or other materials. **Overall, the prevention of nickel leaching from underplates is essential for all the sectors.**

### **Use of chromium trioxide-based surface treatment by the automotive sector**

Chromium trioxide is used by automobile supply chains to manufacture several thousands of metallic chrome plated parts per vehicle manufacturer. Parts cover a wide range of applications, from interior to exterior parts with functional and decorative metallic chrome coating as well as functional metallic chrome coatings in vehicle models with a production period of 7-10 years. Introducing new materials into the automotive market is a complex process, involving multiple phases and checks. Safety is the main driver for this. In the case of replacing chromium trioxide, all affected components must be revalidated using alternative materials. Substance substitution may cause change of function geometry, thermal durability and leads to unexpected impacts on related parts. Even though the automobile industry is highly experienced in material testing procedures, the validation and testing of alternatives will require several years due to the sheer number of parts involved. In addition, performance of potential alternatives must be tested under conditions of large scale production. With regard to both the highly complex nature of supply chains in the automotive industry and the lifetime of vehicles, planning reliability is crucial. Average life cycles of an automobile model is about 22 years, comprising 3-5 years development time, 7 years of production and at least 10 years' service life when there is a need to guarantee availability of spare parts.

Realistically, changes to a vehicle model can only be made in a certain period of time, which decreases rapidly after type-approval by a certified body in the early stages of new model development.

The identification of possible alternatives and the careful validation of their functionalities is a labour/time intensive process that will certainly take several years. According to the European Automobile Manufacturer Association (ACEA), the development of suitable alternatives for functional chrome plating with decorative character using chromium trioxide for current vehicle parts will require a time period of 4 to 5 years followed by industrialization of the technique and implementation in the supply chain. The further minimum timeframe required to develop and implement an alternative is 7 years after the sunset date.

### **Use of chromium trioxide functional chrome plating with decorative character in the sanitary sector**

The sanitary sector relies on functional plating of articles with decorative character to manufacture products including bathroom taps, shower heads, hoses, towel rails, 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). 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. Introducing new coatings into the sanitary sector is therefore a complex process, involving multiple phases and checks. Public safety is the main, but not the only, driver for this. Water quality for human consumption is closely regulated to protect public health and there is a substantial body of regulation in place that must be met before an alternative can be introduced to the market. Directive 98/83/EC, which aims to protect human health against harmful influences which could originate from contaminants in water designated for human consumption, has been transposed in all EU Member States. National laws typically regulate the microbiological and chemical quality of drinking water by specifying maximum threshold values for key indicator parameters. Requirements on installations for the production, preparation and distribution of drinking water may also be regulated at Member State level. Coatings or materials that are potential alternatives to metallic chrome coating for use in contact with drinking water require careful development and evaluation. Experience to date is that potential alternatives to metallic chrome coatings applied using chromium trioxide electroplating will require substantial development to comply with the nickel leaching threshold: ongoing product and technology optimisation and testing is needed to satisfy performance criteria in this regard. As a reference point, compliance with the nickel threshold for the metallic chromium plated products currently in use required 4 trial cycles, and the overall process required more than 4 years in total to complete. The process is expected to be more challenging for potential alternatives.

Sanitary products typically have a production development time of more than 7 years. Planning and design starts years before parts go into production and many sales contracts stipulate a lengthy period of guaranteed delivery (up to 25 years). Accordingly, regular spare part production has to be available for around 10 years after production of the main product has stopped. There are therefore many practical considerations that influence the schedule for replacing functional chrome plating with decorative character using chromium trioxide.

### **Identification and evaluation of potential alternatives**

A large amount of research over the last decades has been deployed to identify and develop viable alternatives to the use of chromium trioxide in functional chrome plating with decorative character.

Due to its unique functionalities and performance, it is challenging and complex to replace chromium trioxide based plating in applications that demand superior performance for several different criteria including corrosion, chemical and wear resistance, hardness, aesthetics and safety over extended periods.

The most promising alternatives to chromium trioxide functional chrome plating with decorative character, across all sectors and substrates, are **trivalent chromium electroplating** and a combination of **lacquer + PVD + lacquer**. Intensive R&D has been performed over many years and is still ongoing on these potential alternatives. Technical improvement of these potential alternatives has been realized in recent years. However, the alternatives are not technically feasible and cannot be considered available to replace chromium trioxide as a commercial application at the current stage of development.

Trivalent chromium coatings do not provide colour stability under the influence of light. Parameters such as corrosion resistance and chemical resistance do not sufficiently fulfil sector specific requirements for an aesthetically acceptable and durable surface. Trivalent chromium based coatings are therefore not likely to be available as a broad alternative to chromium trioxide plating before 7 years after sunset date.

The transition to the lacquer + PVD + lacquer alternative would require high investment costs for each plating company. Production by this process means the coating time is considerably higher and the throughput of parts is much reduced. This would lead to significantly increased costs per part, such that certain sectors could not continue to manufacture competitively. Besides the clear economic arguments, the technical feasibility of this alternative is not yet comparable or competitive to coatings resulting from chromium trioxide plating processes. Thus, this alternative does not represent a suitable coating alternative from a technical perspective and has clear economic disadvantages. Overall, it is unlikely that lacquer + PVD + lacquer system could be available as an alternative to chromium trioxide plating before 7 years after sunset date.

Potential alternatives for etching of plastic as a pre-treatment are technically not feasible at the current stage of development. Additional R&D is necessary to adjust these processes to each other to finally meet the industry requirements. It is not expected that alternatives to plastic etching are technically feasible before 7 years after sunset date and even more years might be needed. It has to be noted that etching of plastic substrate is a pre-treatment and part of the process chain applying a functional coating with decorative character and that all the parts of the process chain always have to be adapted towards each other.

As a result, a review period of 7 years was selected because it coincides with best case (optimistic) estimates by all the industrial sectors of the schedule required to industrialise alternatives to chromium trioxide for functional chrome plating with decorative character for key applications.

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*Please note that only the most relevant legal references and testing standards for this use group are referenced here.*

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**APPENDIX 1 – MASTERLIST OF ALTERNATIVES WITH CLASSIFICATION INTO CATEGORIES 1-3 AND SHORT SUMMARY OF THE REASON FOR CLASSIFICATION OF ALTERNATIVES AS CATEGORY 3.**

Nr.	Alternative Substance/ Alternative Process	Category	Screened out because
Pre-treatment: Etching of plastics			
1	Mineral acid based solutions	1	
2	Potassium permanganate based solution	1	
3	Catalysed plastic (noble metal)	3	Not industrially feasible for high volume production, worse process engineering
4	Conductive paint	3	Not industrially feasible for high volume production
5	Gaseous etching / gas etching	3	Not industrially feasible for high volume production – limitation due to the use of gastight containers
6	Ionic liquids	3	- very early R&D stage (literature research), more R&D necessary - technically not feasible: dissolution of different kind of plastic substrates
7	Laser activated embedded metal particles / etching on catalysed plastic (LPKF)	3	- technically not feasible: process engineering not equivalent, only a few exemplary parts have been tested resulting in insufficient adherence, not applicable for large parts - Not industrially feasible for high volume production
8	Mechanical methods: Mechanical Sanding / shotblasting / media blasting / grinding & machining	3	- not for complex geometries and not for inner diameters
9	Plasma etching	3	- Technically not sufficient, earliest R&D stage, difficult and complex technique, not for high volume throughput of parts
10	Heat treatments: Heat gun	3	-- Not suitable for plastic substrates - possible over-heating and damaging of the substrate
11	Polyamide	2	
Chromium trioxide based electroplating			
12	Satin & black anodized aluminium	2	
13	Chromium free electroplating: Chromium free electroplating: <ul style="list-style-type: none"> <li>multi-layer electroplating system of copper, tin, zinc; nickel, cobalt</li> <li>gold and platinum electroplating</li> <li>zinc electroplating</li> </ul>	2	
14	Wet lacquering	2	
15	CVD (Chemical vapour deposition)	2	
16	DLC (Diamond Like Carbon)	2	

Nr.	Alternative Substance/ Alternative Process	Category	Screened out because
17	Nanocrystalline coating (process: HVOF, Thermal spray processes)	3	- Not seen as 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)
18	Electroless Nickel plating	2	
19	Palladium/Nickel/Tin-Copper + PVD	3	- Not a stand-alone alternative, only describing an alternative multi-layer system with additional PVD - Palladium (or palladium/platinum) only as final coating instead of Metallic chrome coating from chromium trioxide → only niche application due to high costs of the final coating and the two process steps including PVD - hardness and corrosion resistance lower as Metallic chrome coating from chromium trioxide
20	Powder Coating (Pulverlack), unspecified	2	
21	Ormocere layers (Polymere)	3	- very early R&D level (research at universities / institutes), - layers are transparent
22	Stainless steel	2	
23	Trivalent chromium plating	1	
24	PVD (Physical vapour deposition): Lacquer + PVD + Lacquer and PVD metal	1	
25	Case hardening: Carburising, CarboNitriding, Cyaniding, Nitriding, Boronising	3	- No alternative for decorative application, these 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
26	Hot Stamping	3	- 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 much worse compared to metallic chrome coatings from chromium trioxide - colour change due to sun and weathering
27	IMD (Inmould Decoration)/ IML (Inmould Layer) foil	3	- Hardness and scratch resistance 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, very early R&D

## ANALYSIS OF ALTERNATIVES

Nr.	Alternative Substance/ Alternative Process	Category	Screened out because
			stage - yellowish, clouding process marks
28	Aluminium (plus preprocessing) plus clear coat (floating process)	3	- no alternative: optics not comparable, not for complex geometries, reproducibility and availability not sufficient, risk of filiform corrosion of exterior automotive parts
29	Tin-Cobalt / Nickel-Cobalt-Tin plating	3	- This is an alternative multi-layer electroplating system comprising a cobalt layer and cobalt is classified as SVHC substance
30	Aluminium coating on copper plating , followed by anodization	3	- Process is too high for plastic substrates, technically not feasible, - economically not feasible due to the numerous process steps of high costs
31	Copper plating	3	Not sufficient as stand-alone coating, aesthetic not comparable to metallic chrome coatings from a chromium trioxide electrolyte

## APPENDIX 2 – INFORMATION ON RELEVANT SUBSTANCES FOR IDENTIFIED ALTERNATIVES

### APPENDIX 2.1: ELECTROPLATING ALTERNATIVES (MAIN PROCESS)

#### APPENDIX 2.1.1: ALTERNATIVE 1: Trivalent chromium electroplating

**Table 1:** Substance ID and physicochemical properties.

Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Chromium(III) sulphate	Physical state at 20°C and 101.3 kPa	Solid [1]
EC number	233-253-2	Melting point	90 °C [1]
CAS number	10101-53-8	Density	3.10 g/cm <sup>3</sup> (anhydrous) [1]
IUPAC name	Chromium(III) sulphate	Vapour pressure	-
Molecular formula	Cr <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	Water solubility	Insoluble in water and acids (anhydrous). Soluble as hydrate [2]
Molecular weight	392.18 g/mol	Flammability Flash Point	Non-flammable -
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Chromium(III) chloride	Physical state at 20°C and 101.3 kPa	solid
EC number	233-038-3	Melting point	ca. 1150 °C
CAS number	10025-73-7	Density	2.87 g/cm <sup>3</sup> (25 °C)
IUPAC name	Chromium(III) chloride	Vapour pressure	-
Molecular formula	CrCl <sub>3</sub>	Water solubility	0.585 g/cm <sup>3</sup>
Molecular weight	158.36 g/mol	Flammability Flash Point	Non-flammable -
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Chromium trichloride hexahydrate	Physical state at 20°C and 101.3 kPa	Solid (green)
EC number	n.a.	Melting/freezing point [2]	80-83°C
CAS number	10060-12-5	Density	-
IUPAC name	Chromium(III) chloride hexahydrate	Vapour pressure	-
Molecular formula	CrCl <sub>3</sub> · 6H <sub>2</sub> O	Water solubility	590 g/L (at 20°C)
Molecular weight	266.45 g/mol	Flammability Flash point	Non flammable -
Chemical name and	Boric acid (mono	Physical state at 20°C	Solid (crystalline, odourless)

## ANALYSIS OF ALTERNATIVES

Parameter	Value	Physicochemical properties	Value
composition	constituent substance)	and 101.3 kPa	
EC number	233-139-2	Melting/freezing point	No melting point detected below 1000°C
CAS number	10043-35-3	Density	1.49 g/cm <sup>3</sup>
IUPAC name	Boric acid	Vapour pressure	9.90 · 10 <sup>-8</sup> kPa (25 °C)
Molecular formula	BH <sub>3</sub> O <sub>3</sub>	Water solubility	48.40 g/L (20°C, pH = 3.6)
Molecular weight	61.83 g/mol	Flammability	Non flammable
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Ammonium chloride	Physical state at 20°C and 101.3 kPa	Solid (crystalline)
EC number	235-186-4	Melting/freezing point	340°C (sublimation)
CAS number	12125-02-9	Density	1.53 g/cm <sup>3</sup> (at 20°C)
IUPAC name	Ammonium chloride	Vapour pressure	-
Molecular formula	ClH <sub>4</sub> N	Water solubility	283 g/L (25°C)
Molecular weight	53.5 g/mol	Flammability Flash Point	Non flammable -

**Table 2:** Hazard classification and labelling.

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers	Additional classification and labelling comments	Regulatory and CLP status
Chromium sulphate (CAS 10101-53-8) (EC 233-253-2)	Not classified	-	1,103	1,103 notifiers did not classify the substance.	Currently not REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory
Chromium chloride (CAS 10025-73-7) (EC 233-038-3)	Acute Tox. 4	H302 (Harmful if swallowed)	41	Additional 6 parties notified the substance as Acute Tox 4 (H302) only. Further 6 notifiers submitted the classification as as Acute Tox 4 (H302) and Aquatic Chronic 3 (H412).	Currently not REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory
	Skin Irrit. 2	H315 (Causes skin irritation)			
	Eye Irrit. 2	H319 (Causes serious eye irritation)			
	Acute Tox. 1	H330 (Fatal if inhaled)			
Chromium trichloride hexahydrate (CAS 10060-12-5)	Skin Irrit. 2 Eye Irrit. 2 STOT SE 3	H 315 (causes skin irritation) H 319 (causes serious eye irritation)	30		REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers	Additional classification and labelling comments	Regulatory and CLP status
		H 335 (may cause respiratory irritation)			inventory
	Acute TOX 4	H 302 (harmful if swallowed)	24		
	Not classified		5		
Boric acid (CAS 10043-35-3) (EC 233-139-2)	Repr. 1B	H360FD (May damage fertility. May damage the unborn child)	n/a		REACH registered; Included in CLP Regulation, Annex VI (index number 005-007-00-2); <b>Included according to Annex XVI on the candidate list (SVHC substance)</b>
Ammonium chloride (CAS 12125-02-9) (EC 235-186-4)	Acute Tox 4 Eye Irrit. 2	H 302 (harmful if swallowed) H 319 (causes serious eye irritation)			Harmonised classification- Annex VI of Regulation (EC) No 1272/2008 Included in CLP Regulation, Annex VI (index number 017-014-00-8);

**APPENDIX 2.1.2: ALTERNATIVE 2: PVD based processes - Lacquer + PVD + Lacquer and PVD metal****Table 1:** Substance ID and physicochemical properties.

Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Titanium nitride (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Solid (gold)
EC number	247-117-5	Melting/freezing point	2930°C
CAS number	25583-20-4	Density	5.22 g/cm <sup>3</sup>
IUPAC name	Titanium nitride	Vapour pressure	-
Molecular formula	TiN	Water solubility	Insoluble in Water
Molecular weight	61.87 g/mol	Flammability Flash Point:	Non flammable -
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Chromium nitride	Physical state at 20°C and 101.3 kPa	Solid (dark powder, odourless)
EC number	246-016-3	Melting/freezing point	-
CAS number	24094-93-7	Density	5.90 g/cm <sup>3</sup>
IUPAC name <sup>[4]</sup>	Azanylidylnechromium	Vapour pressure	-
Molecular formula	CrN	Water solubility	Insoluble
Molecular weight	66.0 g/mol	Flammability Flash Point:	- -
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Titanium carbonitride	Physical state at 20°C and 101.3 kPa	powder
EC number	603-147-4	Melting/freezing point	> 350°C
CAS number	12654-86-3	Density	5.08 g/ cm <sup>3</sup> (at 25°C)
IUPAC name	Titanium carbonitride	Vapour pressure	n.a
Molecular formula	CNTi <sub>2</sub>	Water solubility	n.a
Molecular weight	121.75 g/mol	Flammability Flash Point:	n.a n.a

**Table 2:** Hazard classification and labelling.

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers	Additional classification and labelling comments	Regulatory and CLP status
Titanium nitride (CAS 25583-20-4 ) (EC 247-117-5)	Not classified		11		Notified Classification
	Flam. Sol. 2 Skin Irrit. 2 Eye Irrit. 2	H 228 (flammable solide) H 315 (causes skin irritation) H 319 (causes serious eye irritation)	10		
Titanium carbo nitride (CAS 12654-86-3) (EC 603-147-4)	Not classified				According to suppliers MSDS this substance is not classified according to EG Nr. 1271/2008.
Chromium nitride (CAS 24094-93-7) (EC 246-016-3)	Not classified		3		Notified Classification

**APPENDIX 2.1.3: ALTERNATIVE 3: Satin & black anodized aluminium****Table 1:** Substance ID and physicochemical properties.

Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Sulphuric acid (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Liquid (odourless)
EC number	231-639-5	Melting/freezing point	3°C (for 98% sulphuric acid) 10.4-10.5°C (for 100% sulphuric acid)
CAS number	7664-93-9	Density	1.81 g/cm <sup>3</sup> (20°C, for 90%) 1.83 g/cm <sup>3</sup> (20°C, for 100%)
IUPAC name	Sulphuric acid	Vapour pressure	0.49 hPa (20°C)
Molecular formula	H <sub>2</sub> SO <sub>4</sub>	Water solubility	Miscible with water
Molecular weight	98.08 g/mol	Flammability Flash Point	Non flammable n.a
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Orthophosphoric acid (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Solid (crystalline, if no water attached)
EC number	231-633-2	Melting/freezing point	41.1 °C (101 kPa)



Parameter	Value	Physicochemical properties	Value
CAS number	7664-38-2	Density	1.84 g/cm <sup>3</sup> (38°C)
IUPAC name	Phosphoric acid	Vapour pressure	80 Pa (25°C, extrapolated)
Molecular formula	H <sub>3</sub> PO <sub>4</sub>	Water solubility	5480g/ L (cold water, pH= 0.5)
Molecular weight	98.00 g/mol	Flammability Flash point	Non flammable -
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	(+)-tartaric acid (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Solid (odourless)
EC number	201-766-0	Melting/freezing point	171°C (101 kPa)
CAS number	87-69-4	Density	1.76 g/cm <sup>3</sup> (20°C)
IUPAC name	Tartaric acid	Vapour pressure	< 0.005 kPa (20°C)
Molecular formula	C <sub>4</sub> H <sub>6</sub> O <sub>6</sub>	Water solubility	1390 g/L (20°C; pH = n.a.)
Molecular weight	150.09 g/mol	Flammability Flash point	Non flammable -
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Cobalt di(acetate) (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Solid (light-pink, crystalline)
EC number	200-755-8	Melting/freezing point	Decomposes around 370°C
CAS number	71-48-7	Density	1.76 g/cm <sup>3</sup> (at 21.4°C)
IUPAC name	Cobalt(2+) diacetate	Vapour pressure	n.a
Molecular formula	C <sub>2</sub> H <sub>4</sub> O <sub>2</sub> 1/2Co	Water solubility	348.0 g/L (at 20°C)
Molecular weight	177.02 g/mol	Flammability Flash Point	Non flammable -
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Ammonium sulphide (aqueous solution)	Physical state at 20°C and 101.3 kPa	Liquid ( yellow, odor of rotten eggs)
EC number	235-223-4	Melting/freezing point	n.a
CAS number	12135-76-1	Density	0.997 g/cm <sup>3</sup>
IUPAC name	Ammonia Sulfide	Vapour pressure	599.95 hPa (at 20°C)
Molecular formula	(NH <sub>4</sub> ) <sub>2</sub> S	Water solubility	Soluble in water
Molecular weight	68.15 g/mol	Flammability Flash Point	Non flammable -
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Tin dichloride (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Solid (crystalline, colourless)

Parameter	Value	Physicochemical properties	Value
EC number	231-868-0	Melting/freezing point	247°C
CAS number	7772-99-8	Density	3.90 g/cm <sup>3</sup>
IUPAC name	Tin(II) chloride (1:2)	Vapour pressure	3.3 kPa (at 429°C)
Molecular formula	Cl <sub>2</sub> Sn	Water solubility	178 g/L (at 20°C)
Molecular weight	189.6 g/mol	Flammability Flash Point	Non flammable -
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Phenolsulfonic acid (mixture of <i>o</i> , <i>m</i> , <i>p</i> -phenolsulfonic acid)	Physical state at 20°C and 101.3 kPa	Liquid
EC number	215-587-0	Melting/freezing point	-
CAS number	1333-39-7	Density	1.35 g/cm <sup>3</sup> (at 25°C)
IUPAC name	hydroxybenzenesulphonic acid	Vapour pressure	-
Molecular formula	C <sub>6</sub> H <sub>6</sub> O <sub>4</sub> S	Water solubility	1000 g/L at 25°C
Molecular weight	174.17	Flammability Flash Point	- -

**Table 2:** Hazard classification and labelling.

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers	Additional classification and labelling comments	Regulatory and CLP status
Sulphuric acid (CAS 7664-93-9) (EC 231-639-5)	Skin Corr. 1A	H314 (Causes severe skin burns and eye damage)	n/a	Specific Concentration limits: Skin Corr. 1A: C ≥ 15%, H314 Skin Irrit. 2: 5% ≤ C < 15%, H315 Eye Irrit. 2: 5% ≤ C < 15%; H319	REACH registered; Included in CLP Regulation, Annex VI (index number 016-020-00-8);
Phosphoric acid (orthophosphoric acid) (CAS 7664-38-2) (EC 231-633-2)	Skin Corr. 1B	H314 (Causes severe skin burns and eye damage)	n/a	Legal classification.	REACH registered; Included in CLP Regulation, Annex VI (index number 015-011-00-6);
	Met. Corr. 1	H290 (May be corrosive to metals)	n/a	Additional self-classification according to REACH registration;	

## ANALYSIS OF ALTERNATIVES

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers	Additional classification and labelling comments	Regulatory and CLP status
Cobalt di(acetate) (CAS 71-48-7) (EC 200-755-8)	Skin Sens. 1 Resp. Sens. 1 Muta. 2 Carc. 1B Repr. 1B Aquatic Acute 1 Aquatic Chronic 1	H317 (May cause allergic skin reactions) H334 (May cause allergy or asthma symptoms or breathing difficulties if inhaled) H341 (suspect of causing genetic defects) H350i (may cause cancer by inhalation) H360F (may damage fertility) H400 (very toxic to aquatic life) H410 (very toxic to aquatic life with long lasting effects)		Specific Concentration limits, M-Factors  M=10 Carc. 1B; H350i: C ≥ 0,01%	REACH registered; Included in CLP Regulation, Annex VI (index number 027-006-00-6);
Ammonium sulfide (CAS 12135-76-1) (EC 235-223-4)	Skin Corr. 1B	H314 (causes severe skin burns and eye damage)	747		REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory
	Flam. Liq. 3 Skin Corr. 1B Eye Dam. 1	H226 (flammable liquid and vapour) H314 (causes severe skin burns and eye damage) H318 (causes serious eye damage)	30		
	Flam. Sol. 2 Skin Corr. 1B Aquatic Acute 1	H228 (Flammable Solid) H314 (causes severe skin burns and eye damage) H400 (very toxic to aquatic life)	23		
Tin dichloride (CAS 7772-99-8) (EC 231-868-0)	Acute Tox. 4 Acute Tox. 4 Skin Corr. 1C Eye Dam. 1 Aquatic Acute 1	H302 (harmful if swallowed) H312 (harmful in contact with skin) H314 (causes severe skin burns and eye damage) H318 (causes serious eye damage) H400 (very toxic to aquatic life)	437		REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers	Additional classification and labelling comments	Regulatory and CLP status
Phenolsulfonic acid (mixture of <i>o</i> , <i>m</i> , <i>p</i> -phenolsulfonic acid) (CAS 1333-39-7) (EC 215-587-0)	Acute Tox. 4 Acute Tox. 4 Skin Corr. 1B	H302 (harmful if swallowed) H312 (harmful in contact with skin) H314 (causes severe skin burns and eye damage)	90		REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory

#### APPENDIX 2.1.4: ALTERNATIVE 4: Chromium free electroplating

**Table 1:** Substance ID and physicochemical properties.

Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Zinc sulphate	Physical state at 20°C and 101.3 kPa	Solid (white, powder)
EC number	231-793-3	Melting/freezing point	Decomposes at 625°C
CAS number	7733-02-0	Density	3.35 g/cm <sup>3</sup> (monohydrate)
IUPAC name	Zinc sulphate	Vapour pressure	-
Molecular formula	ZnSO <sub>4</sub>	Water solubility	210 g/L (monohydrate)
Molecular weight	161.47 g/mol	Flammability	-
		Flash point	-
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Sodium hydroxide (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Solid (white, odourless)
EC number	215-185-5	Melting/freezing point	323°C
CAS number	1310-73-2	Density	2.13 g/cm <sup>3</sup> (at 20°C)
IUPAC name	Sodium hydroxide	Vapour pressure	-
Molecular formula	NaOH	Water solubility	1kg /L (at 25°C)
Molecular weight	39.997 g/mol	Flammability	-
		Flash point	-
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Copper sulphate (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Solid (white-green)
EC number	231-847-6	Melting/freezing point	Decomposes at 560°C

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CAS number	7758-98-7	Density	3.6 g/cm <sup>3</sup>
IUPAC name	Copper(II) sulphate	Vapour pressure	-
Molecular formula	CuSO <sub>4</sub>	Water solubility	220 g/L (at 25°C)
Molecular weight	223.2 g/mol	Flammability	-
		Flash point	-
<b>Parameter</b>	<b>Value</b>	<b>Physicochemical properties</b>	<b>Value</b>
Chemical name and composition	Nickel sulphate	Physical state at 20°C and 101.3 kPa	Solid (greenish-yellow)
EC number	232-104-9	Melting/freezing point	Decomposes at 840°C
CAS number	7786-81-4	Density	3.68 g/cm <sup>3</sup> at 20°C
IUPAC name	nickel(2+) sulphate	Vapour pressure	-
Molecular formula	Ni(SO <sub>4</sub> ) <sub>2</sub>	Water solubility	293 g/L (at 20°C)
Molecular weight	154.8 g/mol	Flammability	Non flammable
		Flash point	-
<b>Parameter</b>	<b>Value</b>	<b>Physicochemical properties</b>	<b>Value</b>
Chemical name and composition	Potassium dicyanoaurate	Physical state at 20°C and 101.3 kPa	Solid (colourless, odourless)
EC number	237-748-4	Melting/freezing point	-
CAS number	13967-50-5	Density	3.45 g/cm <sup>3</sup>
IUPAC name	potassium dicyanoaurate	Vapour pressure	-
Molecular formula	K[Au(CN) <sub>2</sub> ]	Water solubility	-
Molecular weight	288.1 g/mol	Flammability	-
		Flash point	-
<b>Parameter</b>	<b>Value</b>	<b>Physicochemical properties</b>	<b>Value</b>
Chemical name and composition	diamino-dinitro-platinum	Physical state at 20°C and 101.3 kPa	-
EC number	238-203-3	Melting/freezing point	-
CAS number	14286-02-3	Density	-
IUPAC name	diammineplatinum(II) nitrite	Vapour pressure	-
Molecular formula	H <sub>4</sub> N <sub>4</sub> O <sub>4</sub> Pt	Water solubility	-
Molecular weight	319.1 g/mol	Flammability	-
		Flash point	-
<b>Parameter</b>	<b>Value</b>	<b>Physicochemical properties</b>	<b>Value</b>
Chemical name and composition	Cobalt dichloride (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Solid (pale-blue)

EC number	231-589-4	Melting/freezing point	737°C
CAS number	7646-79-9	Density	3.37 g/cm <sup>3</sup> (25°C)
IUPAC name	Cobalt(II) dichloride	Vapour pressure	100 hPa (at 818°C)
Molecular formula	CoCl <sub>2</sub>	Water solubility	585.9 g/L (20°C, pH = 7)
Molecular weight	129.84	Flammability Flash point	- -
<b>Parameter</b>	<b>Value</b>	<b>Physicochemical properties</b>	<b>Value</b>
Chemical name and composition	Potassium cyanide	Physical state at 20°C and 101.3 kPa	White, crystalline solid
EC number	205-792-3	Melting/freezing point	634.5 °C
CAS number	151-50-8	Density	1.56 g/cm <sup>3</sup> (20°C)
IUPAC name	Potassium cyanide	Vapour pressure	-
Molecular formula	KCN	Water solubility	400 g/L (20°C)
Molecular weight	65.12	Flammability Flash point	- -

**Table 2:** Hazard classification and labelling.

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	No. of Notifiers (CLP inventory)	Additional classification and labelling comments	Regulatory and CLP status
Zinc sulphate (CAS 7733-02-0) (EC 231-793-3)	Acute Tox. 4 Eye Dam. 1 Aquatic Acute 1 Aquatic Chronic 1	H302 (harmful if swallowed) H318 (causes serious eye damage) H400 (very toxic to aquatic life) H410 (very toxic to aquatic life with long lasting effects)			REACH registered; Included in CLP Regulation, Annex VI (index number 030-006-00-9);
Sodium hydroxide (CAS 1310-73-2) (EC 215-185-5)	Skin Corr. 1A	H314 (causes severe skin burns and eye damage)		Specific Concentration limits, M-Factors Skin Corr. 1B; H314: 2% ≤ C < 5% Eye Irrit. 2; H319: 0,5% ≤ C < 2% Skin Irrit. 2; H315: 0,5% ≤ C < 2% Skin Corr. 1A;	REACH registered; Included in CLP Regulation, Annex VI (index number 011-002-00-6);

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Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	No. of Notifiers (CLP inventory)	Additional classification and labelling comments	Regulatory and CLP status
				H314: C $\geq$ 5%	
Copper sulphate (CAS 7758-98-7) (EC 231-847-6)	Acute Tox. 4 Skin Irrit. 2 Eye irrit. 2 Aquatic Acute 1 Aquatic Chronic 1	H302 (harmful if swallowed) H315 (causes skin irritation) H319 (causes serious eye irritation) H400 (very toxic to aquatic life) H410 (very toxic to aquatic life with long lasting effects)			REACH registered; Included in CLP Regulation, Annex VI (index number 029-004-00-0);
Nickel sulphate (CAS 7786-81-4) (EC 232-104-9)	Acute Tox. 4 Skin Irrit. 2 Skin Sens. 1 Acute Tox. 4 Resp. Sens. 1 Muta. 2 Carc. 1A Repr. 1B STOT RE 1 Aquatic Acute 1 Aquatic Chronic 1	H302 (harmful if swallowed) H315 (causes skin irritation) H317 (may cause an allergic skin reaction) H332 (harmful if inhaled) H334 (may cause allergy or asthma symptoms or breathing difficulties if inhaled) H341 (suspected of causing genetic defects) H350i (may cause cancer by inhalation) H360D (may damage the unborn child) H372 (cause damage to organs) H400 (very toxic to aquatic life) H410 (very toxic to aquatic life with long lasting effects)		Specific Concentration limits, M-Factors Skin Sens. 1; H317: C $\geq$ 0,01% STOT RE 1; H372: C $\geq$ 1% Skin Irrit. 2; H315: C $\geq$ 20% M=1 STOT RE 1; H373: C $\geq$ 1% STOT RE 2; H373: 0,1% $\leq$ C < 1%	REACH registered; Included in CLP Regulation, Annex VI (index number 028-009-00-5);
Potassium dicyanoaurate (CAS 13967-	Acute Tox. 2 Acute Tox. 1	H300 (fatal if swallowed) H310 (fatal in	97		Pre-registered substance Not included in

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	No. of Notifiers (CLP inventory)	Additional classification and labelling comments	Regulatory and CLP status
50-5) (EC 237-748-4)	Skin Sens. 1 Acute Tox. 2 Aquatic Acute 1 Aquatic Chronic 1	contact with skin) H317 (may cause allergic skin reaction) H330 (fatal if inhaled) H400 (very toxic to aquatic life) H410 (very toxic to aquatic life with long lasting effects)			the CLP Regulation, Annex VI; Included in C&L inventory
Diamino-dinitro-platinum (CAS 14286-02-3) (EC 238-203-3)	Skin Sens. 1A	H317 (may cause allergic skin reaction)	93		Pre-registered substance Not included in the CLP Regulation, Annex VI; Included in C&L inventory
	Skin Irrit. 2 Eye Irrit. 2 STOT SE 3	H315 (causes skin irritation) H319 (causes serious eye irritation) H335 (may cause respiratory irritation)	23		
Cobalt dichloride (CAS 7646-79-9) (EC 231-589-4)	Acute Tox. 4 Skin Sens. 1 Resp. Sens. 1 Muta. 2 Carc. 1B Repr. 1B Aquatic Acute 1 Aquatic Chronic 1	H 302 (harmful if swallowed) H 317 (may cause allergic skin reaction) H 334 (May cause allergy or asthma symptoms or breathing difficulties if inhaled) H 341 (suspect of causing genetic defects) H350i (May cause cancer by inhalation) H 360 F (May damage fertility) H 400 (very toxic to aquatic life) H 410 (very toxic to aquatic life with long lasting effects)		M=10 Carc. 1B; H350i: C ≥ 0,01%	Harmonised classification. REACH registered; Included in CLP Regulation, Annex VI (index number 027-004-00-5);



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Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	No. of Notifiers (CLP inventory)	Additional classification and labelling comments	Regulatory and CLP status
Potassium cyanide (CAS 151-50-8) (EC 205-792-3)	Acute Tox. 2 Acute Tox 1 Aquatic Acute 1 Aquatic Chronic 1 Skin Irrit. 2 Eye Dam. 1 Met. Corr. 1 STOT SE 1 STOT RE 1	H 290 (may be corrosive to metals) H 300 (fatal if swallowed) H 310 (fatal in contact with skin) H 315 (causes skin irritation) H 318 (causes serious eye damage) H 330 (fatal if inhaled) H 370 (causes damage to organs: central nervous system, heart, cardio-vascular system) H 372 (causes damage to organs through prolonged or repeated exposure: central nervous system, heart, cardio-vascular system) H 400 (very toxic to aquatic life) H 410 (very toxic to aquatic life with long lasting effects)	16	EUH032 (contact with acids liberates very toxic gas)  M=10	Harmonised classification. REACH registered; Included in CLP Regulation, Annex VI (index number 027-004-00-5)

**APPENDIX 2.1.5: ALTERNATIVE 5: Wet lacquering/ Colour painting****Table 1:** Substance ID and physicochemical properties.

Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Polydimethylsiloxane	Physical state at 20°C and 101.3 kPa	Liquid (colourless, odourless)
EC number	n.a.	Melting/freezing point	-
CAS number	9016-00-6	Density	0.980 g/cm <sup>3</sup>
IUPAC name	Poly[oxy(dimethylsilylene)]	Vapour pressure	7 hPa (at 20°C)
Molecular formula	(C <sub>2</sub> H <sub>6</sub> OSi) <sub>n</sub>	Water solubility	Insoluble
Molecular weight	74.15 g/mol	Flammability Flash point	- 321°C
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Cyclohexanone oxime (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Solid (crystalline)
EC number	202-874-0	Melting/freezing point	89.05°C
CAS number	100-64-1	Density	1.087 g/cm <sup>3</sup> (at 20°C)
IUPAC name	cyclohexanone oxime	Vapour pressure	1.78 pa (20°C)
Molecular formula	C <sub>6</sub> H <sub>11</sub> NO	Water solubility	16 g/L (at 25°C)
Molecular weight	113.16 g/mol	Flammability Flash point	Highly flammable -
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	4-Methyl-m-phenylene diisocyanate (example for group of polyurethane)	Physical state at 20°C and 101.3 kPa	Solid
EC number	209-544-5	Melting/freezing point	21°C
CAS number	584-84-9	Density	1.21 g/cm <sup>3</sup> (25°C)
IUPAC name	2,4-diisocyanato-1-methylbenzene	Vapour pressure	0.015 hPa (20°C)
Molecular formula	C <sub>9</sub> H <sub>6</sub> N <sub>2</sub> O <sub>2</sub>	Water solubility	0.1-100 mg/L (reacts rapidly with water)
Molecular weight	174.15 g/mol	Flammability Flash point	Not highly flammable -
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Butane-1,4-diol	Physical state at 20°C and 101.3 kPa	Liquid (viscous, colourless)
EC number	203-786-5	Melting/freezing point	20°C (101.3 kPa)
CAS number	110-63-4	Density	1.02 g/cm <sup>3</sup>

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Parameter	Value	Physicochemical properties	Value
IUPAC name	Butane-1,4-diol	Vapour pressure	< 0.1 hPa (20°C)
Molecular formula	C <sub>4</sub> H <sub>10</sub> O <sub>2</sub>	Water solubility	Miscible with water
Molecular weight	90.1 g/mol	Flammability Flash point	n/a -
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Titanium dioxide	Physical state at 20°C and 101.3 kPa	Solid (crystalline)
EC number	236-675-5	Melting/freezing point	1825-1850°C
CAS number	13463-67-7	Density	4.17 g/cm <sup>3</sup> (at 20°C)
IUPAC name	dioxotitanium	Vapour pressure	-
Molecular formula	TiO <sub>2</sub>	Water solubility	< 1 µg (20°C, pH 6-8)
Molecular weight	79.87 g/mol	Flammability Flash point	- -

**Table 2:** Hazard classification and labelling.

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers	Additional classification and labelling comments	Regulatory and CLP status
Polydimethyl-siloxane (CAS 9016-00-6) (EC n.a)	Not classified	-	134		Pre-registered substance Not included in the CLP Regulation, Annex VI; Included in C&L inventory
	Aquatic Chronic 4	H413 (may cause long lasting harmful effects to aquatic life)	83		
	Eye Irrit. 2	H319 (causes serious eye irritation)	15		
Cyclohexanone oxime (CAS 100-64-1) (EC 202-874-0)	Acute Tox.4	H302 (harmful if swallowed)	88		REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory
	Not classified	-	4		
	Flam. Sol. 1 Acute Tox. 4 Eye Irrit. 2 STOT RE 2 Aquatic Chronic 3	H228 (flammable solid) H302 (harmful if swallowed) H319 (causes serious eye irritation) H373 (may cause damage to organs) H412 (harmful to aquatic life with long lasting effects)	1		
4-methyl-m-phenylene diisocyanate (CAS 584-84-9) (EC 209-544-5)	Skin irrit. 2	H315 (causes skin irritation)	n.a.		Harmonised classification-Annex VI of Regulation (EC) No 1272/2008 (CLP Regulation)
	Skin sens. 1	H317 (may cause an allergic skin reaction)			
	Eye irrit. 2	H319 (causes serious eye irritation)			

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers	Additional classification and labelling comments	Regulatory and CLP status
	Acute Tox. 2	H330 (fatal if inhaled)			
	Resp. Sens.1	H334 (may cause allergy or asthma symptoms or breathing difficulties if inhaled)			
	STOT SE 3	H335 (may cause respiratory irritation)			
	Carc. 2	H351 (suspected of causing cancer)			
	Aquatic chronic 3	H412 (harmful to aquatic life with long lasting effects)			
Butane-1,4-diol (EC 203-786-5) (CAS 110-63-4)	Acute Tox. 4	H302 (harmful if swallowed)	599		REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory
	STOT SE 3	H336 (may cause drowsiness or dizziness)			
	Acute. Tox 4	H302 (harmful if swallowed)	117		
	Acute. Tox 4	H302 (harmful if swallowed)	80		
	Eye Irrit. 2	H319 (causes serious eye irritation)			
Titanium dioxide (CAS 13463-67-7) (EC 236-675-5)	Not classified	-	2550		REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory
	Acute Tox. 4 Carc.2	H332 (harmful if inhaled) H351 (suspected of causing cancer)	45		

**APPENDIX 2.1.6: ALTERNATIVE 6: Chemical Vapour Deposition****Table 1:** Substance ID and physicochemical properties.

Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Titanium carbide (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Solid (crystalline)
EC number	235-120-4	Melting/freezing point	3067°C
CAS number	12070-08-5	Density	4.93 g/cm <sup>3</sup>
IUPAC name	Titanium carbide	Vapour pressure	-
Molecular formula	TiC	Water solubility	Insoluble (< 0.1 mg/L)
Molecular weight	59.88 g/mol	Flammability Flash Point:	Non flammable -
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Titanium nitride (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Solid (brown)
EC number	247-117-5	Melting/freezing point	2930°C
CAS number	25583-20-4	Density	5.22 g/cm <sup>3</sup>
IUPAC name	Titanium nitride	Vapour pressure	-
Molecular formula	TiN	Water solubility	-
Molecular weight	61.87 g/mol	Flammability Flash Point:	Non flammable -

**Table 2:** Hazard classification and labelling.

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers	Additional classification and labelling comments	Regulatory and CLP status
Titanium Carbide (CAS 12070-08-5) (EC 235-120-4)	Not classified		18		REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory
	Flam. Sol	H 228 (flammable Solid)	1		
Titanium nitride (CAS 25583-20-4) (EC 247-117-5)	Not classified		11		Pre-registered substance Not included in the CLP Regulation, Annex VI; Included in C&L inventory
	Flam. Sol. 2 Skin Irrit. 2 Eye Irrit. 2	H 228 (flammable Solid) H 315 (causes skin irritation) H 319 (causes serious eye irritation)	10		

**APPENDIX 2.1.7: ALTERNATIVE 7: DLC: Diamond Like Carbon****Table 1:** Substance ID and physicochemical properties.

Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Graphite (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Solid (black, odourless)
EC number	231-955-3	Melting/freezing point	T >600°C
CAS number	7782-42-5	Density	2.21 g/cm <sup>3</sup> (at 25°C)
IUPAC name	graphite	Vapour pressure	-
Molecular formula	C	Water solubility	< 45 mg/L (at 20°C)
Molecular weight	12.0 g/mol	Flammability Flash Point:	Not highly flammable -

**Table 2:** Hazard classification and labelling overview.

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers	Additional classification and labelling comments	Regulatory and CLP status
Graphite (CAS 7782-42-5) (EC 231-955-3)	Not classified	H319 (causes serious eye irritation) H335 (may cause respiratory irritation)	861		REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory
	Eye Irrit. 2 STOT SE 2		90		

**APPENDIX 2.1.8: ALTERNATIVE 8: Electroless Nickel plating****Table 1:** Substance ID and physicochemical properties.

Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Nickel sulphate	Physical state at 20°C and 101.3 kPa	Solid (greenish-yellow)
EC number	232-104-9	Melting/freezing point	Decomposes at 840°C
CAS number	7786-81-4	Density	3.68 g/cm <sup>3</sup> at 20°C
IUPAC name	nickel(2+) sulfate	Vapour pressure	-
Molecular formula	Ni(SO <sub>4</sub> ) <sub>2</sub>	Water solubility	293 g/L (at 20°C)
Molecular weight	154.8 g/mol	Flammability Flash point	Non flammable -

Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Sodium hypophosphite (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Solid (colourless)
EC number	231-669-9	Melting/freezing point	Decomposes at 238°C
CAS number	7681-53-0	Density	1.77 g/cm <sup>3</sup> (monohydrate)
IUPAC name	Sodium phosphinate	Vapour pressure	-
Molecular formula	NaPO <sub>2</sub> H <sub>2</sub>	Water solubility	909 g/L (monohydrate at 30°C)
Molecular weight	87.98 g/mol	Flammability Flash point	Non flammable -
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Lactic Acid (D, L), (exemplarily for carboxylic acid – complexing agent)	Physical state at 20°C and 101.3 kPa	Liquid (viscous)
EC number	209-954-4	Melting/freezing point	18°C
CAS number	598-82-3	Density	1.21 g/cm <sup>3</sup>
IUPAC name	2-hydroxypropanoic acid	Vapour pressure	0.1 hPa (at 20°C)
Molecular formula	C <sub>3</sub> H <sub>6</sub> O <sub>3</sub>	Water solubility	Soluble in water
Molecular weight	90.07 g/mol	Flammability Flash point	- -

**Table 2:** Hazard classification and labelling overview.

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers	Additional classification and labelling comments	Regulatory and CLP status
Nickel sulphate (CAS 7786-81-4) (EC 232-104-9)	Acute Tox. 4 Skin Irrit. 2 Skin Sens. 1 Acute Tox. 4 Resp. Sens. 1 Muta. 2 Carc. 1A Repr. 1B STOT RE 1 Aquatic Acute 1 Aquatic Chronic 1	H302 (harmful if swallowed) H315 (causes skin irritation) H317 (may cause an allergic skin reaction) H332 (harmful if inhaled) H334 (may cause allergy or asthma symptoms or breathing difficulties if inhaled) H341 (suspected of causing genetic defects) H350i (may cause cancer by inhalation) H360D (may damage the		Specific Concentration limits, M-Factors Skin Sens. 1; H317: C ≥ 0,01% STOT RE 1; H372: C ≥ 1% Skin Irrit. 2; H315: C ≥ 20% M=1 STOT RE 1; H373: C ≥ 1% STOT RE 2; H373: 0,1% ≤ C < 1%	REACH registered; Included in CLP Regulation, Annex VI (index number 028-009-00-5);

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers	Additional classification and labelling comments	Regulatory and CLP status
		unborn child) H372 (cause damage to organs) H400 (very toxic to aquatic life) H410 (very toxic to aquatic life with long lasting effects)			
Sodium hypophosphite (CAS 7681-53-0) (EC 231-669-9)	Not classified		326		REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory
	Eye Irrit. 2 Skin Irrit. 2	H319 (causes serious eye irritation) H315 (causes skin irritation)	23		
D,L-Lactic Acid (CAS 598-82-3) (EC 209-954-4)	Skin Irrit. 2 Eye Dam. 1	H315 (causes skin irritation) H318 (causes serious eye damage)	830		REACH registered; Not included in the CLP Regulation, Annex VI; Included in C&L inventory
	Skin Corr. 1C Eye Dam. 1	H314 (causes severe skin burns and eye damage) H318 (causes serious eye damage)			

### APPENDIX 2.1.9: ALTERNATIVE 9: Powder Coating (Pulverlack)

There is a broad range of different kinds of powder coatings and in general, the details of the ingredients are not publicly available. Therefore, only groups of chemical ingredients can be described without details of their physicochemical properties, or hazard classification and labelling.

### APPENDIX 2.1.10: ALTERNATIVE 10: Stainless steel (alternative substrate)

Stainless steel is not a chemical substance and therefore no distinct hazardous classification and labelling information can be provided.



## APPENDIX 2.2: PRE-TREATMENTS

## APPENDIX 2.2.1: ALTERNATIVE 11: Mineral acid based etching solution

Table 1: Substance ID and physicochemical properties.

Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Sulphuric acid (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Liquid (odourless)
EC number	231-639-5	Melting/freezing point	3°C (for 98% sulphuric acid) 10.4-10.5°C (for 100% sulphuric acid)
CAS number	7664-93-9	Density	1.81 g/cm <sup>3</sup> (20°C, for 90%) 1.83 g/cm <sup>3</sup> (20°C, for 100%)
IUPAC name	Sulphuric acid	Vapour pressure	0.49 hPa (20°C)
Molecular formula	H <sub>2</sub> SO <sub>4</sub>	Water solubility	Miscible with water
Molecular weight	98.08 g/mol	Flammability	Non flammable
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Nitric acid (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Liquid (fumes in moist air)
EC number	231-714-2	Melting/freezing point	- 41.60 °C
CAS number	7697-37-2	Density	1.51 g/cm <sup>3</sup> (20°C)
IUPAC name	Nitric acid	Vapour pressure	9.00 kPa (25°C)
Molecular formula	HNO <sub>3</sub>	Water solubility	> 1000g /L (20°C, pH= -1)
Molecular weight	63.01 g/mol	Flammability Flash point	Non flammable but can enhance combustion of other materials
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Iron sulphate (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Solid
EC number	231-753-5	Melting/freezing point	Decomposes at 300°C
CAS number	7720-78-7	Density	3.65 g/cm <sup>3</sup>
IUPAC name	iron(2+) sulphate	Vapour pressure	-
Molecular formula	FeSO <sub>4</sub>	Water solubility	295 g/L (25°C)
Molecular weight	151.91 g/mol	Flammability: Flash point:	Non flammable -
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Formic acid (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Liquid (clear, colourless)
EC number	200-579-1	Melting/freezing point	4°C

Parameter	Value	Physicochemical properties	Value
CAS number	64-18-6	Density	1.22 g/cm <sup>3</sup> (20°C)
IUPAC name	formic acid	Vapour pressure	54.96 hPa (25°C)
Molecular formula	CH <sub>2</sub> O <sub>2</sub>	Water solubility	Miscible in any ratio
Molecular weight <sup>[2]</sup>	46.03 g/mol	Flammability: Flash point:	- -

**Table 2:** Hazard classification and labelling overview.

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers	Additional classification and labelling comments	Regulatory and CLP status
Sulphuric acid (CAS 7664-93-9) (EC 231-639-5)	Skin Corr. 1A	H314 (Causes severe skin burns and eye damage)	n/a	Specific Concentration limits: Skin Corr. 1A: $C \geq 15\%$ , H314 Skin Irrit. 2: $5\% \leq C < 15\%$ , H315 Eye Irrit. 2: $5\% \leq C < 15\%$ ; H319	REACH registered; Included in CLP Regulation, Annex VI (index number 016-020-00-8);
Nitric acid (CAS 7697-37-2) (EC 231-714-2)	Ox. Liq. 3	H272 (May intensify fire; oxidiser)	n/a		REACH registered; Included in CLP Regulation, Annex VI (index number 007-004-00-1)
	Skin Corr. 1A	H314 (Causes severe skin burns and eye damage)			
	Met. Corr. 1	H290 (May be corrosive to metals)		Additional classification according to REACH registration.	
Iron sulphate (CAS 7720-78-7) (EC 231-753-5)	Acute Tox. 4 Skin Irrit. 2 Eye Irrit. 2	H302 (harmful if swallowed) H315 (causes skin irritation) H319 (causes serious eye irritation)	-		REACH registered; Included in CLP Regulation, Annex VI (index number 026-003-00-7)
Formic acid (CAS 64-18-6) (EC 200-579-1)	Skin Corr. 1A	H314 (causes severe skin burns and eye damage)		Skin Corr. 1A; H314: $C \geq 90\%$ Skin Corr. 1B; H314: $10\% \leq C < 90\%$ Skin Irrit. 2; H315: $2\% \leq C < 10\%$ Eye Irrit. 2; H319: $2\% \leq C < 10\%$	REACH registered; Included in CLP Regulation, Annex VI (index number 607-001-00-0)

**APPENDIX 2.2.2: ALTERNATIVE 12: Potassium permanganate based etching solution****Table 1:** Substance ID and physicochemical properties.

Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Potassium permanganate (mono constituent substance)	Physical state at 20°C and 101.3 kPa	Solid (dark purple)
EC number	231-760-3	Melting/freezing point	Decomposes at 240°C
CAS number	7722-64-7	Density	2.7 g/cm <sup>3</sup> (at 20°C)
IUPAC name	Potassium oxido(trioxo)manganese	Vapour pressure	-
Molecular formula	KMnO <sub>4</sub>	Water solubility	≥ 64 g/L at 20°C
Molecular weight	158.034 g/mol	Flammability Flash point	Non flammable but will accelerate the burning of combustible material. -

**Table 2:** Hazard classification and labelling overview.

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers	Additional classification and labelling comments	Regulatory and CLP status
Potassium permanganate (CAS 7722-64-7) (EC 231-760-3)	Oxid Solid 2 Acute Tox. 4 Aquatic Acute 1 Aquatic Chronic 1	H272 (may intensify fire; oxidiser) H302 (harmful if swallowed) H400 (very toxic to aquatic life) H410 (very toxic to aquatic life with long lasting effects)			REACH registered; Included in CLP Regulation, Annex VI (index number 025-002-00-9)

**APPENDIX 2.2.3: ALTERNATIVE 13: Polyamide (Alternative Substrate)**

The most typically used polyamide polymers are PA 6 and PA 6.6 based on the monomers evaluated in the following tables.

**Table 1:** Substance ID and physicochemical properties.

Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Polycaprolactam (Polymer: Polyamide 6 (Nylon 6))	Physical state at 20°C and 101.3 kPa	Solid
EC number	-	Melting point	220 °C
CAS number	25038-54-4	Density	1.084 g/cm <sup>3</sup> at 25 °C
IUPAC name	Poly(hexano-6-lactam)	Vapour pressure	-

Parameter	Value	Physicochemical properties	Value
Molecular formula	(C <sub>6</sub> H <sub>11</sub> NO) <sub>n</sub>	Water solubility	Insoluble
Molecular weight	113.08 g/mol	Flammability	-
Parameter	Value	Physicochemical properties	Value
Chemical name and composition	Polyhexamethylene adipamide (Polymer : Polyamide 6.6 (Nylon 6.6))	Physical state at 20°C and 101.3 kPa	Solid
EC number	-	Melting point	250-260 °C
CAS number	32131-17-2	Density	-
IUPAC name	Polyhexamethylene adipamide	Vapour pressure	-
Molecular formula	(C <sub>12</sub> H <sub>22</sub> N <sub>2</sub> O <sub>2</sub> ) <sub>n</sub>	Water solubility	Insoluble
Molecular weight	262.35 g/mol	Flammability	-

**Table 2:** Hazard classification and labelling overview.

Substance Name	Hazard Class and Category Code(s)	Hazard Statement Code(s) (labelling)	Number of Notifiers	Additional classification and labelling comments	Regulatory and CLP status
Polyamide 6 (Nylon 6) (CAS 25038-54-4)	Skin Irrit. 2 Eye Irrit. 2 Aquatic Chronic 4	H315 (Causes skin irritation) H319 (Causes serious eye irritation) H413 (May cause long lasting harmful effects to aquatic life)	19	-	REACH pre-registered.
Polyamide 6.6 (Nylon 6.6) (CAS 32131-17-2)	Skin Irrit. 2	H315 (Causes skin irritation)	18	-	REACH pre-registered.

### APPENDIX 2.3: SOURCES OF INFORMATION

Information on substance identities, physicochemical properties, hazard classification and labelling are based on online data searches. All online sources were accessed between June and September 2014. The main sources are:

Source:

- European Chemicals Agency: <http://echa.europa.eu/de/>
- ChemSpider <http://www.chemspider.com>
- <http://www.chemicalbook.com>
- <http://pubchem.ncbi.nlm.nih.gov>
- <http://www.scbt.com>
- Merck Safety Data Sheet: <http://www.merck-performance-materials.com/>
- Sigma Aldrich Safety Data Sheet: <http://www.sigmaaldrich.com/>
- <http://www.sciencelab.com/msds.php?msdsId=9927079>
- Alfa Aesar Safety Data Sheet: <http://www.alfa.com/>
- United States Environmental Protection Agency internet site: <http://www.epa.gov>
- Carlroth Safety Data Sheet: <http://www.carlroth.com/>
- Fisher Scientific Safety Data Sheet: <http://www.fishersci.com>
- Carl Roth Safety Data Sheet: <http://www.carlroth.com/media>
- [www.nyltek.com/pdf/SAFETY.pdf](http://www.nyltek.com/pdf/SAFETY.pdf)