# Decorative Trivalent Chromium Plating – The Challenges of Change Facing the Industry

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**Decorative chromium electroplating from an electrolyte based on chromium trioxide has been successfully used for many years. The deposit satisfies many demands including aesthetics, durability and economy. However, the materials used in this type of system have now been classified as carcinogenic. For this reason, new legislation is being introduced (or existing legislation is being tightened) to control, restrict or even prohibit their use. Consequently the chromium plating industry is being driven to change the way it operates and the materials it uses. The goal is to manage this change for the benefit of all of the stakeholders by eliminating, rather than minimizing the risk of exposure of the industry workforce to chromium trioxide. This paper describes the primary applications for decorative chromium plating and the systems used to meet today's demands. It then explains the principal macro drivers of change. Finally the use of best practice alternative systems, based on trivalent chromium electrolytes and the potential effect on the supply chain are evaluated. The key question posed is, can the industry meet the challenge?**

## Introduction

Decorative chromium electroplating has been successfully used for more than 80 years. The majority of chromium platers uses electrolytes based on chromium trioxide and sulfuric acid, which have remained the default systems for many decades. The term "chromium plate" is used to define more than just a single metallic deposit. Chromium electroplating refers to a multi-layer deposit consisting of a copper and/or nickel undercoat and thin chromium top coat. The function of the chromium layer is to provide a strong, powerful and effective anti-tarnish to the bright nickel coating. Today chromium electroplating is carried out on many different and varied components including automotive bright exterior trim and alloy wheels, sanitary and bathroom fittings, tubular furniture, point of sale equipment (shop fittings) and consumer electronic goods.

However, chromium trioxide has now been reclassified as a hazardous substance that may cause cancer. Consequently, the industry now finds itself under intense pressure from international occupational health legislation and corporate demands to reduce the exposure effects of this material to their employees.

The industry faces two choices:

- To minimize the risk of exposure and continue to use chromium trioxide electrolyte, or
- To eliminate the risk entirely by committing to the alternative trivalent chromium plating process.

Adopting an alternative technology is a major step for the industry that will have both direct and indirect repercussions for the supply chain. For this change to be successful, the needs and opinions of all stakeholders must be taken into consideration. This paper makes the case that the elimination of risk secured by the use of trivalent chromium plating electrolytes is the way forward and that the successful management of this change within the supply chain can lead to benefits for all participants

## The industry today

Chromium plate continues to be the coating of choice for many applications. Demand for the bright and lustrous finish continues to grow despite competition from other finishes such as organic coatings and vacuum deposition. Reasons why chromium has survived so long include not only unmatched aesthetics but also technical factors such as exceptional corrosion performance, multi substrate capability and supply chain factors such as economy bulk industrial scale, extensive installed applicator base and long application history and experience.

### *Industries served*

Chromium electroplating provides a high aesthetic performance and corrosion-resistant coating for many industries, the largest market segment being the automotive industry. This industry can be broken down into various applications, usually identified by the material being plated: plastic (primarily ABS) is used extensively for bright trim (*i.e.*, badges, grilles); alloy wheels, usually fabricated from aluminum (although the market now appears to be going in the direction of plastic cladding[1]); steel used for bumpers and trim; and zinc die castings, used for articles such as door handles. Sanitary/plumbing fittings is another large market segment, where the use of chromium electroplating still dominates, due mainly to its easy cleaning and wear resistance properties. This industry also uses many substrates such as brass (*i.e.*, plumber's brassware), plastic and zinc-based die castings, making electroplating a good choice. Chromium electroplating is also used for more traditional steel articles including tubular furniture, point of sale equipment (or shopfittings) and electrical consumer goods. These applications still use chromium electroplates extensively but as fashion changes, the threat of alternative finishes becomes more real. The use of chromium electroplating is very well embedded in today's component design and usage, so that any changes in the process technology will have wide-ranging effect.

Despite its inherent advantages, other factors can affect the choice to use chromium. These include:

- Availability of applicators (both number and quality),
- Attitudes and buying preferences,
- Fashion and culture.

In most applications demand for chromium electroplating is predominantly fashion driven and therefore cyclical. One of the best indicators of the current strength of the chromium electroplating market is to review the consumption of chromic acid and electrolytic nickel metal. Around 20 to 25%[2,3,*] of the world's chromic acid is used for metal finishing and demand grows at 2 to 3% annually.[4] This growth rate is reflected in nickel metal consumption as well. While the use of electrolytic nickel for the plating market remains consistent at around 8%[5] of total world nickel production, demand for total nickel metal increases globally at 2 to 3%.[6] Therefore, because materials usage, and in particular metals, is more efficient today than at any time in the past, we can safely assume that electroplated nickel and chromium continue to show modest growth in both volume and applications.

## *Chromium plating technology and systems*

What is generally referred to as bright chromium electroplating is in fact a thin coating, usually 0.1 to 0.3 $\mu$m of chromium metal, over a bright and leveled coating of nickel. The actual type(s) of nickel used, the number of nickel layers and the total nickel thickness will depend on the base material being plated and the service condition specified (see Table 1[7]). For example a component plated to service condition SC5, will typically require a 20-$\mu$m layer of semibright nickel,[**] a 10-$\mu$m layer of bright nickel and finished by a 0.3-$\mu$m layer of microporous chromium.[***] Where a component is plated to service condition SC1, it will have a minimum nickel thickness of 10 $\mu$m (single layer, typically bright) and a coating of regular uniform chromium. When a less reflective "matte" type finish is required, a satin nickel finish can be employed to replace the bright layer.

[*] *This includes all metal finishing including hard, decorative, chromates and anodizing.*

[**] *Semibright nickel is a low sulfur (<0.005%) nickel deposit which acts as a barrier to further penetration to the base material once the top layer has been penetrated.*

[***] *Microporous chromium is achieved by depositing the chromium over a special thin nickel layer which contains inert non-conducting particles, the special nickel layer being applied on top of either bright or satin nickel for microporous chromium, containing a minimum of 10,000 pores per cm$^2$.*

**Table 1**

**Service performance of chromium electroplating[7]**

| Service condition number | Description | Details |
|---|---|---|
| **SC5** | Extended very severe | Service conditions that include likely damage from denting, scratching and abrasive wear in addition to exposure to corrosive environments where *long-term protection* of the substrate is required; *e.g.*, conditions encountered by some exterior components of automobiles. |
| **SC4** | Very severe | Conditions that include likely damage from denting, scratching and abrasive wear in addition to exposure to corrosive environments; *e.g.*, conditions encountered by exterior components of automobiles and by boat fittings in salt water service. |
| **SC3** | Severe | Exposure that is likely to include occasional or frequent wetting by rain or dew or possibly strong cleaners and saline solutions; *e.g.*, conditions encountered by porch and lawn furniture, bicycle and perambulator parts, hospital furniture and fixtures. |
| **SC2** | Moderate | Indoor exposure in places where condensation of moisture may occur; *e.g.*, in kitchens and bathrooms. |
| **SC1** | Mild | Indoor exposure in normally warm, dry atmospheres with coating exposed to minimum abrasion. |

# Why change?

## Industry issues

All organizations are subject to external drivers within both the macro-environment and their own marketplace. These drivers can ultimately dictate the success or indeed the failure of whole industries or organizations within it. The metal finishing industry has had to face a change in the way it operates and in the choice of materials it can use in order to comply with environmental, health and safety legislation and pressures.

The chromium electroplating industry now finds itself at the center of a health and safety debate that has the potential to drive major change within the industry. This debate revolves, either directly or indirectly, around the use of chromium trioxide.[†] This is because this material is known to be both mutagenic and carcinogenic. When used in chromium electroplating, workers are exposed to its risks in three primary ways:

- When handling the dry material (*i.e.*, dust exposure)
- By electrolysis (*i.e.*, as an airborne mist)
- By skin contact with the process solution (splashes, drips, etc.)

These factors have precipitated new legislation and raised the issues into corporate policies. These risks only apply to chromium trioxide-containing processes or materials. There is no such risk posed by the finished chromium plated surface. The metal itself poses no such health risk.

## Drivers for change

There are different specific drivers in North America, the European Union and Asia, although there is much overlap. Some of these are outlined here:

*Control of Substances Hazardous to Health (COSHH) (EU).* This legislation requires users to carry out a risk assessment and then (1) find a viable alternative or (2) if one doesn't exist, take preventative measures to avoid the user coming into contact with the substance. The best practice is option (1).

[†] *Also known as chromic acid ($CrO_3$), chromic anhydride, chromic oxide and chromium (VI) oxide (1:3).*

*Control of Major Accident Hazards Regulations 1999 (COMAH) (EU).* This legislation is based on the potential for certain industrial activities involving dangerous substances having the potential for major accidents. A potential accident may cause serious injury to many people and/or extensive damage to the environment, perhaps some distance from the site of the accident. This legislation was prompted by previous major accidents involving chemicals (*e.g.*, Flixborough, UK 1974; Seveso, Italy 1976; Bhopal, India 1984 and Basle, Switzerland 1986). It requires that operators of COMAH sites take "all measures necessary" to prevent major accidents and to limit their consequences to both people and the environment.[8] There are two levels (tiers) that classify a site as needing to register as a COMAH site. These are detailed in Table 2.

*Permissible Exposure Limit (North America).*[9] The Occupational Safety and Health Administration (OSHA) has amended the existing standard which limits occupational exposure to hexavalent chromium. Based on the best evidence currently available, OSHA has determined, at the current permissible exposure limit (PEL) for hexavalent chromium, that workers face a significant risk to material impairment of their health. The evidence in the record for this rulemaking indicates that workers exposed to hexavalent chromium are at an increased risk of developing lung cancer. The record also indicates that occupational exposure to hexavalent chromium may result in asthma and damage to the nasal epithelia and skin. The final rule establishes an 8-hr time-weighted average (TWA) exposure limit of 5 micrograms ($\mu$g) of hexavalent chromium per cubic meter ($m^3$) of air. This is a considerable reduction from the previous PEL of 1 mg per 10 $m^3$ of air, or 100 reported as $CrO_3$, which is equivalent to a limit of 52 $\mu$g as hexavalent chromium. As a reference, the UK has an exposure limit of 50 $\mu$g of hexavalent chromium per $m^3$ of air (which is fairly typical of a European standard), 10 times more than the USA.

*Registration, Evaluation and Authorization of Chemicals (REACH) (EU).* To meet this proposed legislation, manufacturers and importers of substances are obliged to submit a registration to the newly established European Chemicals Agency. This agency will be responsible for the implementation of the REACH legislation, for each substance manufactured or imported in quantities of 1 tonne (1,000 kg; 2,200 lb.) or above per year. Those using or making

**Table 2**

**Overview of COMAH regulations**

| **Generic categories of dangerous substances** | **Lower tier** | **Top tier** |
|---|---|---|
| | **Quantity in tonnes ( ≥ )** | |
| 1 **Very Toxic** | 5 | 20 |
| 2 **Toxic** | 50 | 200 |
| 9 **Dangerous for the environment** in combination with the following risk phrases: | | |
| (i) R50: "Very toxic to aquatic organisms" | 200<br>*(100)** | 500<br>*(200)** |
| (ii) R51: "Toxic to aquatic organisms"; and<br>(iii) R53: "May cause long-term adverse effects in aquatic environment" | 500<br>*(200)** | 2,000<br>*(500)** |
| **Qualifying thresholds to be reduced July 2005 as result of amendments to COMAH regulations.* | | |

available a substance of very high concern will need to apply to the Agency for an authorization for each use of the substance within set deadlines. Applicants must demonstrate that the risks related to the use of the substance concerned are adequately controlled or that the socio-economic benefits of its use outweigh the risks, taking into account the availability of alternative substances (substitution) or processes. The socio-economic argument is deemed to be a less strong argument and any authorization for use given on this basis will generally be time-limited.[10]

### *Control of chromic acid mist (perfluorooctanyl sulfonate, PFOS)*

Perfluorooctanyl sulfonate (or PFOS for short) is a member of a large family of perflurooctanyl sulfonate chemicals. These chemicals have been used in a variety of industrial, commercial and consumer products. In chromium electroplating, these PFOS materials are used to lower the surface tension of the plating solutions to prevent the formation of harmful chromium mists above electroplating baths. These "mist suppressors" have been in use for many decades, helping to eliminate hazardous chromic acid spray above electroplating baths. However, these suppressors present an environmental hazard themselves. The hazard associated with them is the persistence of PFOS in the environment, as well as its toxicity and bioaccumulation potential, indicating a cause for concern for the environment and for human health.[11,††] Based on this, the EU is now proposing restrictions on the marketing and use of perfluorooctane sulfonates (amendment of Council Directive 76/769/EEC). However, studies into the use of PFOS in decorative chromium plating solutions conclude that at this time:

- These materials provide a unique means of controlling exposure to hexavalent chromium mist and thereby controlling the OH&S risks associated with such exposure.
- No alternative to PFOS exists for mist suppression and it is unlikely that an alternative can be identified or developed within the foreseeable future.
- In order to reduce the amount of PFOS losses into the environment, it is quite possible that companies using these materials will have to prevent any solution loss to effluent through closed loop systems.
- The net effect of the above is that chromium platers now have to find alternative materials to control chromic acid mist. These alternatives are not as effective as the PFOS material, which makes it more difficult and/or expensive to meet the national health and safety requirements/legislation.

### *Corporate Social Responsibility (CSR)*[†††]

An intangible factor which stretches across all geographical regions is the desire of major corporations to adopt safer and more environmentally acceptable technologies. Although these organizations may not actually use the processes, they can have a major influence in the supply channel by insisting that suppliers use less damaging materials by specifying alternatives. This may be one of the greater drivers for change as it essentially combines known health issues and current and proposed related legislations. Many larger corporations are now taking a proactive stance and asking their supply chains to seek alternatives to decorative chromium electroplating from hexavalent systems. This is particularly prevalent in Asian countries for, in particular, automotive components and electronic consumer goods.

## Stakeholders

Today,businesses have to take into consideration the needs and perceptions of diverse groups of stakeholders each of which has an impact on the way an organization goes about its business. For an electroplating company these groups will probably include its customers, suppliers, employees, shareholders, competitors, industry bodies, OEMs, government bodies, non-governmental organizations and local residents. These different groups may have very different expectations and place what sometimes appear to be diametrically opposed requirements on the plating company. For example, upstream customers will probably want the highest quality chromium electroplating at the lowest cost. Conversely, conforming to ever more demanding legislation would appear to increase an organization's cost base and make it potentially less competitive to meet these customer demands.

This type of debate rages on in the business world, in many varied industries far removed from the surface finishing world. Industry leaders such as Jack Welch have gone on record as saying that the time has passed when making a profit and paying taxes was all that a company had to worry about. Note also how companies such as BP have tackled the issue over emissions and the long term viability of fossil fuels. By addressing the needs of different stakeholder groups (*i.e.*, shareholders and environmentalists), they have repositioned the company as an energy supplier (not just fossil fuel-based) concerned about long term sustainability and shareholder value. Contrast this to companies such as sportswear manufacturers and fast food outlets which have had to take a more reactive approach to their business after extensive criticism about third world labor exploitation from indirectly related stakeholders such as Oxfam and governments. Whichever side of the argument you take, stakeholders are a critical factor to take into account when doing business, and their sometimes disparate views need to be taken into account.

## What can be done?

As outlined above, the popularity and desire for chromium electroplating continues to be strong. Therefore, if the industry is to continue to satisfy its customers and stakeholders in supplying high quality chromium plate, it needs to (1) meet the industry drivers or (2) consider alternatives:

### *Meeting industry drivers*

This is the option that most companies have adopted for many years now, even against the backdrop of increasing legislation and social awareness of the issues. This course of action has been followed because of the lack of suitable alternative coatings. However, as outlined above, the drivers now come from different perspectives (sometimes seemingly diametrically-opposed *e.g.*, mist reduction and PFOS removal), are more international (EU legislation) and sometimes quite intangible (*e.g.*, CSR). A plater now faced with these multifaceted issues may find it difficult to both understand

*†† An ongoing research project PERFORCE (http://www.science.uva.nl/perforce/), which is financed by the Research Framework Program is generating new data on exposures, sources, routes and physico-chemical parameters of PFOS.*

*††† CSR is the business contribution to sustainable development goals. Essentially it is about how business takes account of its economic, social and environmental impacts in the way it operates, maximizing the benefits and minimizing the downsides (See S. Dibb, L. Simkin, W. Pride and O.C. Ferrell, Marketing Concepts and Strategies, 4th European Edition, Houghton-Mifflin, 2001).*

and implement any necessary changes. This of course presupposes that further tightening of current legislation as well as new drivers do not surface, which in a constantly changing and more environmentally-aware world is probably unlikely.

### Alternatives

The most readily available technologies to replace decorative hexavalent based chromium electroplating solutions are those based on trivalent chromium. This type of system either meets or is exempt from the various legislative acts outlined above and is also perfectly acceptable in most corporate supply chains. However, even though these systems have actually been in commercial use since the mid-1970s, they have not been viable for all applications. The main drawbacks being the color difference and inferior corrosion resistance when compared to deposits plated from a traditional electrolyte based on hexavalent chromium. This has meant limited market penetration for trivalent-based electrolytes accounting for less than 5% of the total global chromium installed process volume. The majority of companies using trivalent chromium tend to be captive shops (manufacturers and platers) which can both specify and plate to their own needs. New trivalent chromium technologies which answer these drawbacks are being introduced, allowing all platers to have a real alternative to replace hexavalent-based systems in all applications.

## Trivalent chromium plating

Trivalent-based electrolytes are available which overcome the quality and cosmetic issues of older systems. The chromium deposits have purity very close to that produced from a hexavalent system, meaning that both the color and corrosion resistance are virtually indistinguishable from each other. These new trivalent processes can also plate deposit thicknesses up to 0.3 $\mu$m, making them suitable for meeting even the tough service conditions outlined in Table 1. So do these systems mean a simple change with no adjustment to work practices? The answer of course is no. Subtle process differences and current industry acceptance mean that a certain amount of learning and adaptation needs to take place. Let us consider what adaptations are required by evaluating the existing needs of some of the key stakeholders identified above.

### The plater and its employees

The biggest change for a current chromium plater is to learn new work practices. This will require communication to the employee based on the need for change and the inherent benefits. Only by passing on this information will potential operators embrace the new work practices and implement systems as quickly and efficiently as possible.

### Direct customers

Electroplaters need to be sure that their customers actively support moving from hexavalent-based systems. This means raising the awareness of the issues outlined above, so that customers can make their own evaluation of alternative finishes. Although the color difference is almost imperceptible to the human eye, and some companies are today mixing both components from hexavalent and trivalent on finished articles, optimized supply chain management would use similar generic systems if they are sourcing from different plating lines.

### Trade associations

Industry bodies have the opportunity to help manage change within industries as they are the voice of the industry and have lobbying access to the relevant government and NGO bodies. They should support its members the plating industry (*i.e.*, the plating companies), by reviewing all the arguments, industry drivers and potential alternatives and presenting a balanced argument to all stakeholders.

### Chemical suppliers

As owners of the technology, chemical suppliers will be able to present the best alternative to chromium trioxide. They are also the key point of reference in the supply chain for consultation on best practices for change.

### OEMs or specifiers

Some specifiers of chromium electroplating know that potential change in the supply chain are imminent and have started to discuss implications with their suppliers, platers and chemical suppliers. The two major market segments for specification-driven chromium plate (*i.e.*, automotive and sanitary ware) will need to instigate test programs to validate and recommend alternatives. A program of this kind takes many months and significant resources. Therefore a reasoned argument needs to be made for them to partner in any test program.

### Government departments and NGOs

Government departments understand that non-consultative legislation would potentially mean job losses and risk votes. However, they also know that industries do not regulate themselves very well, especially with regard to using less polluting / less harmful chemicals and their duty of care to employees. As described above, change to new technology takes time, both in education and implementation. This needs to be communicated in open dialogue so that change can be implemented in a controlled and timely fashion.

## Summary

Overcoming legislation by the introduction of improved safety practices with the continued use of hexavalent-based processes may appear to be the most straightforward and cost effective solution. However, failure to comply with new limits will probably mean having to revisit the issues repeatedly in the future as legislation becomes further tightened. If, on the other hand, the industry decides that moving to trivalent chromium systems is the answer, a longer term solution can be found. It is evident when considering the arguments suggested in this text that many stakeholders' needs and perceptions will need addressing to facilitate change in the industry. No individual element of the supply chain can initiate complete change by itself. For this type of change to take place in a controlled and sustainable manner, the whole supply chain must work in a collaborative best practice way so that the benefits of chromium electroplating can be enjoyed for many more years.

## Conclusions

The goal for our industry is to manage the change away from the now increasingly unacceptable hexavalent-based chromium processes towards the safer use of the newer alternative technologies in a way that benefits all stakeholders. Attaining this goal will be the challenge

Overcoming legislation by the introduction of improved safety practices and the continued use of hexavalent-based processes may appear to be the most straightforward and cost effective solution to the current situation. While this may be attractive to part of the supply chain in the short term, other more powerful influences may not see this as the best choice. This is not the goal, since it will not satisfy all stakeholders.

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