ANALYSIS OF ALTERNATIVES

Evaluation of substances and parallel technologies for suitability as an alternative option

Applicant:	*HAPOC GmbH & Co KG*
Applied for by:	*HAPOC GmbH & Co KG*
Substance(s):	*Chromium trioxide and its aqueous solutions*
Name of use:	*Use of chromium trioxide in solid form and in aqueous solution of any composition to modify the properties of surfaces made of metal or plastic, with or without current flow, in category III.*
Use number:	*2*
Description of category:	*Use at an exposure limit of 5µg/m³ and an exposure duration of not more than 8 hours.*

CONTENTS

Basis of the analysis performed for authorisation in CSR, AoA and SEA

1. The analysis performed for the application for authorisation relates to the use that is typically used by a surface-finishing service provider, which may result in various applications. ***The analysis does not consider specific products, articles or their applications.*** In fact, priority is given to the variable use of the substance by a surface-finishing service provider. This is necessary because it is the use of chromium trioxide that is to be authorised, and not the final use of the surface-modified component or article (which, in the scope of this application, does not contain the substance requiring authorisation). The latter are not influenced nor can be selected or modified by the surface-finishing service provider, rather they are always specified by the client.
2. This report essentially considers an individual company and how it identifies and minimises its specific, operational risk. The level of risk would otherwise depend statistically on the current number of companies active across Europe and would therefore vary with time. This kind of overall risk cannot be regulated with individual authorisations.
3. The present application predominately uses official data, measurements and assessment criteria (e.g. dose-response relationship) and their recommendations and guidelines. Using these specifications, the real observable risk from using the SVHC in the individual company is determined. This is the basis for evaluating the indirect costs from the use scenario.
4. For the socio-economic assessment, both operating parameters and parameters in the supply chains are used.
5. The applicant commits itself and the companies supplied by the applicant, regularly to document compliance with the boundary conditions defined in this application, even during the review period. This relates first, of course, to the risk level that must be adhered to and the minimum socio-economic requirements. It is also obligatory continuously to document the active development of measures for further minimising the risk and the substitution options. If the applicant receives the necessary authorisations, these obligations will become part of the General Terms of Delivery.

Context of the full application

for the

Use of chromium trioxide in solid form and in aqueous solution of any composition to modify the properties of surfaces made of metal or plastic, with or without current flow, at a maximum risk level of 2:100

The applicant defines conditions that a downstream user must fulfil in order to make use of the present authorisation and to be supplied on this basis. The applicant places particular value on a level playing field. Furthermore, it wishes to provide documented evidence itself that the downstream users comply with the framework conditions required for the authorisation. There should not be sole reliance on national implementation.
The risk assessment of the Chemical Safety Report (CSR) is broken down into two parts:

1. Presentation of the standard technical equipment of the downstream user companies assessed that carry out the use on their site. It also contains a description of the contributing exposure scenarios and the risk minimisation measures. It also contains statements on the company organisation and its impact on the risk situation.
2. The real operational risk is quantified in three ways in order to evaluate the plausibility of the results by means of a comparison:
    a. assessment of the real risk impact using numbers of official cases (using Germany as an example);
    b. evaluation using a WHO meta-study;
    c. evaluation using the ECHA-defined dose-response relationship for chromium trioxide.

The following key results were found:

- In recent decades, the technical equipment of companies has changed a great deal because of automation and risk management; modified company organisation resulted in a great reduction in the routine exposure period of workers.
- Examples of real measurements in companies in the past few years corroborate the low exposure concentrations and the steady reduction thereof as a result of continuing implementation of risk minimisation measures.
- Similar technical equipment may result in considerably different exposure doses, depending on the production spectrum, which makes it necessary to cap the maximum risk for the application.
- All three of the above ways of describing risk yield comparable quantitative levels of risk depending on the dose.
- To compare different risk scenarios quantitatively, the term ‘statistical first case limit’ was introduced; it describes the maximum number of exposed workers, which in 50 years of operation, has not yet resulted in a statistically expected first case of illness in the company.
- The statistical first case limit in the present case of a maximum risk of 2:100 is at least 40; i.e. only at a number of more than 40 exposed workers would a first case of illness be statistically expected within 50 years of operation.
- As downstream users of the use assessed are generally SMEs or smaller, specialised divisions of larger companies, this statistical first case limit is often far above the reality;

there are usually 1–20 exposed workers. As a logical consequence, it must be assumed under the given conditions that no case of illness must be expected during more than 100 operating years.

- As a logical consequence, further risk minimisation measures beyond the defined risk maximum or the reduction in the use as a result of non-issued authorisations under the given conditions of this application, may not lead to a measurable result or a detectable improvement in the risk situation and are therefore not useful.

When assessing other (parallel) technologies as alternatives to the requested use, the following was found:

- the use of the aqueous solution of chromium trioxide is a technology that has been used for a long time. As a result of extensive experience, its use is closely linked to the function of the finished product and therefore the finished product itself.
- Consequently, when chromium plating, it is not technically possible in most cases to separate the coating and the finished product by implementing a new technology and produce a final coating other than the metallic chromium coating.
- This similarly applies to the use of chromium trioxide to treat materials by means of electropolishing, passivating, anodising or other technologies. The physicochemical properties of the aqueous solution of chromium trioxide were used, for example, to develop materials or material compositions, the treatment or conditioning of which as an overall system is harmonised.
- The overall system, in addition to production, also includes the properties during the use such as cleaning or repair or reconditioning of worn or damaged components.
- The parallel technologies being assessed have already been used for a long period of time (20–30 years) and have secured a market share. They are growing in line with the requirements of the market and the required functions, however, they have not yet been able to replace metal coatings, especially chromium plating because the properties are not identical.
- It is therefore not expected that the methods currently being discussed can replace both metal chromium plating with the necessary accompanying applications and the methods to treat materials in production and use (without forfeiting suitability and quality). In particular, safety properties of the product cannot conceivably be achieved or replaced by treating the surface with chromium trioxide. Nor can the risks of the various alternative methods be assessed as being lower overall.
- A parallel technology should only therefore be considered if this technology can adequately reproduce the properties required by the user (at least 90% of the levels achieved by the chromium coating is considered plausible.), both in terms of physical attainability and the physical values. This is also influenced by economic constraints.
- As a result of the data available in the literature, the risk potential of the applications is assessed as being comparable for all technologies.
- Overall it should be stressed that the available information on the parallel technologies being discussed does not permit a transparent and clear assessment in all matters. In the majority of cases, replacement with parallel technologies would be high risk in terms of actual feasibility.

The core findings of the socio-economic analysis (SEA) are expressed in the following:

- The requested use with its diverse applications is mainly used by specialist companies that perform a small step in extensive and numerous supply chains.
- As the analysis of alternatives does not yield any comprehensive alternatives, the non-use scenario would be synonymous with the loss of the company in its previous form.
- The socio-economic disadvantages of the non-use scenario for society consist of three components:
    - loss of profit to date = loss of taxable income for the whole community (time limited);
    - loss of turnover to date = necessary subsistence of the affected former employees by the whole community (time limited);
    - loss of ‘added value’ to the value-added chain in its form to date = decreased added value of the finished products (permanent).
- The welfare costs of the use scenario were calculated based on the ECHA-defined dose-response relationship; the assumed average costs of an illness represent the worst case scenario as the absolute amount could not be made plausible and therefore had to be set lower.
- The maximum risk level of 2:100 assumed in this application gives a ratio of at least 1:30 of welfare costs to socio-economic benefit. The annual welfare costs per worker do not even exceed the value of EUR 750 even in the most unfavourable conditions.
- With minimal socio-economic advantages and maximum welfare costs of the use scenario and assuming a maximum risk level, the socio-economic advantages of the use scenario significantly exceed the disadvantages.

Summary of the AoA

State of technology development for the use of chromium trioxide in the surface-finishing industry

1. The use of the aqueous solution of chromium trioxide is a technology that has been used for a long time. As a result of extensive experience, its application is closely linked to the function of the finished product and therefore the finished product itself.

   Consequently, in most cases when chromium plating, it is not technically possible to separate the coating and the finished product by implementing a new technology and produce a final coating other than the metallic chromium coating.

   This similarly applies to the use of chromium trioxide to treat materials by means of electropolishing, passivating, anodising or other technologies. The physicochemical properties of the aqueous solution of chromium trioxide were used, for example, to develop materials or material compositions, the treatment or conditioning of which as an overall system is harmonised.

   It must be stressed that no application discussed in this dossier results in chromium (VI) compounds remaining on the surface of the treated product.

   The overall system, in addition to production, also includes the properties during the use such as cleaning or repair or reconditioning of worn or damaged components.
2. The parallel technologies being assessed have already been used for a long period of time (20–30 years) and have secured a market share. They are growing in line with the requirements of the market and the required functions, however, they have not yet been able to replace metal coatings, especially chromium plating because the properties are not identical.

   It is therefore not expected that the methods currently being discussed can replace both metal chromium plating with the necessary accompanying applications and the methods to treat materials in production and use (without forfeiting suitability and quality). In particular, safety properties of the product by treating the surface with chromium trioxide cannot conceivably be achieved or replaced by the alternative methods. Nor can the risks of the various alternative methods be assessed as being lower overall.
3. A parallel technology should only therefore be considered if this technology can adequately reproduce the properties required by the user (at least 90% of the levels achieved by the chromium coating is considered plausible.), both in terms of physical attainability and the physical values. This is also influenced by economic constraints.
4. As a result of the data available in the literature, the risk potential of the applications is assessed as being comparable for all technologies.

   Overall it should be stressed that the available information on the parallel technologies being discussed does not permit a transparent and clear assessment in all matters. In the majority of cases, replacement with parallel technologies would be high risk in terms of actual feasibility.

Content and objective of this dossier

6. The analysis performed relates to an application typically used by a contract company – chromium trioxide in aqueous solutions, so-called electrolytes.

   It is therefore related to an application and not a product. The resulting procedure therefore refers to the use of the aqueous solution of chromium trioxide and presents the various applications as sub-categories.

   In presenting the alternatives, therefore, the purpose of this dossier is not to list the alternatives encyclopaedically in their entirety and detail. The challenge is in presenting a basis for decisions on their use in future applications and developments.

7. The assessed use is the use of chromium trioxide in aqueous solutions. The business model of the company that modifies surfaces is based on the diverse possibilities of surface treatment using chromium trioxide in solution.
8. The aim of the analysis is to identify the possibilities that a surface-finishing company and its customers may have to use another technology, and to evaluate and achieve its implementation (economic feasibility, cost-effectiveness and risk potential).
9. The surface-modification company itself has no possibility of reducing the risk by independently changing the technology because it would thereby have to give up providing its service as part of various supply chains.

   However, it is possible for the company to optimise its own plant with a view to minimising a potential risk.
10. For surface-modification companies, most of the parallel technologies that are being assessed and considered are still at the development stage.
11. Every kind of conceivable substitution of chromium trioxide-based uses needs to first be evaluated on this basis of the current situation. If the same or similar circumstances or risks are established, this solution should be rejected.
12. In principle, new technologies are not anticipated because previously developed methods have been established on the market for a long time as parallel technologies in specialist fields.

1 Summary/procedure

1.1 Baseline

As with all parts of this application for authorisation, the analysis of possible alternatives must be assessed in relation to individual companies. This means that first, the types of companies need to be differentiated and how they can identify and implement alternatives.

Consequently, the different technologies are not treated as mutually exclusive alternatives but as technologies that comply with different requirements in parallel to each other. For this reason the alternatives are also described in the following as ‘parallel technologies’.

The requirements are described as precisely as possible using the necessary physical parameters and their significance assigned on a scale of 1–100. By directly comparing the relevant parameters in a comparative diagram, it is possible to compare the possible uses of the technologies. In this analysis this is achieved by using a network chart.

The electroplating companies that use electrolytes containing chromium trioxide can be differentiated in general by the type of product spectrum for the application of electrolytes that contain aqueous chromium trioxide.

1. Contract coaters/users (1:n type, see also CSR)

   The contract company needs to keep in stock and be able to provide the entire range of aqueous solutions of chromium trioxide at all times. This is the basis of its business model.

   Its field of activities can be described as follows:

   - No defined components; high fluctuation in the range of components in terms of quantity and time.
   - In principle, any requirement is provided for in the range of services.
   - Often there is no precise specification, instead the customer orders according to ‘the known properties’.
   - Often they deal with low numbers of individual units; this possibility is a particular market advantage of the contract company.
   - They process single orders, sporadic repeat orders and series of differing length and scope.
   - Rarely they deal with framework agreements; virtually no long-term contractual customer relationships.
   - Generally, or in the majority of cases they process third-party components supplied by the customer. Consequently, the surface-modifying company has no influence on the development, design, construction or specification of the surface (processing).

2. Specialist coaters/users (1:1 type, see also CSR)

   The specialist company works long term on a predominantly small range of components. They can focus on the profile of characteristics of the specific part, created by the relevant parameters and specifically study the applicability of the parallel technologies.

   The components being treated may be produced by the company itself or supplied as third-party components by the customer or production partner.

   Generally, work is performed to the precise specification of the repeat customer(s).

Consequently, it is necessary to present a summary of the properties to illustrate the companies’ capability. This also serves as a general plausibility check of the fundamental interrelationships.

These considerations apply to the overwhelming majority of companies. Specific considerations are only necessary in exceptional cases.

The examples presented illustrate the current situation of the companies. They also provide concrete indications of the operational feasibility of deviating technical solutions in terms of the CURRENT situation.

The analysis performed relates to the typically used applications of electrolytes that contain chromium trioxide as used by a contract company that provides surface engineering services. This is described in summary as

'Use of chromium trioxide in solid form and in aqueous solution of any composition to modify the properties of surfaces made of metal or plastic, with or without current.'

It is therefore related to an application and not a product.

(For more detailed explanations see the CSR.)

The following video provides an introduction to the method:

https://www.youtube.com/watch?v=CYwYjjvX7e4&feature=share

(Electroplated coatings: sustainable & efficient! – Fraunhofer IPA)

1.2 Fundamental consideration of the potential alternatives

Combining the alternatives is based on the available data in the literature.

This data is combined with information provided by the contract and specialist company/user, and summarised by the applicant.

Several fundamental perspectives of the discussion in the literature should be highlighted that are key to an assessment.

1. When studying the topics discussed in the literature it should be noted that no alternative substances are discussed for applying surfaces that contain chromium. Only methods using Cr(III) electrolytes are discussed as alternative substances.
2. As a result, it is essentially technologies that are compared. In many reviews, it is generally assumed that there is a potential risk from the Cr(VI) compounds, whereas when discussing the alternatives, a low to minor or even negligible risk is frequently assumed. However, the real risk is often unknown.

   An analysis from 2006 emphasises this /1/:

   'The alternatives were prioritized using environmental health and safety, performance and the availability of information as the primary criteria. Cost may not be an important factor in evaluating hexavalent chromium alternatives since its severe toxicity is driving many manufacturers to adopt alternatives. For example, it is likely that the new PEL will be very difficult for many manufacturers to meet using traditional engineering controls such as local exhaust ventilation. In addition, EU directives are driving manufacturers to find hexavalent chromium-free alternatives.'
3. Risk assessments of potential alternatives are only performed once the technology is introduced on the market.
4. The consideration of fundamental changes to the finished product as a result of design or changing the material is not considered because this cannot be performed by the companies that apply surface finishes to products that are developed and defined by the customer, and especially not if a surface processor is involved in multiple or even many different supply chains.

As a logical consequence, substances that are subject to the same regulations as the assessed substance (CrO_3) or have a high risk to human health and/or the environment, cannot be used as alternatives.

It is essential that the above-specified points are considered when evaluating the alternatives to firstly avoid risk reductions that companies have achieved in the past few years being reversed by introducing alternatives with risks that have not been addressed, and secondly, to avoid cascading authorisations.

1.3 Structure of the analysis

The analysis does not consider specific products or applications. All discussions relate to the product or application of companies that perform ‘surface treatment using electrolytes containing aqueous chromium trioxide’ and therefore describe the typical situation of a small to medium-sized contract or specialist company.

Principle

- ➔ The principle is to assign an application to a parameter field which is selected from a combination of typical functional requirements that need to be fulfilled by the components processed using this application.
- ➔ The requirements were compiled both from the literature and from consultations with users.
- ➔ The alternatives being discussed are compared on the basis of the resulting requirement matrix with the application ‘surface treatment with solutions containing aqueous chromium trioxide’ and in this way the technical feasibility is assessed.
- ➔ The assessment is not performed with detailed values but uses the significance of the typical functional requirements.
- ➔ Literature data is sorted in the relevant function matrix to make the comparison as complete as possible.
- ➔ To illustrate the potential hazards, reference is made as far as possible to statements from key studies because it is not possible to perform our own analysis of the multitude of potential parallel technologies.
- ➔ As a result of the very large number of both scientific publications and commercial product data sheets and purely marketing publications, only key review studies by neutral institutions are consulted in the comparison.

1.4 Discussion of the market developments of surface-treatment methods

Various surface-treatment methods and their market share shall be briefly presented to assess the use. The objective is to use this data to illustrate that the parallel technologies discussed in the field of surface treatment as alternatives for the use of chromium trioxide have already been successfully employed for a long time and the methods have not replaced surface treatment with chromium trioxide. At the same time, the technologies for treating surfaces with chromium trioxide continue to be required by the market and can report a growth, similarly to the other technologies.

In 2014 the distribution of turnover was as follows /2/:

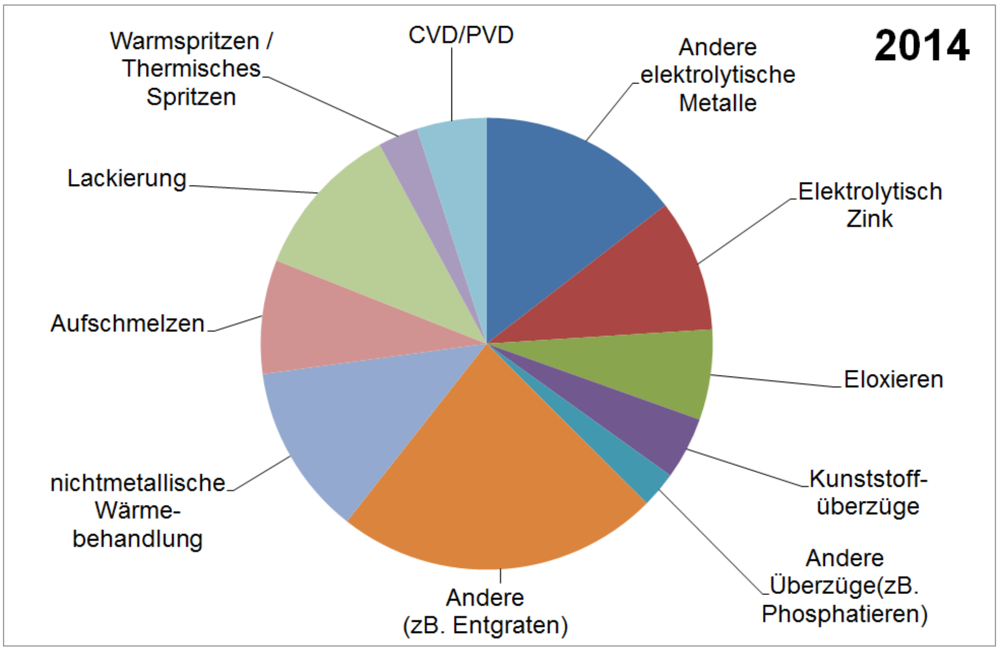

Figure 1: distribution of turnover between surface-engineering technologies 2014

CVD/PVD	CVD/PVD
Andere elektrolytische Metalle	Other electrolytic metals
Elektrolytisch Zink	Electrolytic zinc
Eloxieren	Anodisation
Kunststoffüberzüge	Plastic coatings
Andere Überzüge (zB. Phosphatieren)	Other coatings (e.g. phosphating)
Andere (zB. Entgraten)	Other (e.g. deburring)
nichtmetallische Wärme-behandlung	Non-metallic heat treatment
Aufschmelzen	Fusing
Lackierung	Painting
Warmspritzen / Thermisches Spritzen	Flame spraying/thermal spraying

The applications being assessed of the aqueous solutions of chromium trioxide for surface modification are classified under 'other electrolytic metals'. This group comprises, for example, nickel, copper, chromium coatings, gold plating, silver plating, platinising by means of electrolysis and chemical processes.

Based on surveys in the electroplating industry (chemical suppliers and coatings), the distribution presented in the following can be assumed in this group.

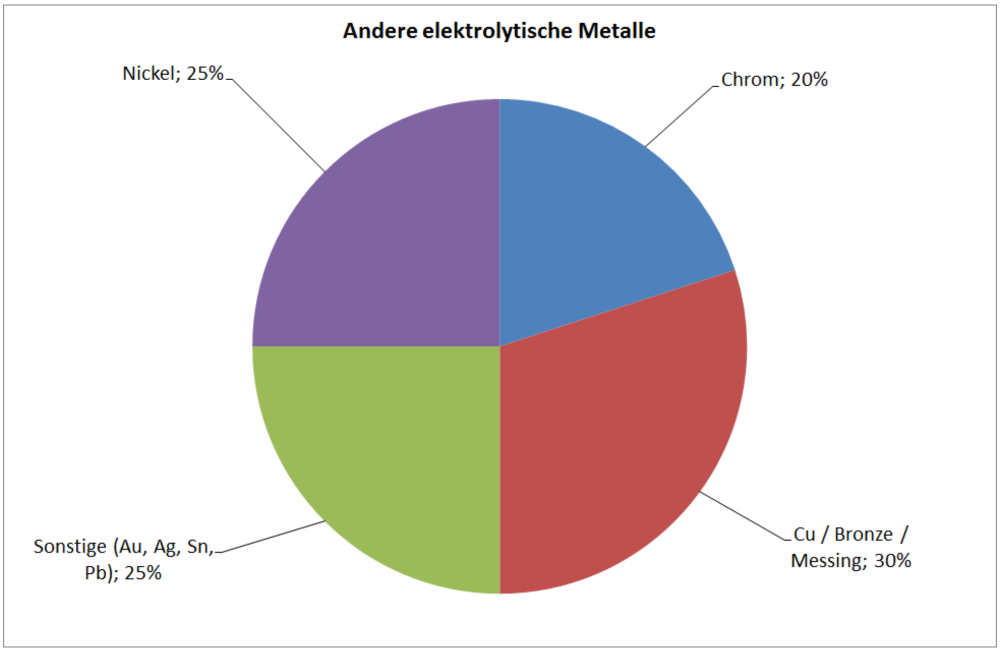

Figure 2: distribution of turnover for the group 'other electrolytic metals' 2014

Andere elektrolytische Metalle	**Other electrolytic metals**
Chrom	Chrome
Cu / Bronze / Messing	Cu/bronze/brass
Sonstige (Au, Ag, Sn, Pb)	Other (Au, Ag, Sn, Pb)
Nickel	Nickel

The following chart shows furthermore the development of turnover from 2011 to 2014 for various surface-treatment methods, i.e. where there is intensive discussion on the topic of alternative technologies:

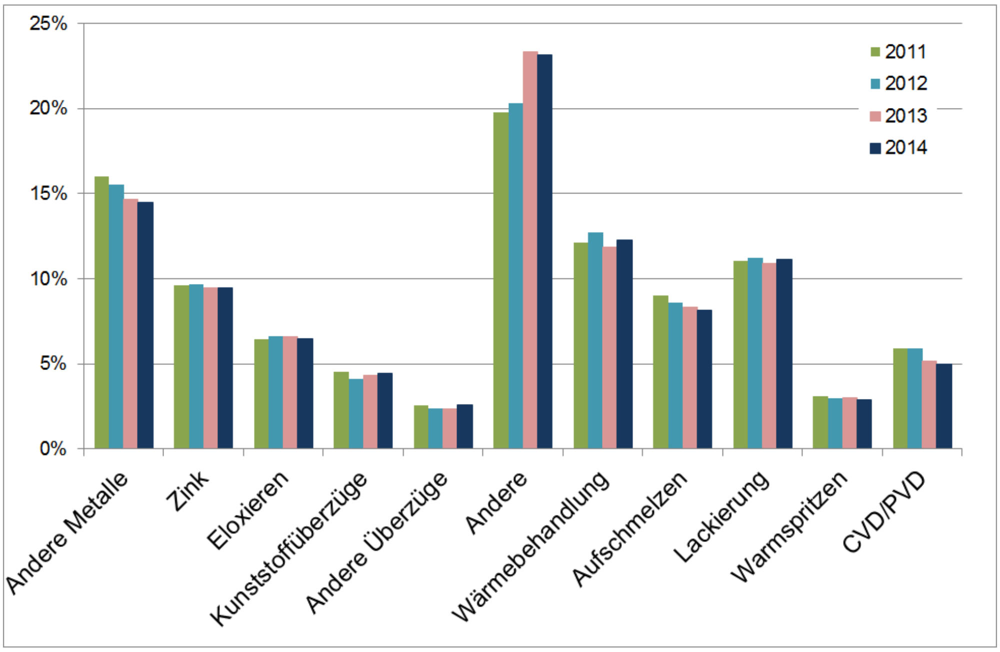

Figure 3: share of turnover of surface-engineering technologies 2011–2014

Andere Metalle	Other metals
Zink	Zinc
Eloxieren	Anodisation
Kunststoffüberzüge	Plastic coatings
Andere Überzüge	Other coatings
Andere	Other
Wärmebehandlung	Heat treatment
Aufschmelzen	Fusing
Lackierung	Painting
Warmspritzen	Flame spraying
CVD/PVD	CVD/PVD

The following figure shows the division of the group of ‘other electrolytic metals’:

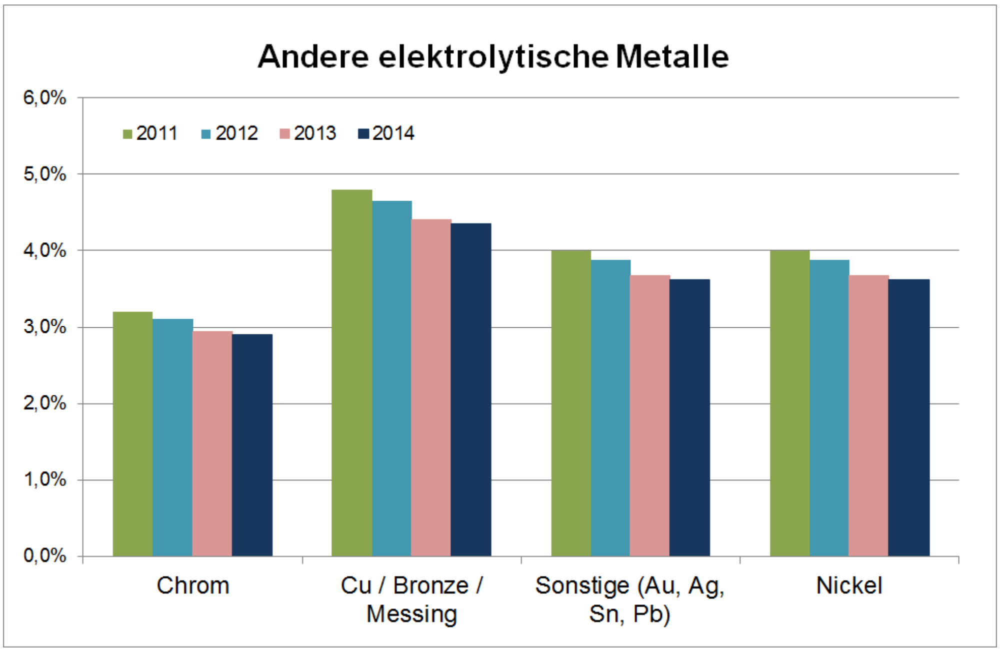

Figure 4: turnover share of the group ‘other electrolytic metals’ 2011 to 2014

Andere elektrolytische Metalle	**Other electrolytic metals**
Chrom	Chrome
Cu / Bronze / Messing	Cu/bronze/brass
Sonstige (Au, Ag, Sn, Pb)	Other (Au, Ag, Sn, Pb)
Nickel	Nickel

The total turnover was EUR 6.5 billion in 2011 and EUR 7.1 billion in 2014.

The proportion of chromium plating (~3%) was thus EUR 208 million (2011) and EUR 206 million (2014). The demand for chromium plating has therefore remained virtually consistent.

It is also observed that the total turnover of the surface-engineering industry increased between 2004 and 2014 from EUR 4.4 billion to EUR 7.1 billion, which demonstrates the importance of the entire industry.

According to the figures of the German Federal Statistical Office, this growth is distributed as follows:

	2004	**2014**	**Increase**
Total	**EUR 4 401 m**	**EUR 7 114 m**	**62%**
Other electrolytic metals	**EUR 721 m**	**EUR 1 032 m**	**43%**
Chromium (20%)	*EUR 144 m*	*EUR 206 m*	
Cu/bronze/brass (30%)	*EUR 216 m*	*EUR 309 m*	
Other (Au, Ag, Sn, Pb, etc.) (25 %)	*EUR 180 m*	*EUR 258 m*	
Nickel (25%)	*EUR 180 m*	*EUR 258 m*	

Electrolytic zinc	EUR 512 m	EUR 675 m	32%
Anodisation	EUR 318 m	EUR 460 m	45%
Plastic coatings	EUR 149 m	EUR 317 m	114%
Other coatings (e.g. phosphating)	EUR 102 m	EUR 182 m	79%
Other (e.g. deburring)	EUR 885 m	EUR 1 645 m	86%
Non-metallic heat treatment	EUR 551 m	EUR 872 m	58%
Fusing	EUR 380 m	EUR 580 m	53%
Painting	EUR 479 m	EUR 792 m	65%
Flame spraying/thermal spraying	EUR 106 m	EUR 205 m	92%
CVD/PVD	EUR 198 m	EUR 354 m	79%

Table 1: development of turnover of surface-engineering technologies between 2004 and 2014

Unfortunately no information is available on the distribution of metals processed using CVD/PVD. However, it is expected that because of the highly comprehensive manufacture of headlight reflectors and of photovoltaic systems, the proportion of aluminium is dominant.

It should also be noted that the total surface technology turnover specified in the table has been generated by a total of 1 074 recorded companies (2004) or 1 314 (2014). This equates to 32 chromium-plating companies recorded (2004) and 39 (2014).

An analysis by the electroplating industry association *Zentralverband Oberflächentechnik* ZVO /3/ [Central association for surface technology] in a survey in 2006 established a figure of approximately 2 000 companies for electroplating alone. This means that the number of recorded companies is too low. It needs to be supplemented with the large number of contract electroplating plants and to a lesser extent with in-house electroplating plants, which in many cases are medium-sized workshops that often have fewer than 20 employees /4/. However, their number is not currently recorded statistically and needs to be estimated. A comparison of the proportion of electroplating technology of 30% of the recorded companies for 2004 gives a number of just 300 recorded companies. It may therefore be assumed that the number of recorded companies is too low by a factor of 8-10.

Despite these statistical inaccuracies we can make the following statements:

1. The proportion of recorded chromium plating of the total turnover of the surface-engineering industry is about 3%. In the field of ‘other electrolytic metals’ this is about 20%.
2. Based on the industry structure and based on the dominance of electroplating by small businesses, we can assume at least a doubling of the quoted shares for chromium plating.
3. Chromium plating has retained its market share between 2011 and 2014. Between 2004 and 2014 the share increased by about 43%.
4. The proportion of recorded chromium plating is comparable to the proportion of thermal spraying, which emphasises the importance of both processes as complementary technologies.

5. If we assume a doubling of the proportion of chromium plating based on the industry structure, then the proportion of chromium plating is approximately comparable to the sum of the proportions of the technologies PVD/CVD (~ 5%) and thermal spraying (~3%).
6. Chromium plating has not been displaced by alternative technologies.

Summary
The alternatives being assessed have already been used for a long period of time (20-30 years) and have secured their market shares. They are growing in line with the requirements of the market and the required functions, however, they have not yet been able to replace metal coatings, especially chromium plating.
It is therefore not expected that the methods being discussed at present will replace metallic chromium plating and the necessary accompanying applications.

1.5 Fundamental criteria for analysis and assessment

1. An alternative that is being considered for possible implementation in a company must fulfil the following criteria:
   - Availability, particularly the accessibility of information on relevant data such as attainable functions, environmental data, exposure scenarios, risk potential, cost, process reliability need to be comparable with the method used.
   - Evidence of market viability and market acceptance.
   - Approval by customers and the authorities.
   - Guarantee to achieve the required functionalities.
   - The risk of the method is lower than that for the employed chromium trioxide-based methods. Risks that are estimated to be comparable or even higher shall exclude the method.

     If this data is not available, this must not result in this issue being disregarded. Without being able to evaluate the data, switching to an alternative technology cannot be justified economically nor in terms of the risk.
   - Meaningful long-term results or field trials.

2. This excludes the following alternatives (or at least regards them as being impractical at present):
   - Technologies that have only been available for a short time and the results of which are not supported by field trials.
   - Technologies that are only available on a laboratory scale.
   - Technologies that have not yet shown their process reliability under real conditions.
   - Technologies that do not fulfil customer requirements or the requirements of relevant standards and norms.
   - Technologies that do not yet have any customer or official approval.
   - Technologies that use substances that are discussed as being SVHC substances or that are acutely toxic, such as cyanides. The latter case in particular does not enable the companies to weigh up the benefits or risks.

1.5.1 Exclusion criteria that are not based on the properties of the assessed substances

Each criterion should be discussed as part of the overall process. In the modern, metallic surface-finishing industry, a mix of various substances and process steps are used to achieve the required functionalities.

1. Necessary conditions in terms of the intrinsic substance properties
    a. The potential alternative does not use any substance that is listed in Annex XV or that is being discussed for inclusion in Annex XIV.
    b. The potential alternative does not use any acutely toxic substances, as a result of which workers would be exposed to a potentially higher or comparable or simply other type of risk than in the given exposure situation. This also relates to substances that need or would need increased monitoring.
    c. The potential alternative does not increase the expenditure to treat the waste water or produce any additional environmentally damaging substances during the waste treatment. Objectively weighing up the benefits in this way would be virtually impossible.
    d. The potential alternative is or will be according to current knowledge, approved by the competent national and/or European authorities and does not require any additional regulatory expenditure as a result of additional water legislation, for instance.

2. Necessary conditions in terms of technical feasibility
    a. The potential alternative has demonstrated its applicability in daily production or in meaningful field trials.
    b. The potential alternative guarantees the same functionalities that are ensured by the current process. This must also ensure that scrap is not increased in the life cycle of the end product, i.e. the working life and durability of the components is comparable with the current situation. Values of 90% of the present situation are assumed to be a plausible basis to be able to present an alternative.

3. Necessary conditions in terms of the availability of information and therefore the assessment capability/comparability:
    a. The potential alternative is available and not restricted in terms of availability by factors such as patent law. As a real alternative, an implementation phase that proceeds without delay and has the standard adaptation measures and times, must be possible without any doubt.
    b. The dose-response relationship is known and clearly recognised by the regulators (European and national).
    c. All data is publicly available. Potential alternatives, for which the distributors and suppliers cannot or do not wish to provide the necessary assessment data, are not suitable for real implementation.
    d. The potential alternative methods need to present their safety and performance in the same way as the chromium trioxide-based methods; in a manner that is public and can be verified and reproduced.
    e. Considerations relating to resource preservation, CO_2 footprint or life cycle analyses must also be used and be able to be evaluated, as this is required by the use of electrolytes containing chromium trioxide.

4. Necessary conditions in terms of economic feasibility:
    a. The alternative is technically possible for the applicant based on their training/technical skills, and can be used reliably in production.
    b. The introduction of the potential alternative does not incur disproportionately increased costs. Alternatively it must be ensured that customers accept the higher prices and have no possibility to switch to a cheaper process, for example from non-EU countries.
    c. Specialist staff must be available for the potential alternative, previous staff must be interchangeable without additional costs.

d. The process of customer approval of the potential alternatives must be able to be completed promptly and be cost neutral.
e. Dismantling the existing plants including auxiliary units (e.g. waste water plants, exhaust ventilation, etc.) must be possible in a prompt and cost-neutral manner.
f. The space required for the potential alternative must not significantly exceed that of the established applications.

Summary

Every kind of conceivable substitution of chromium trioxide must be analysed and assessed under the conditions presented in points 1 to 4.

1.5.2 Assessment of the relationship between the scientific basis, marketing and reliable process implementation

The available information must be meaningful. In this case, the discussions in the literature cannot be clearly assigned.

The following publications are available and can be consulted:

- Fundamental publications on laboratory experiments /29/:

  Statements on production implementation are scarcely possible, therefore neither is it possible to draw conclusions on suitability as alternatives.
- Marketing /23/

  Presents possible positive properties in the run-up to the market launch. No objective consideration is desired or intended.

  As it frequently relates to commercially relevant expertise, the performance and capability of the possible alternatives cannot be checked or reproduced.
- Patent searches:

  Qualification can only be evaluated to a limited extent as generally only the first studies or ideas are published. Statements on efficiency, costs or additional requirements (e.g. safety measures, hazard potential and level, disposal, etc.) are not typically included.
- Synthesis studies

  These generally consist of the results discussed in the literature. They may be used as an initial source of information, however, they do not enable the applicability to be assessed. Frequently, the presented results cannot generally be used.

Summary

The above-mentioned sources can therefore only provide indications of conceivable alternatives. All publications should always be checked for their objective and tested under practical implementation conditions. They therefore require very critical assessment.

Sound evidence of technical and economic feasibility can only be obtained from reliable production (implementation) and product use in the field or in series application.

As a contract coater or service provider to the surface-processing industry needs to provide guarantees or take into account potential claims of recourse to global product recalls, clear, meaningful and reliable information is needed for their survival.

1.6 Summary of the alternatives being considered

The assessment of the potential alternatives for the use of chromium trioxide compounds to modify surface properties is only possible to a limited extent because it is not the substance that is being discussed but the technical process to produce a surface with defined properties and the created product.

It is recalled that changing the product in design or material use is exclusive to the part producer and cannot be the subject of this analysis.

Consequently there are only the following alternative possibilities:

1. **Replacing the Cr(VI) electrolytes with Cr(III) electrolytes (substance and therefore process change).**
2. **Transition to another technology, thereby process and modification of the surface change.**
3. **No change to the substance or process, instead increased risk minimisation measures (RMO), optimisation.**

An overall property is assessed in the discussion, both of the process and of the created finished product.

Chromium trioxide is only used as a starting substance, it is not found on the processed product. Consequently the assessment of the alternatives needs to deal with the properties of the surface of the component modified by using chromium trioxide.

It must be stressed that no application discussed in the following causes chromium (VI) compounds to remain on the surface of the treated product.

1.6.1 Substance-specific alternatives

Fundamental studies have already been performed for many years by research institutes and chemical suppliers.

For the most part the developments are conducted without the collaboration of the contract company or without its involvement.

In the given case the only substance alternative for the chromium plating applications is Cr(III) salts as only these compounds would theoretically generate metallic chromium layers. For the use of chromium trioxide to treat the surface without applying a chromium layer, pickling or oxidising substances are considered.

However, for hard chromium plating, it is consistent in the literature that no Cr(III) method is available as yet or even known to be promising. Results from laboratory experiments show that under laboratory conditions, comparable coating properties can be achieved on level surfaces /14, 29/. However, under application conditions these cannot be reliably achieved in production and do not easily apply to all component geometries.

Other methods are discussed for the further applications of electrolytes that contain chromium trioxide, however these methods only partly achieve the specific conditions of using electrolytes that contain chromium trioxide. Methods that are reliable in production could only be developed in individual cases despite in-depth studies /1, 9/ and are already used in some cases, for instance in treating components by means of electropolishing or anodising.

At the same time, the necessary holistic assessment requires assurance that, as for the Cr(III)-based processes, the additionally required substances for the alternatives are available long term, at least for the amortisation period of the associated production plant. This means that there is no risk of a ban on the use and there is no risk to the availability on the market.

Consequently, the processes discussed at present for the use of electrolytes containing Cr(III) are based on a boric acid system. As boric acid is listed in Annex XV and is currently being prepared for inclusion in Annex XIV, the assessment of the Cr(III)-based method is essentially void or will soon need to be re-registered, which could result in a subsequent rejection of the potentially accepted Cr(III)-based method in the Cr(VI) context. Even if boric acid is not included in Annex XIV at the time of this application for authorisation (2015), the user must assume that this is possible at a later date and therefore there is no production or investment security. A technical reorganisation of companies and workers could also become invalid as rapidly.

1.6.2 Property-specific alternatives – parallel technologies

It is not possible for companies that provide electrolytic surface modification to change by introducing a parallel technology because the physical fundamentals differ. A contract company only has the option of entirely restructuring its business. It is not generally possible to adapt the existing technical installations or integrate the new technology in the existing production process. This also applies to alternative methods based on electroplating such as the use of Cr(III) electrolytes for coating or even other surface processing methods because the chemical properties differ greatly in production and particularly in waste water treatment.

In the case of chromium plating, all the coating methods are specified here that potentially fulfil part of the requirements made on a metallic chromium coating by the customer equally well or better.

The most frequently investigated methods are thermal spraying and PVD/CVD methods. Under specific conditions (aviation, space travel, military sector), properties that are comparable to hard chromium plating could be achieved for specific components.

It is consistently recommended in the literature not to discuss methods that use critical substances. This relates to compounds including nickel, tungsten and boron compounds.

As a logical consequence, the high-risk substances that are generated during the process of surface finishing must also cause an alternative process to be rejected, for example the formation of chromates during HVOF coating using chromium-based particles.

At the same time, it must be ensured that the substances that are potentially required for the alternative are available in the long term (no risk of a prohibition on use, no risk in supply, etc.).

Typically, the following methods are referred to frequently /1/:

- coating with nickel or nickel compounds
- other electrolytic coatings
- electroplating of nanocrystalline coatings
- methods using thermal spraying
- welding methods, also metal arc welding
- heat treatment; plasma nitriding
- laser methods
- vapour deposition/sputtering (PVD).
- chemical vapour deposition (CVD)

The following methods are only discussed to a limited extent:

- nickel-based methods as a result of environmental, health and safety criteria because nickel and nickel compounds are classified as critical in terms of carcinogenicity by IARC (International Agency for Research on Cancer) /5/.

Based on this discussion, in this paper the following will only be discussed to a limited extent:

- Acutely toxic substances must be avoided throughout the entire company. If these kind of substances are used in individual cases, these will be assessed.

  In the event of a combination, the higher risk substance will always be used as the criterion.

- If critical substances are used in the alternative process (for example boric acid when using the Cr(III) electrolytes).

1.6.3 Assessing the viability of the alternative

In this analysis, assessment is primarily based on the comparability of functions and the surface/coating or component properties that can be generated.

As information should generally be available for functional (hard) chromium plating, the basic procedures using this application will be used for illustration:

1. **Functionality: comparison of (functional) chromium plating vs thermal spraying**

   The following figure presents the illustrative comparison of the properties being generated at present by the chromium coatings produced by using electrolytes containing chromium trioxide, and WC/Co coatings produced by thermal spraying.

   The WC/Co coatings (red) are compared with the required properties of chromium coatings (blue).

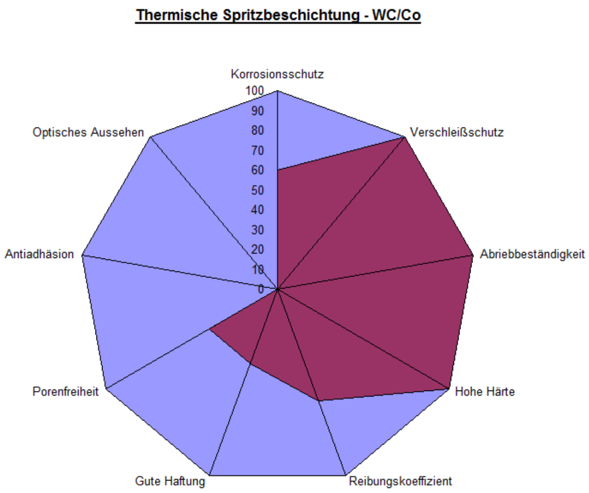

Figure 5: illustration of the procedures in this dossier

Thermische Spritzbeschichtung - WC/Co	Thermal spray coating – WC/Co
Korrosionsschutz	Corrosion protection
Verschleißschutz	Wear protection
Abriebbeständigkeit	Abrasion resistance
Hohe Härte	High degree of hardness
Reibungskoeffizient	Friction coefficient
Gute Haftung	Good adhesion
Porenfreiheit	Non-porosity
Antiadhäsion	Anti-adhesion
Optisches Aussehen	Visual appearance

Assessment
An alternative should only be considered if this technology can adequately reproduce the required properties (> 90% of the levels achieved by using electrolytes containing chromium trioxide), both in terms of physical attainability and the physical values.

2. Risk assessment

In 2007, the *Deutsche Verband für Schweißen und verwandte Verfahren* [German Welding Society, DVS] together with the *Gemeinschaft Thermisches Spritzen* [German Association of Thermal Spraying, GTS] published a study on the situation of thermal spraying applications /6/ and concluded that different thermal spray coatings could replace functional chromium coatings in suitable operating sites. These different thermal spray coatings are created by using various welding materials (spray powder) and different thermal spraying methods. In the literature it is noted that substances that are hazardous to health in the starting materials for thermal spraying need to be replaced, which is unfortunately not further explained; consequently, the risk situation for the thermal spraying method cannot be assessed in detail.

C. Rupprecht in his postdoctoral thesis /7/ notes that the methods of HVOF spraying and the material systems WC/Co or WC/CoCr have essentially been evaluated as salient alternatives, in particular by the American association HCAT (Hard Chrome Alternatives Team – consisting of the US Department of Defense, the Canadian Department of National Defense and an industrial consortium of American and Canadian businesses). In this context, Rupprecht further notes that in addition to replacing functional chromium coatings with coatings based on thermal spraying, other material systems, particularly those that are suspected of triggering allergies such as Ni and Co and materials with increasing prices such as molybdenum and tungsten-based hard materials, are being discussed. Useful alternatives are, for example, iron-based alloys, however, which do not achieve the necessary performance.

In a more recent study by the U.S. Department of Defense on the application of thermal spraying in the aerospace industry /8/, it is noted that this technology also has potential hazards although these are adequately controlled:

'The principal environmental and worker safety issues associated with HVOF thermal spraying are air emissions containing overspray particles and the noise of the gun itself. All the depots that use thermal spray have the appropriate spray booths, spray equipment, air handling equipment (booth exhaust systems and dust collection bag houses), fuel supplies, and air handling equipment in place as well as the appropriate air permits to cover operation of the HVOF systems.

The equipment is installed in soundproof booths, with robot and computer-controlled spray systems. Spray booths are designed to be explosion-proof, with hydrogen detectors for hydrogen-fuelled systems. Operators do not enter the booth during spraying, and whenever they do enter the booth before or after a spray run, they are protected with a proper dust mask. This ensures that there is no operator exposure either to noise or to dust generated during spraying.'

In this way the risk assessment of thermal spraying is no different to that of functional (hard) chromium plating. Both are reported to be extensively controlled. However, there is a lack of comprehensive data for thermal spraying, which is known for the use of Cr(VI) on the actual real risk in the workplace.

This is also emphasised as a key point in the synthesis study recommended by the BAuA as a basis for discussion by Chromgrün /9/.

For the PVD/CVD field, the IZT – *Institut für Zukunftsstudien und Technologiebewertung* [Institute for Futures Studies and Technology Assessment] published a report in 2009 /10/, which is concerned with comparing the total load of PVD methods and electroplating black chromium plating in the field of thermal solar reflectors.

The risk data from the entire preceding chains for creating the coating, i.e. the manufacture of the Cr(VI) electrolytes and that of the metallic chromium for the necessary PVD target are compared.

Black chromium plating is assessed. The study concludes that even when manufacturing metallic chromium for the use of the PVD target, significant quantities of Cr(VI) are produced. It shows that the aqueous methods using Cr(VI) compounds essentially produce emissions to water whereas the use of chromate chemicals to produce metallic chromium for the use as PVD targets primarily results in air and soil emissions. It assumes pollution that is three times higher using the aqueous method.

It also shows that black chromium plating has a considerably longer service life than other methods.

Overall, this analysis demonstrates that coating with metallic chromium is not possible without Cr(VI)-based intermediate products. An assessment needs to be made that equally incorporates exposure data, service life and risk minimisation measures. For instance, in a modern chromium-plating company there are no environmental emissions to water.

Summary

It can be assumed that every parallel technology has corresponding risks which must be assumed to be essentially comparable in their impact.

Consequently, in this analysis, a comparable risk and a comparable control of the risk are always assumed. This is therefore not a relevant criterion for differentiation.

1.6.4 Risk-minimising, process-specific (alternatives) – optimisations

The primary aim is to reduce the risk of using electrolytes containing chromium trioxide. A contract coater/user can achieve this objective independently, ideally by optimising their own production process. The vast majority of contract coaters/users are demonstrably active in this area and have been successful for many years. By improving the process used, resources can be saved in addition to increasing safety.

For example, IARC (International Agency for Research on Cancer) describes a continuous reduction in exposure in Cr(VI)-processing businesses of 0.72 mg/m^3 in the 1940s to 0.27 mg/m^3 in 1957–64 and to 0.039 mg/m^3 in 1965–72 /11/. This needs to be supplemented with current values to the level of 5 µg/m^3 in 2000 and to 1 µg/m^3 in 2014 as a result of the regulation of the current TRGS 910.

As this illustration shows that there is a high potential for minimising the exposure risk by optimising the production conditions, this technical alternative is also mentioned in this paper. The measures are presented in detail in the CSR.

2 Analysis of substance function based on the substance/Analysis of Process

2.1 Use

The basis of the procedure is the

'Use of chromium trioxide in solid form and in aqueous solution of any composition to modify the properties of surfaces made of metal or plastic, with or without current.'

The various applications are defined and explained in the CSR.

1. The impact of solutions in accordance with the requested use on surfaces to deposit chromium layers, principally for technical and functional purposes.

   (Abbreviated to: 'functional chromium plating')
2. The impact of solutions in accordance with the requested use on surfaces principally for decorative and functional purposes.

   (Abbreviated to: 'decorative chromium plating')
3. The impact of solutions in accordance with the requested use on surfaces to electropolish metallic surfaces.

   (Abbreviated to: 'electropolishing')
4. The impact of solutions in accordance with the requested use on surfaces to strip any components from substrate surfaces.

   (Abbreviated to: 'stripping')
5. The impact of solutions in accordance with the requested use on surfaces for pickling plastic parts, particularly those made of ABS (acrylonitrile butadiene styrene) or PC/ABS (polycarbonate/acrylonitrile butadiene styrene).

   (Abbreviated to: 'plastics pickle')
6. The impact of solutions in accordance with the requested application on surfaces for anodising, particularly aluminium, magnesium or titanium or components coated with these metals.

   (Abbreviated to: 'anodising')
7. The impact of solutions in accordance with the requested use on surfaces for the oxidative modification of surfaces of components made of stainless steels, particularly corrosion-resistant chromium-nickel steels.

   (Abbreviated to: 'stainless steel dyes')

The background is the close interconnection of the different applications. The following figure illustrates that the applications are closely interconnected within the supply chains:

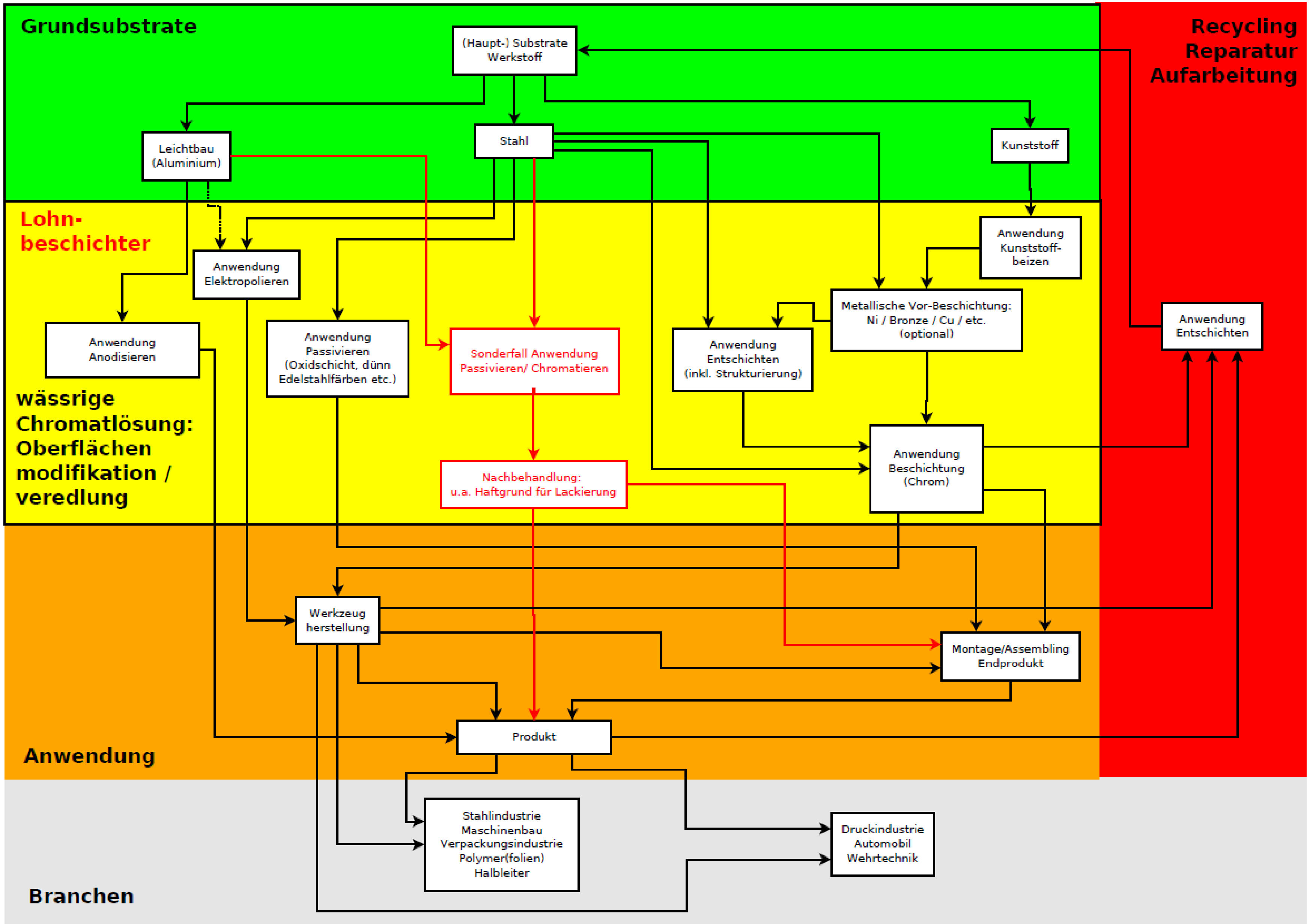

Figure 6: compounds of the different applications in the value-added or supply chain

Grundsubstrate	Basic substrates
Leichtbau (Aluminium)	Lightweight construction (aluminium)
(Haupt-) Substrate Werkstoff	(Main) substrate material
Stahl	Steel
Kunststoff	Plastic
Recycling Reparatur Aufarbeitung	Recycling Repair Reconditioning
Anwendung Entschichten	Stripping application
Lohnbeschichter	Contract coaters
Anwendung Anodisieren	Anodising application
Wässrige Chromatlösung: Oberflächen modifikation / veredlung	Aqueous chromate solution: surface modification/finishing
Anwendung Elektropolieren	Electropolishing application
Anwendung Passivieren (Oxidschicht, dünn Edelstahlfärben etc.)	Passivating application (oxide layer, thin stainless steel dyes, etc.)
Sonderfall Anwendung Passivieren / Chromatieren	Special application – passivating/chromating
Nachbehandlung: u.a. Haftgrund für Lackierung	Post treatment: including etching primer for painting
Anwendung Entschichten (inkl. Strukturierung)	Stripping application (incl. texturising)
Metallische Vor-Beschichtung: Ni / Bronze / Cu / etc. (optional)	Metallic pre-coating: Ni/bronze/Cu/etc. (optional)
Anwendung Beschichtung (Chrom)	Coating application (chromium)
Anwendung Kunststoffbeizen	Plastics pickling application
Anwendung	Application
Werkzeugherstellung	Tool manufacture
Produkt	Product
Montage/Assembling Endprodukt	Installation/assembling end product
Branchen	Industries
Stahlindustrie Maschinenbau Verpackungsindustrie Polymer(folien) Halbleiter	Steel industry Mechanical engineering Packaging industry Polymer (foils) Semi-conductors
Druckindustrie Automobil Wehrtechnik	Printing industry Automotive Defence technology

2.2 Procedure

2.2.1 Grouping the applications based on function

The analysis performed in section 1 shows that the functions required by the customer are ideally suited to illustrating the applications. The method of grouping that is frequently used, also in the literature, according to abbreviated descriptions e.g. decorative or functional, was not found to be practical because the transition is fluid and there is no clear technical differentiation criterion.

For this reason the basis is the required functions of the final created surface. For a better understanding, the applications are supplemented by the more widely known or common abbreviated descriptions.

This approach enables the reader to make reference to the groupings in the available studies that focus on comparing technologies.

The challenge lies in the diversity of the possible and required parameters that depend on the final applications or customers.

However, a contract coater or surface-finishing service provider needs to potentially implement all these properties so awareness of these and the property definition is crucial.

For this reason we decided on the following approach:

1. Definition of the overall function as precisely as possible using relevant parameters.
2. Definition of specialist functions as required by the end users or customers.
3. In accordance with the description of the approach in section x, the functions of the parallel technologies are compared with the applications of chromium trioxide described in point 2.1.
4. The data available in the literature is evaluated insofar as the specified parameters make this possible.

2.2.2 Consideration of standards, norms, certifications and approvals

The majority of applications of electrolytes containing chromium trioxide greatly influence the use of the finished product. The control and guarantee of their properties are generally of a high standard, irrespective of the applications described in section 2.1.

The applications are under continuous monitoring at an international level, for example, to ensure the conditions required for safety or for beverages and tobacco.

Many of the companies are part of value-added chains in fields in which these kinds of requirements are critical (these include aerospace, the automotive industry, the food sector and military engineering).

The following requirements in particular need to be thoroughly tested and certified:

- military and defence
- food safety
- drinking water usability
- biocompatibility (medicine)
- medical, pharmaceutical and healthcare applications
- electronic components.

2.3 Functional requirements

The desired functions are based firstly on the oxidising effect of the chromium trioxide combined with the passivating effect of the base substrate, and secondly on the supply of dissolved chromium species for electrochemical deposition.

Frequently, only chromium (VI) compounds can physically fulfil these functions in the required combination. Irrespective of other chromium salts in the case of chromium plating (e.g. Cr(III) salts, see below), no other substances can therefore fulfil this function.

Individual substances cannot therefore be considered alternatives. An entire change in technology needs to be considered.

The following fundamentally required or existing properties that are created by the described applications could be identified. It should be stressed that in the course of technical developments, new properties and functions are being continuously developed.

- Corrosion protection
- Abrasion resistance

- Wear resistance
- High degree of hardness
- Chemical resistance/temperature resistance
- Anti-adhesion
- Low friction
- Non-porosity
- Good adhesion
- Repairability
- Visual appearance/design, consistent colour quality
- Microcracking
- Shine and reflectivity
- Haptics/valence
- Tarnish protection
- Food safety
- Independence to linear pressure load/self-supporting properties
- Skin tolerance
- Modifications/storage possible
- Impermeability to gas
- Minimum tolerances
- Maximum slippage
- Magnetic barrier
- Polishability
- Thermal conductivity
- Elasticity, roll-over capacity
- Targeted degree of gloss, e.g. high-shine mirror finish by achieving extremely low surface roughness
- Good ductility
- High resistance to gas erosion
- High density, no foreign substances
- Roughness adjustment using mechanical blasting
- Low tendency to ‘seize’ compared with metal rubbing partners
- Scalability to any level

Chromium trioxide and the chromates derived from this are chemically simple to handle. Consequently, mixing, monitoring, disposal and waste water treatment can be reliably achieved using simple process technology.

This contributes to the extraordinarily good price-performance ratio that is greatly valued by customers and processors alike.

In addition, the finished part contains no substance containing Cr(VI), which greatly simplifies transportation and distribution. Consequently, there is no risk to the (end) user from surfaces that have been treated with chromium trioxide.

The multitude of relevant parameters is shown by the following video:

https://www.youtube.com/watch?v=robI4OIKGYc&feature=share

(Explaining electroplating with a multi-parameter specification – Thoma MV)

2.3.1 Function matrix

The resulting function matrix is used to evaluate the necessary requirements that the possible alternative methods also need to fulfil to the same extent so that they represent realistic alternatives. Possible alternatives should be analysed using the resulting matrix. This combines the qualitative requirements of the functions with the quantitative values. Examples are provided by the number of entries by members of the German association VECCO e.V., which represents many surface-finishing companies that use chromium trioxide.

The specified parameters should be regarded as a selection of typical requirements that customers place on contract companies for surface processing. The illustration shows typical basic requirements that virtually all finished surfaces need to meet. In addition, the surface needs to fulfil a series of special requirements, which not every product needs to achieve.

The great importance of surface treatment using chromium trioxide lies in the fact that this fulfils all these requirements and so a contract company can always offer its customer this large range of possible functions.

Figure 7 therefore does not give an assessment or ranking of functions but expresses the multitude of requirements and their implementation.

To create a workable form, the requirements are divided into basic requirements, additional requirements and special requirements. These are shown in Figure 8, Figure 9 and Figure 10.

It should be noted that the specified properties are always in a combination that is essential to the function of a finished product.

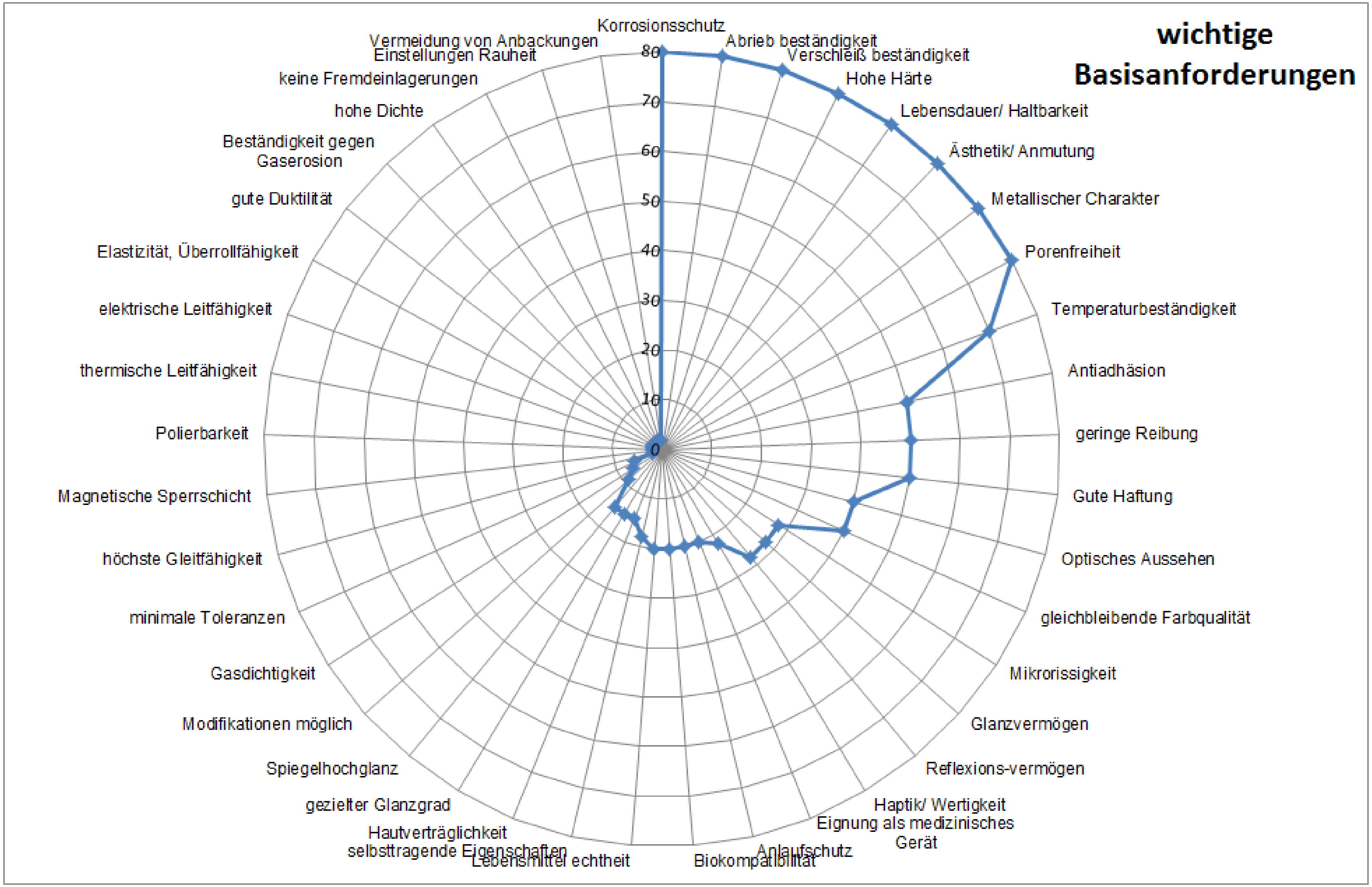

Figure 7: summary of key basic requirements that can be achieved by the chromium coating

wichtige Basisanforderungen	**Key basic requirements**
Korrosionsschutz	Corrosion protection
Abriebbeständigkeit	Abrasion resistance
Verschleißbeständigkeit	Wear resistance
Hohe Härte	High degree of hardness
Lebensdauer/ Haltbarkeit	Service life/durability
Ästhetik/ Anmutung	Aesthetics/appearance
Metallischer Charakter	Metallic character
Porenfreiheit	Non-porosity
Temperaturbeständigkeit	Temperature resistance
Antiadhäsion	Anti-adhesion
geringe Reibung	Low friction
Gute Haftung	Good adhesion
Optisches Aussehen	Visual appearance
gleichbleibende Farbqualität	Consistent colour quality
Mikrorissigkeit	Microcracking
Glanzvermögen	Shine
Reflexionsvermögen	Reflectivity
Haptik/ Wertigkeit	Haptics/valence
Eignung als medizinisches Gerät	Suitability as a medicinal device
Anlaufschutz	Tarnish protection
Biokompatibilität	Biocompatibility
Lebensmittelechtheit	Food safety
Hautverträglichkeit selbsttragende Eigenschaften	Skin tolerance Self-supporting properties
gezielter Glanzgrad	Targeted degree of gloss
Spiegelhochglanz	High-shine mirror finish
Modifikationen möglich	Modifications possible
Gasdichtigkeit	Impermeability to gas
minimale Toleranzen	Minimum tolerances
höchste Gleitfähigkeit	Maximum slippage
Magnetische Sperrschicht	Magnetic barrier
Polierbarkeit	Polishability
thermische Leitfähigkeit	Thermal conductivity
elektrische Leitfähigkeit	Electrical conductivity
Elastizität, Überrollfähigkeit	Elasticity, roll-over capacity
gute Duktilität	Good ductility
Beständigkeit gegen Gaserosion	Resistance to gas erosion
hohe Dichte	High density
keine Fremdeinlagerungen	No foreign substances
Einstellungen Rauheit	Roughness adjustment
Vermeidung von Anbackungen	Prevention of build-up

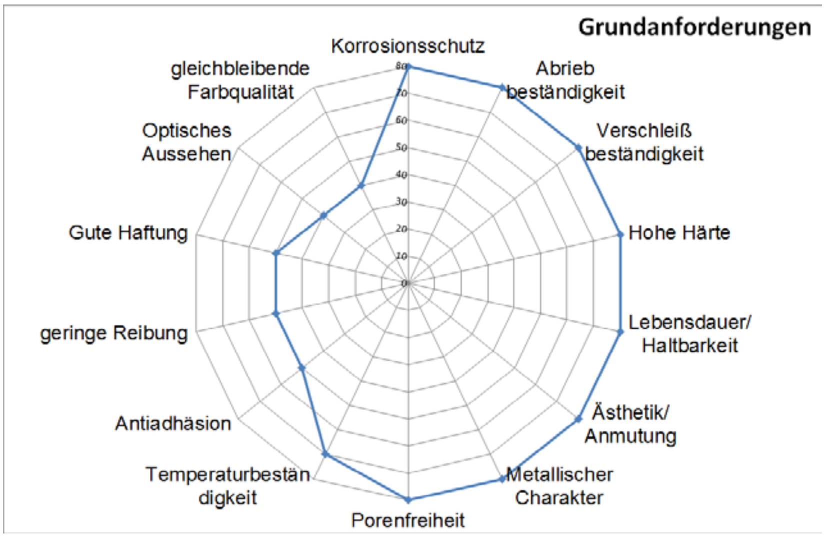

Figure 8: basic requirements that are fulfilled by the chromium coating

Grundanforderungen	**Basic requirements**
Korrosionsschutz	Corrosion protection
Abrieb beständigkeit	Abrasion resistance
Verschleiß beständigkeit	Wear resistance
Hohe Härte	High degree of hardness
Lebensdauer/ Haltbarkeit	Service life/durability
Ästhetik/ Anmutung	Aesthetics/appearance
Metallischer Charakter	Metallic character
Porenfreiheit	Non-porosity
Temperaturbeständigkeit	Temperature resistance
Antiadhäsion	Anti-adhesion
geringe Reibung	Low friction
Gute Haftung	Good adhesion
Optisches Aussehen	Visual appearance
gleichbleibende Farbqualität	Consistent colour quality

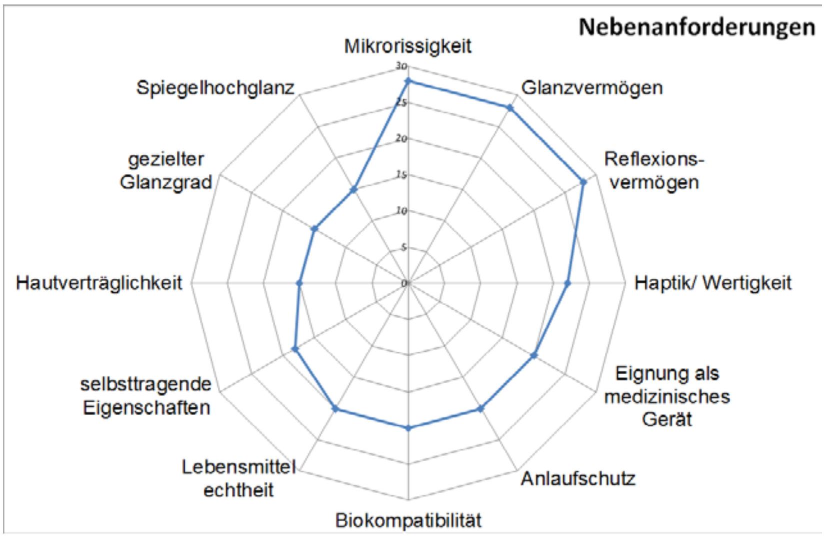

Figure 9: additional requirements that are fulfilled by the chromium coating

Nebenanforderungen	**Additional requirements**
Mikrorissigkeit	Microcracking
Glanzvermögen	Shine
Reflexionsvermögen	Reflectivity
Haptik/ Wertigkeit	Haptics/valence
Eignung als medizinisches Gerät	Suitability as a medicinal device
Anlaufschutz	Tarnish protection
Biokompatibilität	Biocompatibility
Lebensmittelechtheit	Food safety
selbsttragende Eigenschaften	Self-supporting properties
Hautverträglichkeit	Skin tolerance
gezielter Glanzgrad	Targeted degree of gloss
Spiegelhochglanz	High-shine mirror finish

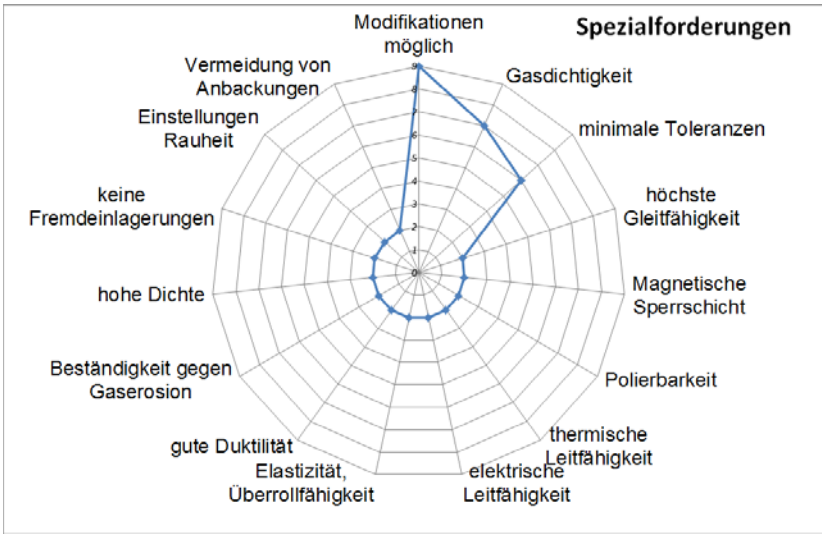

Figure 10: special requirements that are fulfilled by the chromium coating

Spezialforderungen	**Special requirements**
Modifikationen möglich	Modifications possible
Gasdichtigkeit	Impermeability to gas
minimale Toleranzen	Minimum tolerances
höchste Gleitfähigkeit	Maximum slippage
Magnetische Sperrschicht	Magnetic barrier
Polierbarkeit	Polishability
thermische Leitfähigkeit	Thermal conductivity
elektrische Leitfähigkeit	Electrical conductivity
Elastizität, Überrollfähigkeit	Elasticity, roll-over capacity
gute Duktilität	Good ductility
Beständigkeit gegen Gaserosion	Resistance to gas erosion
hohe Dichte	High density
Keine Fremdeinlagerungen	No foreign substances
Einstellungen Rauheit	Roughness adjustment
Vermeidung von Anbackungen	Prevention of build-up

2.4 Applications

The following describes the resulting applications from using chromium trioxide in aqueous solution. As in the introduction, the applications are described by the resulting function matrix.

2.4.1 Application 1: functional chromium plating

Functional chromium plating finishes parts by depositing an extremely hard, uniform, precisely tailored and stable metallic chromium coating. The properties are closely aligned with those of the finished product. Functional chromium plating is essentially determined by the functions listed in 2.3.

The essential properties and their importance are shown by the following function matrix. It should be noted that these can be supplemented depending on the requirement and so the following matrix can be viewed as a typical example.

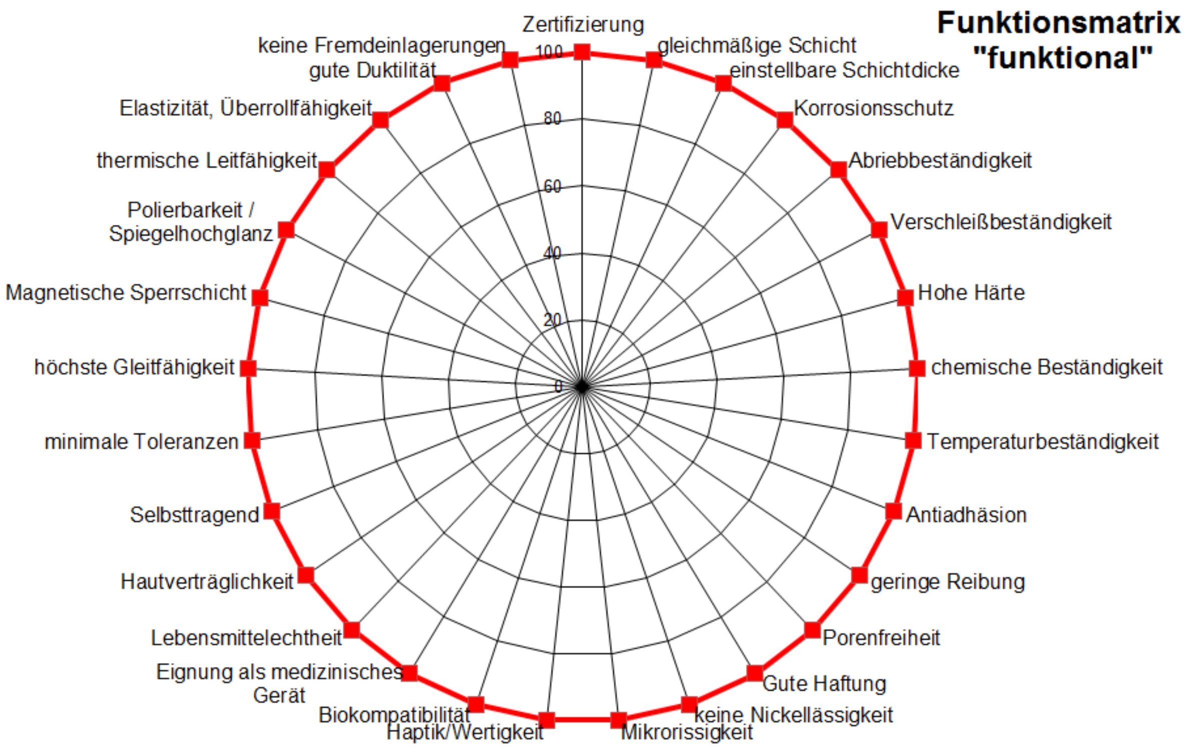

Figure 11: function matrix to describe the requirements of application 1 ‘functional chromium plating’

Funktionsmatrix „funktional“	**Function matrix ‘functional’**
Zertifizierung	Certification
gleichmäßige Schicht	Uniform coating
einstellbare Schichtdicke	Adjustable coating thickness
Korrosionsschutz	Corrosion protection
Abriebbeständigkeit	Abrasion resistance
Verschleißbeständigkeit	Wear resistance
Hohe Härte	High degree of hardness
chemische Beständigkeit	Chemical resistance
Temperaturbeständigkeit	Temperature resistance
Antiadhäsion	Anti-adhesion
geringe Reibung	Low friction
Porenfreiheit	Non-porosity
Gute Haftung	Good adhesion
keine Nickellässigkeit	No nickel release
Mikrorissigkeit	Microcracking
Haptik/ Wertigkeit	Haptics/valence
Biokompatibilität	Biocompatibility
Eignung als medizinisches Gerät	Suitability as a medicinal device
Lebensmittelechtheit	Food safety
Hautverträglichkeit	Skin tolerance
Selbsttragend	Self-supporting

minimale Toleranzen	Minimum tolerances
höchste Gleitfähigkeit	Maximum slippage
Magnetische Sperrschicht	Magnetic barrier
Polierbarkeit / Spiegelhochglanz	Polishability/high-shine mirror finish
thermische Leitfähigkeit	Thermal conductivity
Elastizität, Überrollfähigkeit	Elasticity, roll-over capacity
keine Fremdeinlagerung gute Duktilität	No foreign substances, good ductility

As the list of the natural properties of metallic chromium coatings shows, chromium combines both functional and decorative properties. Depending on the use and operating site, individual or multiple properties are requested and required at the same time. As part of a survey within the different supply chains, the following qualitative weightings of typical properties were revealed for different cases (this weighting can, however, be shifted considerably; and further properties may be added).

2.4.2 Application 2: decorative chromium plating/bright chromium plating

Decorative chromium plating finishes components by applying a uniform and stable chromium coating. Fundamentally, the requirement is an appealing appearance and sufficient corrosion protection.

The essential properties and their importance are shown by the following function matrix. It should also be noted that these can be supplemented depending on the requirement and so the following matrix can be viewed as a typical example.

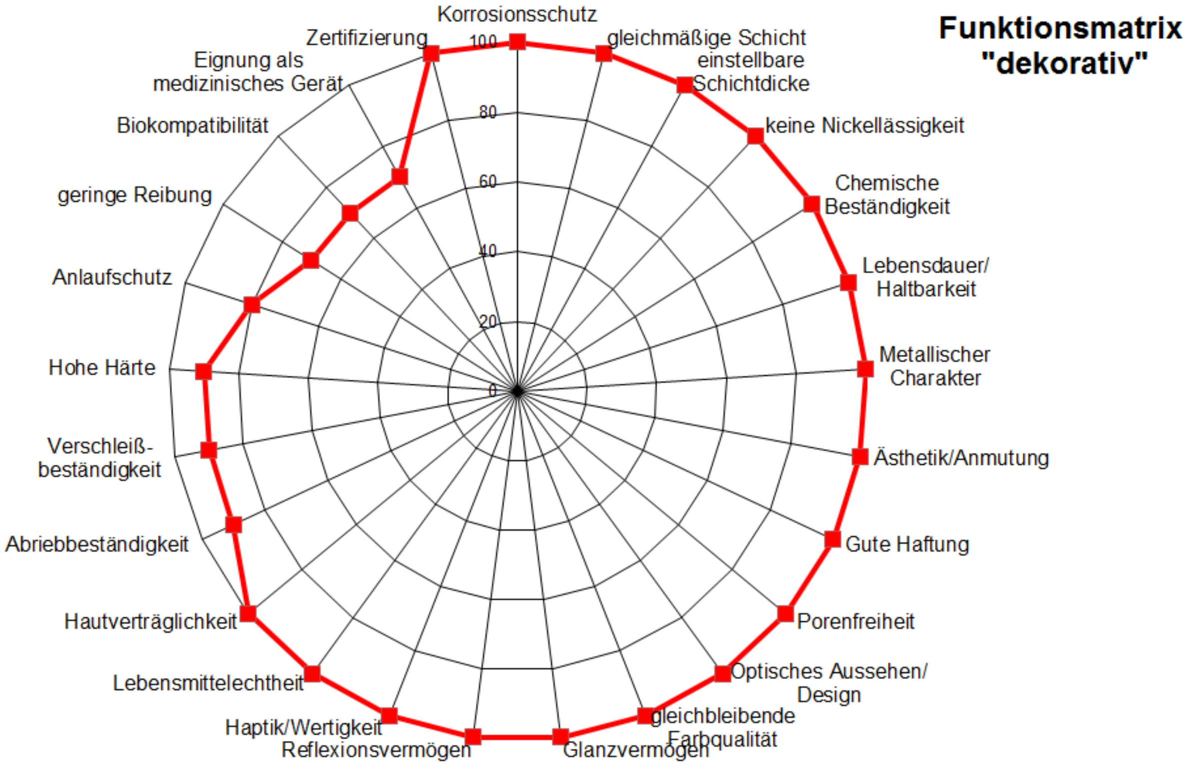

Figure 12: function matrix to describe the requirements of application 2 'decorative chromium plating' – part bright chromium plating

Funktionsmatrix „dekorativ“	**Function matrix 'decorative'**
Korrosionsschutz	Corrosion protection
gleichmäßige Schicht	Uniform coating
einstellbare Schichtdicke	Adjustable coating thickness
keine Nickellässigkeit	No nickel release
Chemische Beständigkeit	Chemical resistance
Lebensdauer/ Haltbarkeit	Service life/durability
Metallischer Charakter	Metallic character
Ästhetik/Anmutung	Aesthetics/appearance
Gute Haftung	Good adhesion
Porenfreiheit	Non-porosity
Optisches Aussehen/ Design	Visual appearance/design
gleichbleibende Farbqualität	Consistent colour quality
Glanzvermögen	Shine
Reflexionsvermögen	Reflectivity
Haptik/Wertigkeit	Haptics/valence
Lebensmittelechtheit	Food safety
Hautverträglichkeit	Skin tolerance
Abriebbeständigkeit	Abrasion resistance
Verschleißbeständigkeit	Wear resistance
Hohe Härte	High degree of hardness
Anlaufschutz	Tarnish protection

geringe Reibung	Low friction
Biokompatibilität	Biocompatibility
Eignung als medizinisches Gerät	Suitability as a medicinal device
Zertifizierung	Certification

2.4.3 Application 2a: black chromium plating

Black chromium plating finishes the components by providing a range of requirements similar to decorative coatings. In addition, important, adjustable electromagnetic properties are required. A considerable challenge is posed by the requirement for dense coatings and at the same time sufficient texturisation for colouring and achieving electromagnetic properties.

The essential properties and their importance are shown by the following function matrix:

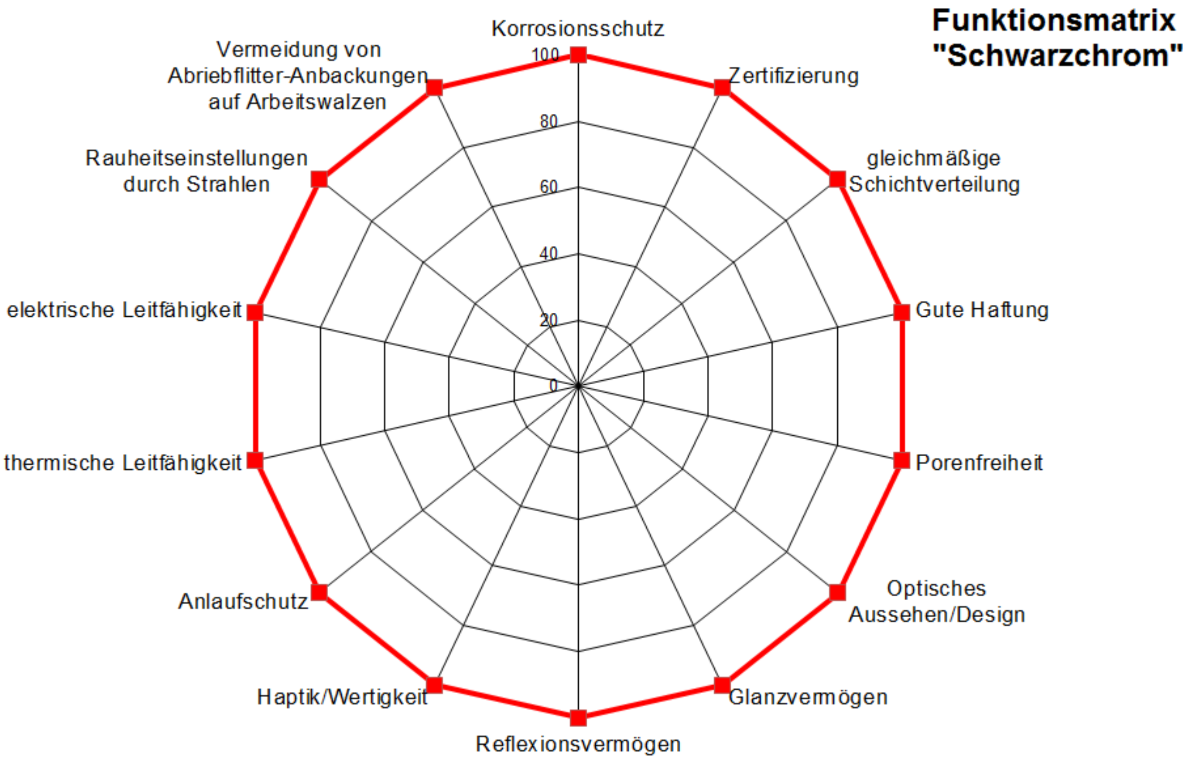

Figure 13: function matrix to describe the requirements of application 2 'decorative chromium plating' – part black chromium plating

Funktionsmatrix „Schwarzchrom"	Function matrix 'black chromium'
Korrosionsschutz	Corrosion protection
Zertifizierung	Certification
gleichmäßige Schichtverteilung	Uniform coating distribution
Gute Haftung	Good adhesion
Porenfreiheit	Non-porosity
Optisches Aussehen/Design	Visual appearance/design
Glanzvermögen	Shine
Reflexionsvermögen	Reflectivity

Haptik/Wertigkeit	Haptics/valence
Anlaufschutz	Tarnish protection
thermische Leitfähigkeit	Thermal conductivity
elektrische Leitfähigkeit	Electrical conductivity
Rauheitseinstellungen durch Strahlen	Roughness adjustment by means of blasting
Vermeidung von Abriebflitter-Anbackungen auf Arbeitswalzen	Prevention of abrasion flash build-up on work rolls

2.4.4 Application 3: electropolishing

Electropolishing finishes the components by forming a uniform surface that is free of defects and does not contain any foreign particles. The resulting surface with an extremely low level of roughness is used as the starting point for other surface treatments.

Differentiation should be made between electropolishing a standard substrate and electropolishing a coated workpiece.

The necessary function of the chromium trioxide lies in the high oxidation potential that reliably oxidises foreign particles on the surface. At the same time, the passivating effect of the chromium trioxide ensures that the material can be removed with control, which consequently protects the base material. For materials that are coatings and can be passivated, such as steel substrates, it ensures that this base material is not attacked (passivation effect).

The latter property can essentially only be achieved by the chromium trioxide and is one of the basic requirements of users.

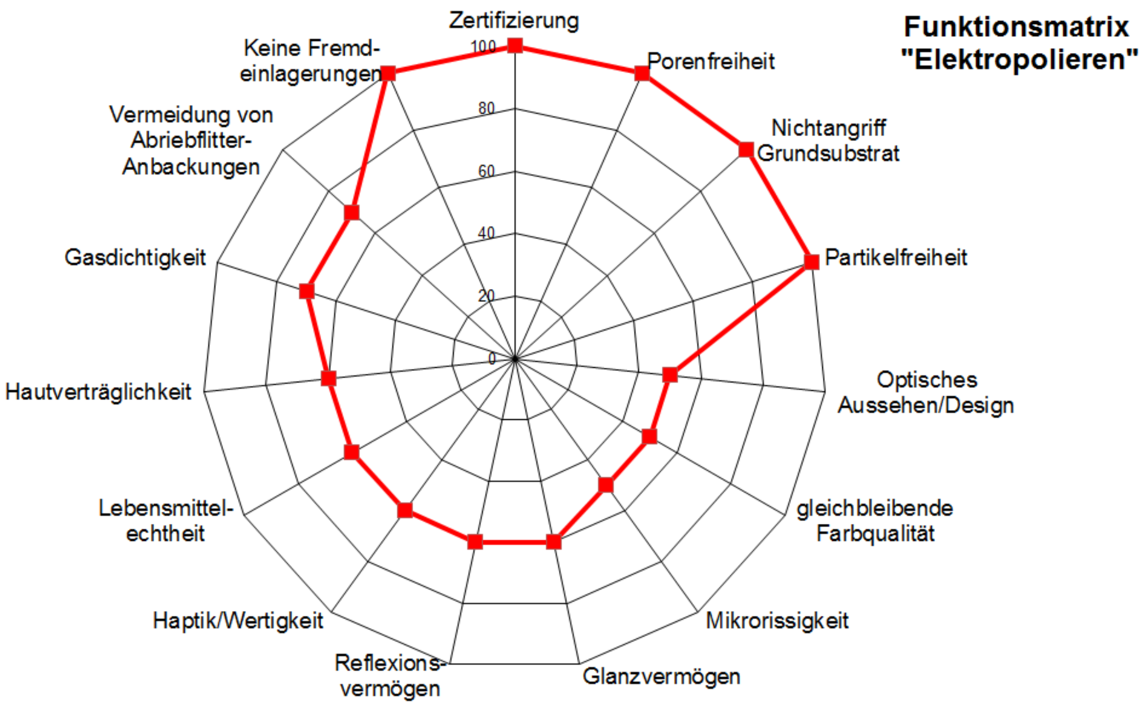

Figure 14: function matrix to describe the requirements of application 3 'electropolishing'

Funktionsmatrix „Elektropolieren“	**Function matrix 'electropolishing'**
Zertifizierung	Certification
Porenfreiheit	Non-porosity
Nichtangriff Grundsubstrat	Does not attack base substrate

Partikelfreiheit	Particle free
Optisches Aussehen/Design	Visual appearance/design
gleichbleibende Farbqualität	Consistent colour quality
Mikrorissigkeit	Microcracking
Glanzvermögen	Shine
Reflexionsvermögen	Reflectivity
Haptik/Wertigkeit	Haptics/valence
Lebensmittelechtheit	Food safety
Hautverträglichkeit	Skin tolerance
Gasdichtigkeit	Impermeability to gas
Vermeidung von Abriebflitter-Anbackungen	Prevention of flash build-up
Keine Fremdeinlagerungen	No foreign substances

2.4.5 Application 4: stripping

Stripping with chromium trioxide removes a metallic coating for the further use of the part. The essential properties and their importance are shown by the following function matrix:

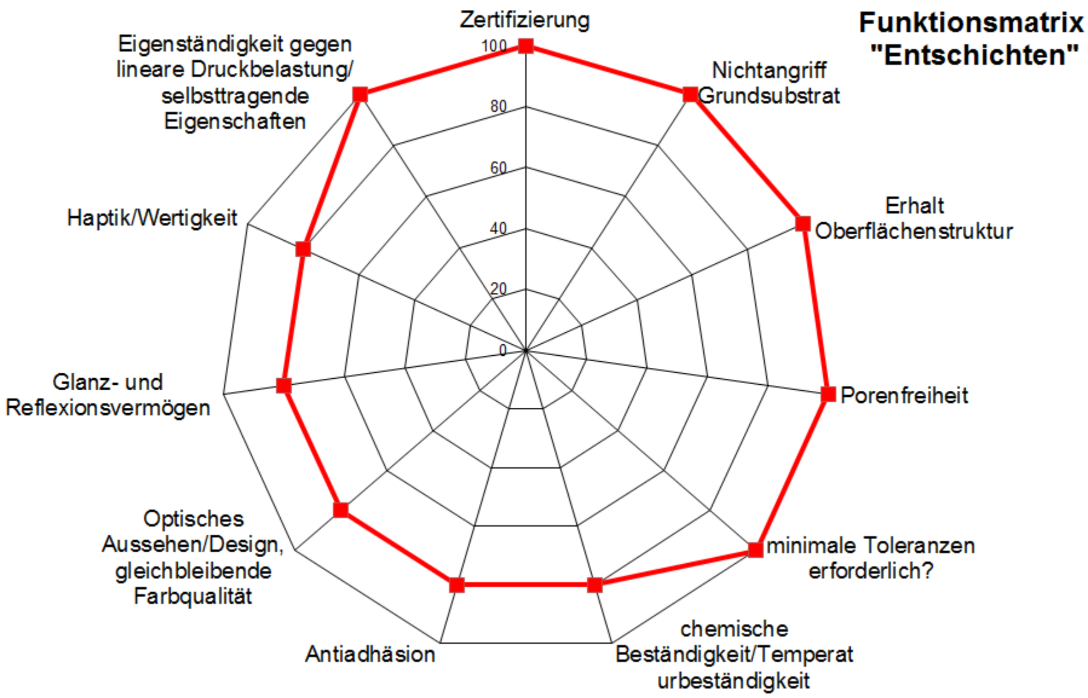

Figure 15: function matrix to describe the requirements of application 3 ‘electropolishing’

Funktionsmatrix „Entschichten“	Function matrix ‘stripping’
Zertifizierung	Certification
Nichtangriff Grundsubstrat	Does not attack base substrate
Erhalt Oberflächenstruktur	Retains the surface structure
Porenfreiheit	Non-porosity
minimale Toleranzen erforderlich?	Minimum tolerances required?
chemische Beständigkeit/Temperaturbeständigkeit	Chemical resistance/temperature resistance

Antiadhäsion	Anti-adhesion
Optisches Aussehen/Design, gleichbleibende Farbqualität	Visual appearance/design, consistent colour quality
Glanz- und Reflexionsvermögen	Shine and reflectivity
Haptik/Wertigkeit	Haptics/valence
Eigenständigkeit gegen lineare Druckbelastung/selbsttragende Eigenschaften	Independence to linear pressure load/self-supporting properties

The necessary function of the chromium trioxide lies in the high oxidation potential that reliably removes the metallic coating. At the same time, the passivating effect of the chromium trioxide ensures that the base material is not attacked.

As the base material varies greatly, special electrolytes containing chromium trioxide are developed that remove any coating but at the same time do not attack the base material.

2.4.6 Application 5: plastics pickle

The essential properties and their importance are shown by the following function matrix:

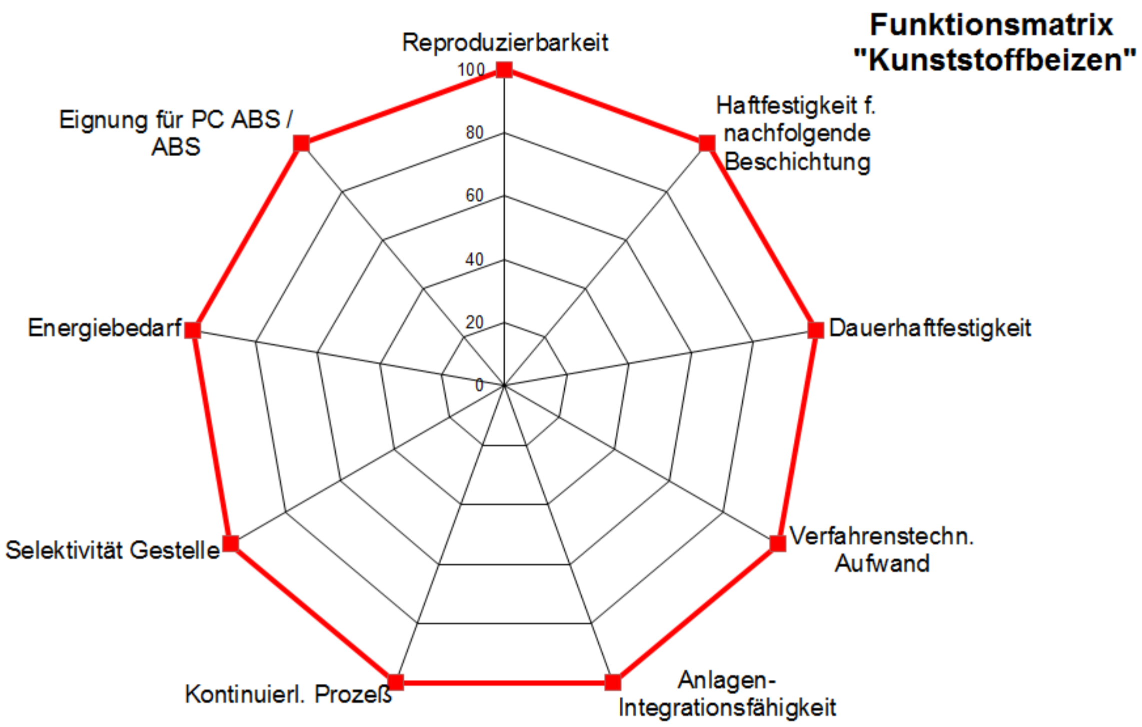

Figure 16: function matrix to describe the requirements of application 3 'electropolishing'

Funktionsmatrix „Kunststoffbeizen“	**Function matrix 'plastics pickling'**
Reproduzierbarkeit	Reproducibility
Haftfestigkeit f. nachfolgende Beschichtung	Adhesive strength to subsequent coating
Dauerhaftfestigkeit	Long-term adhesive strength
Verfahrenstechn. Aufwand	Process-engineering outlay
Anlagen- Integrationsfähigkeit	Plant integration capacity

Kontinuierl. Prozeß	Continuous process
Selektivität Gestelle	Selectivity framework
Energiebedarf	Energy requirement
Eignung für PC ABS / ABS	Suitability for PC ABS/ABS

Pickling plastics with chromium trioxide produces a highly textured surface via an oxidative reaction, and active polymer chain terminals, which creates sufficient adhesion of the metallic nuclei for a subsequent coating.

The required function of the chromium trioxide lies in the high oxidation potential, which reliably dissolves the polymer matrix and activates it for post-treatment.

2.4.7 Application 6: anodising (hard anodising)

Components made from aluminium are anodised to produce a uniform, thick oxide layer with a defined structure.

Differentiation must be made between functional coatings that are used for wear protection and corrosion protection, and thinner coatings that are used to bind the base material to a subsequent coating. The latter is not discussed in this paper because other methods are already used.

To produce functional coatings, the necessary function of the chromate is in its high oxidation potential which facilitates a highly ordered structure of the oxide. This structure achieves adjustable hardness, roughness and a good level of corrosion protection.

The use of chromium trioxide ensures a stable pH value during deposition, which is only possible to a limited extent with other substances. This means that the process of creating the oxide is consistent and the structure of the oxide equally so. The coatings obtained in this way give particularly good wear and corrosion protection.

For instance, the uniform structures are mandatory to prevent corrosion in the medical field, for example by anaesthetic gases.

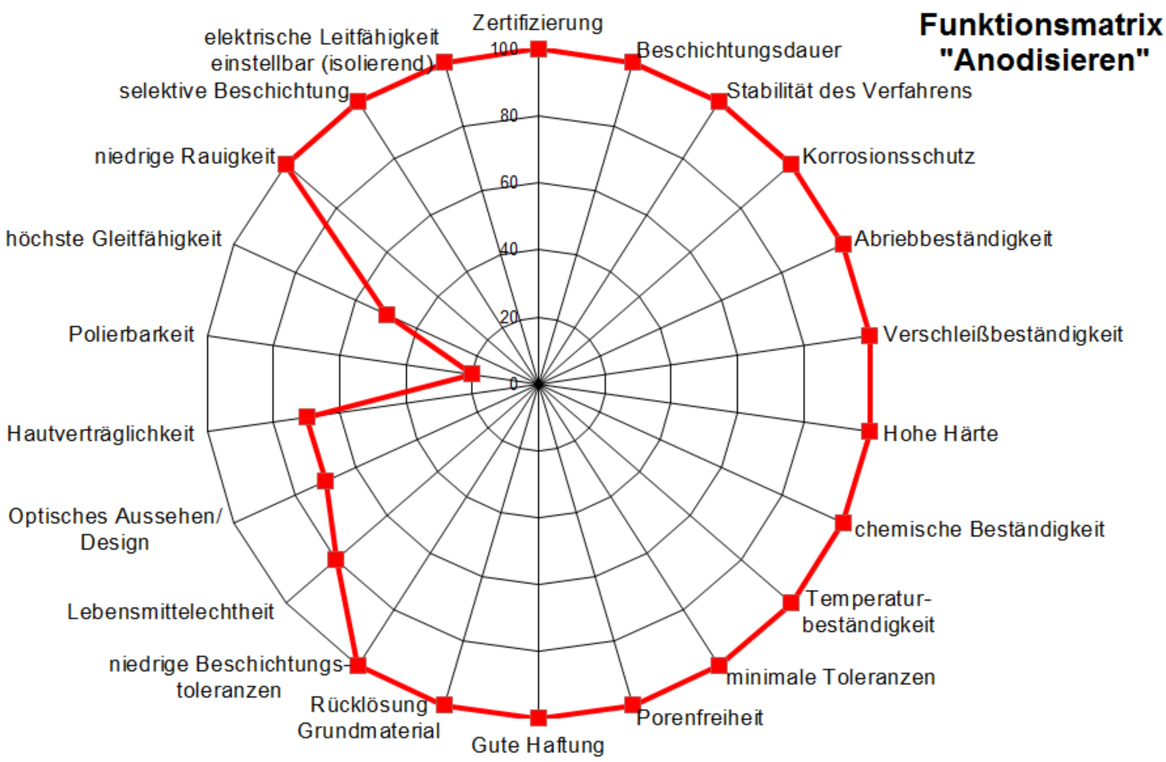

Figure 17: function matrix to describe the requirements of application 3 ‘electropolishing’

Funktionsmatrix „Anodisieren“	**Function matrix ‘anodising’**
Zertifizierung	Certification
Beschichtungsdauer	Coating duration
Stabilität des Verfahrens	Stability of the method
Korrosionsschutz	Corrosion protection
Abriebbeständigkeit	Abrasion resistance
Verschleißbeständigkeit	Wear resistance
Hohe Härte	High degree of hardness
chemische Beständigkeit	Chemical resistance
Temperaturbeständigkeit	Temperature resistance
minimale Toleranzen	Minimum tolerances
Porenfreiheit	Non-porosity
Gute Haftung	Good adhesion
Rücklösung Grundmaterial	Dissolution of base material
niedrige Beschichtungstoleranzen	Low coating tolerances
Lebensmittelechtheit	Food safety
Optisches Aussehen/ Design	Visual appearance/design
Hautverträglichkeit	Skin tolerance
Polierbarkeit	Polishability
höchste Gleitfähigkeit	Maximum slippage
niedrige Rauigkeit	Low roughness
selektive Beschichtung	Selective coating

elektrische Leitfähigkeit einstellbar (isolierend)	Adjustable electrical conductivity (insulating)

2.4.8 Application 7: stainless steel dyes (formation of functional, thin passive coatings)

Steel materials are passivated to produce a uniform, thin oxide layer in the nanometre range with a defined structure.

The necessary function of the chromium trioxide is in the high oxidation potential, which enables the steel to be passivated, and the passivating effect of the chromic acid also ensures that the base material is not attacked and the thickness of the coating remains in the nanometre range. The high oxidation potential also ensures the surface is cleaned and creates a virtual seal as a result of the passive layer.

The adjustable thickness of the oxide in the nanometre range means that it is possible to create interference colour effects and to enhance these using suitable additives.

The essential properties and their importance are shown by the following function matrix:

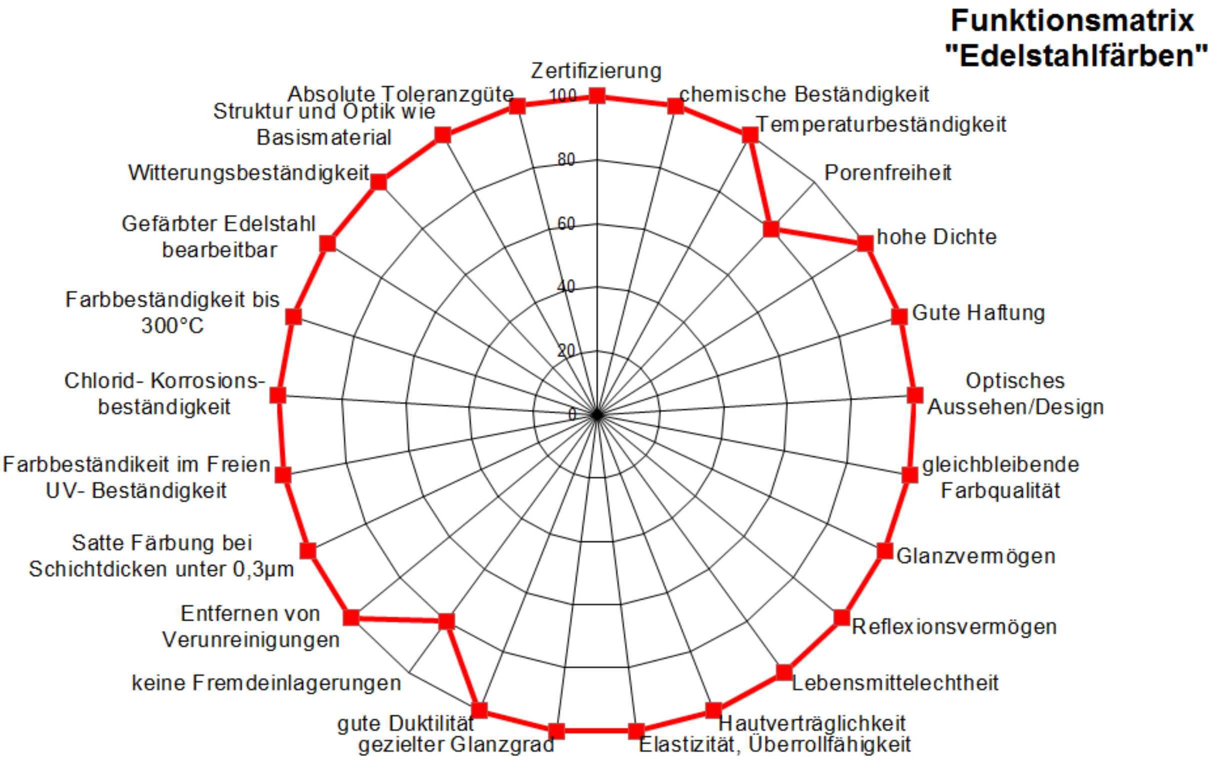

Figure 18: function matrix to describe the requirements of application 3 'electropolishing'

Funktionsmatrix „Edelstahlfärben“	**Function matrix 'stainless steel dyes'**
Zertifizierung	Certification
chemische Beständigkeit	Chemical resistance
Temperaturbeständigkeit	Temperature resistance
Porenfreiheit	Non-porosity
hohe Dichte	High density
Gute Haftung	Good adhesion
Optisches Aussehen/Design	Visual appearance/design
gleichbleibende Farbqualität	Consistent colour quality
Glanzvermögen	Shine

Reflexionsvermögen	Reflectivity
Lebensmittelechtheit	Food safety
Hautverträglichkeit	Skin tolerance
Elastizität, Überrollfähigkeit	Elasticity, roll-over capacity
gezielter Glanzgrad	Targeted degree of gloss
gute Duktilität	Good ductility
keine Fremdeinlagerungen	No foreign substances
Entfernen von Verunreinigungen	Removal of impurities
Satte Färbung bei Schichtdicken unter 0;3µm	Rich colours in coatings less than 0.3 µm thick
Farbbeständigkeit im Freien UV- Beständigkeit	Colour stability outdoors UV resistance
Chlorid- Korrosionsbeständigkeit	Chloride and corrosion resistance
Farbbeständigkeit bis 300°C	Colour stability up to 300 °C
Gefärbter Edelstahl bearbeitbar	Coloured stainless steel can be processed
Witterungsbeständigkeit	Weathering resistance
Struktur und Optik wie Basismaterial	Structure and visual appearance as base material
Absolute Toleranzgüte	Absolute tolerance level

3 ANNUAL TONNAGE

Estimation:

The quantity of chromium trioxide used is between 10 kg/a and 200 t/a chromium trioxide per operating site.

4 IDENTIFICATION OF POSSIBLE ALTERNATIVES/parallel technologies

Numerous supposed alternatives are being discussed publicly and in professional circles. However, on closer analysis they quickly prove to be unsuitable. As became clear from the surveys of members of VECCO e.V. /12/, many of these technologies have been tested unsuccessfully, many were not accepted by customers or they were rejected right from the start as a result of differing technical specifications. Several have been used for some time as parallel technologies on a permanent basis, however, in general they could not be used as an alternative technology to entirely replace the original technology. Other coatings that could be considered for a few specialist applications (sol-gel coatings, polymer coatings, etc.) are not specifically analysed.

1. The following methods are considered to be relevant according to the survey of companies:

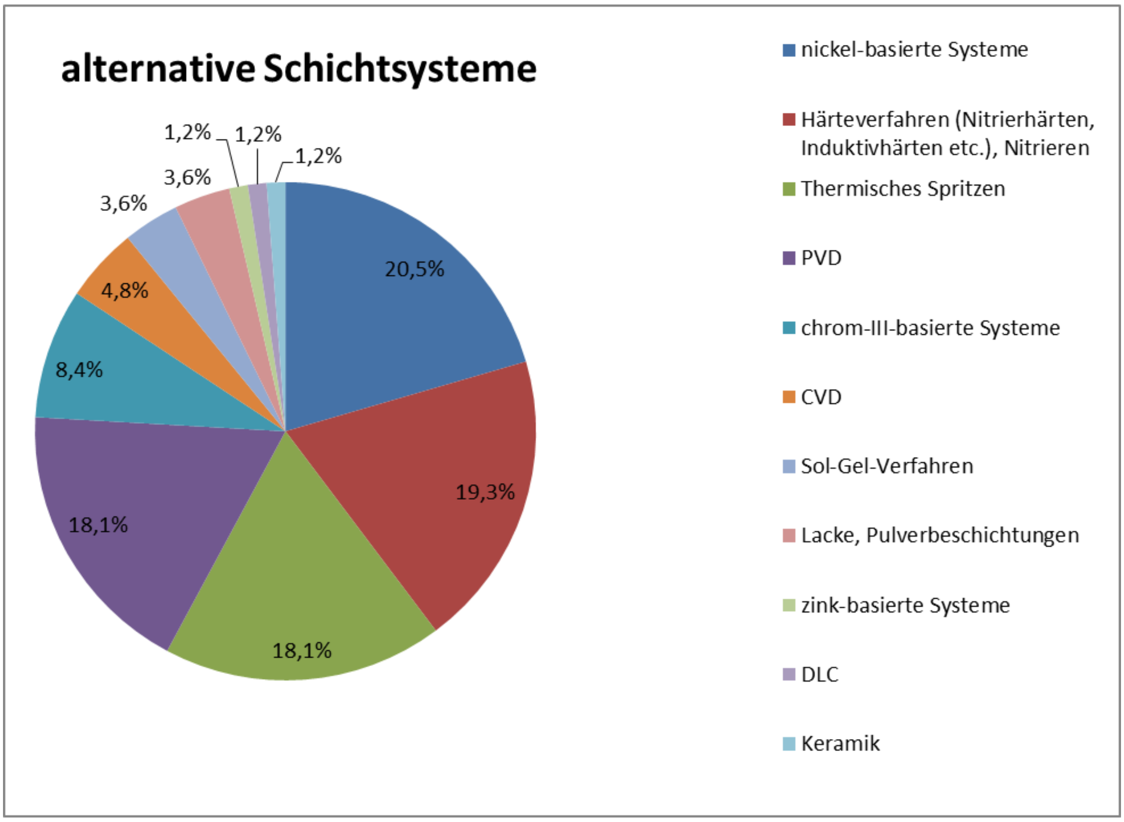

Figure 19: coating methods being discussed at present and considered to be possible alternatives

alternative Schichtsysteme	alternative coating systems
nickel-basierte Systeme	Nickel-based systems
Härteverfahren (Nitrierhärten, Induktivhärten etc.), Nitrieren	Hardening processes (nitriding, inductive hardening, etc.), nitriding
Thermisches Spritzen	Thermal spraying
PVD	PVD
chrom-III-basierte Systeme	Chromium III-based systems
CVD	CVD
Sol-Gel-Verfahren	Sol-gel method
Lacke, Pulverbeschichtungen	Paints, powder coatings
zink-basierte Systeme	Zinc-based systems
DLC	DLC
Keramik	Ceramic

2. For a literature comparison we used:
   a. Chromgrün study (recommendation of BAuA) /9/.
   b. Five Chemicals – Alternatives Assessment Study /1/.
      prepared by the Massachusetts Toxics Use Reduction Institute, University of Massachusetts Lowell, June 2006
   c. HCAT Project (Hard Chrome Alternatives Team, 2011; International Project) /29, 39/.

The literature evaluations are based on the technologies presented in the Chromgrün study.

The technologies proposed in this paper should be investigated for suitability as alternatives, which has been addressed primarily in /9/ and /13/; other technologies are in the trial or early marketing stage.

The technologies have been assessed in a survey by the members of VECCO e.V. in terms of their practical experience. The corresponding results can be found following the reports a to c.

Technology	Advantage	Disadvantage	Risk assessment
Chromium (III) electrolyte-based hard chromium coating (various processes)	**Chromgrün study Functional chromium**		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		• Lower toxicity • Not relevant for accident prevention regulations for hazardous substances
	In development	• High demand of process control • Complex electrolytes (membrane separation) • Patented or laboratory tests, no industrial use	
	Economic		
	No information	No information	
	TURI (2006)		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
		Conventional Cr(III)-based electrolytes are unsuitable for replacing hard chromium plating: • Low efficiency • Low deposition rate • Limited coating thickness (~ 1 µm)	
	Economic		
	HCAT (2004–2011)		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
		• Not suitable for functional chromium plating	
	Economic		
		• No statements	
	Assessment and experiences of VECCO members		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		• Use of boric acid (treated as a SVHC substance)
		General experiences: • No constructive solution is possible • Insufficient coating thickness • Poor wear resistance • Insufficient hardness • The surface does not offer the range of functions	

		required by hard chromium plating **Scientific experiences** • It is not elementary Cr that is deposited as in conventional hard chromium, but Cr carbide, Cr phosphide or similar substances, depending on the bath composition. This explains the change in properties with increasing temperature (hardness increase, internal tension, as a result of further dispersion hardening (structural transformation) similar to chemical Nickel) • Coatings with too high an internal tension result in inadequate adhesion and an inadequate crack structure. This causes insufficient corrosion protection. • Problems with adhesive strength as a result of the risk of hydroxide deposition (depletion in the cathode area, buffering)	
	Economic		
		• The quality of results in the overall value-added chain is considerably impacted by a substitution. • The process management expense is not cost effective. • As a result of the insufficient quality of the coating, no acceptable results were achieved and development is not currently being pursued. • Expensive chemistry and infrastructure • Unstable electrolytes and an extremely elaborate bath management. • Long-term stability is currently only possible with expensive membrane technology • High proportion of chelating chemicals. This means that the waste water treatment is more problematic than for solutions containing Cr(VI)	
Thermal	**Chromgrün study** **Functional chromium**		

spraying (HVOF)	**Advantage**	**Disadvantage**	**Risk assessment**
	Technical		• Form low quantities of Cr(VI) during coating • Fine particulate pollution for the workers, may be contaminated with Co
	• Quicker than electroplating • Better suited to repairs • Higher hardness and lower wear • Low porosity • No waste water • Low space requirement	• Low adhesion • Cannot be used for internal coatings	
	Economic		
	• Partially reduced processing time and increased service life • Reduction in maintenance costs • Low waste disposal • Low energy costs • Low cost for environmental management	• Additional operating costs in some cases (e.g. powder) • Additional training • Additional investment	
	TURI (2006)		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		• Co toxicity
	• Broad range of substances and compounds that can be used for coating • Higher hardness • Better wear resistance • Longer operating times, therefore less time for replacement • Lower material fatigue • Better corrosion protection • Lower embrittlement • The coating material can be adapted to the maintenance conditions. • Large surfaces can be coated quickly • The coatings can be chemically stripped • Proven marketability • No emission • Low quantities of rinsing water	• No internal coating • High operating temperature, therefore restricted to heat-resistant materials • Possible embrittlement fractures, chipping possible at high load • More complex coating methods, maintenance intensive • Requires careful quality control • Post-treatment (grinding) requires diamond tools.	
	Economic		
	• Possibly cost-effective for 1:1 companies	• For mass parts (1:n companies) can only be implemented at high expense	
	HCAT		

Advantage	Disadvantage	Risk assessment
Technical		
• Suitable and tested for aviation vehicles		
Economic		
• No information		

Assessment and experiences of VECCO members		
Advantage	**Disadvantage**	**Risk assessment**
Technical		
• Ceramics, material combinations and alloys can be sprayed • No hard chromium (often strategic decision) • High scrap rates, very quickly obtain very thick coatings • Millturning for soft coatings as quick intermediate machining • Process makes it possible to process the majority of metals and alloys (powder) • Coatings are chemically very pure and dense with fine-grained, virtually homogeneous structure • Very thick coatings are possible • Highly suited to coatings made from carbide materials and super alloys • Highly suited to grinding and microfinishing • Coating workpieces with complex geometry • Partial coatings with low effort are possible (simple covering) • High process capability as can be fully automated	• It is not possible to obtain a non-porous coating • It is not possible to obtain a high-shine coating • Only limited polishability, no high-shine mirror finish possible • Precision coating is impossible • Anti-adhesive and wetting properties are not achieved • Cannot be polished or can only be poorly polished • Low hardness • Insufficient coating properties • Topographies cannot be controlled • Less resilient to thermoshock • Insufficient corrosion protection • Reworking is required • Regrinding is only successful to a limited extent • Post-treatment after coating is required (in some cases CrO_3 is used) • Adhesive strength (only interlocking with blasted surface) • Insufficient wear protection (except for hard material coating) • Processing effort (for hard material and ceramic coatings) • Internal coating is at the very least problematic • Risk of chipping when edge finishing • Difficult to achieve a homogeneous surface finish • Risk of warping with insufficient heat dissipation • Extensive accompanying tests (powder quality) • Complex plant engineering: control system, process diagnosis, chamber and filter systems, soundproofing, kerosene storage and supply,	• Dusts in post-treatment (grinding) are toxic and environmentally toxic • Development of Cr(VI) in the spray powder that contains chromium • Metal dusts of nickel and cobalt are suspected of being carcinogenic (SVHC relevant) • Fine particulate pollution (see also *BG Holz und Metall* [German wood and metal trade association] /18/) • High risk to health that cannot be assessed

	Advantage	Disadvantage	Risk assessment
		oxygen tanks, etc. • Repairability of the coating • Explosion protection required in the plant	
	Economic		
	• Significant plant investment combined with highly trained operating staff • Cost advantages are generally only with the processing centre immediately downstream	• High investment costs • High material costs (primarily spray powder) • A larger selection of powders needs to be kept in stock according to the required properties. • High equipment expense to collect the dust • Process stability and plant availability insufficient • High scrap rates • Defect costs/repair costs • Lack of certification • Resulting high coating price • High cost of regrinding for the mechanical machining required as a result of the resulting inhomogeneous surface structure	
		Long-standing experience in the market (more than 10 years) shows that as a result of the high maintenance effort (for example, piston rods, shafts, calender rollers, printing rollers, etc.) and chipping, increasing numbers of end customers reject these finishes and return to the more reliable hard chromium coatings.	
Vacuum method	**Chromgrün**		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
		Not for repairs	
	Economic		
	No information	No information	
	TURI (2006)		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
		Not for repairs	
	Economic		
	No information	No information	
	HCAT		

	Advantage	Disadvantage	Risk assessment
	Technical		
		Not for repairs	
	Economic		
	No information	No information	
	Assessment and experiences of VECCO members		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
		• Effectiveness is dependent upon base substrate • Coatings too thin • Limited part size • Not ductile enough • Eggshell effect (large difference in hardness coating – substrate) • Corrosion resistance too low • Change in the hardness of the base material • Cannot be used universally • Only fulfils a few properties simultaneously	• Releases fine dust
	Economic		
		• Lack of certification • Niche product • Trial and pilot project stage • Very limited fields of application • Part service life too low • Vacuum chamber required: limited part size	
Electroplating nano-coatings Thin film systems	**Chromgrün**		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
	• Better corrosion and wear conditions • Lower porosity • No embrittlement	• Additional heat treatment for wear resistance, therefore only heat-resistant materials can be used	• Additives such as Co compounds are SVHC relevant
	Economic		

	• Costs comparable with the Cr(VI) process • Energy costs lower	• Coating costs double those of the Cr(VI) process	
	TURI (2006)		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
	Not addressed		
	Economic		
	HCAT		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
	Not addressed		
	Economic		
	Assessment and experiences of VECCO members		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
		• Only possible in combination with corrosion-resistant and/or hardened base material • Only small components can be coated • Too little wear capacity • Topographies cannot be controlled • Massive wear on the friction partner • Insufficient corrosion protection • The surface does not offer the same advantages as the hard chromium plating method • Property combinations are insufficient (e.g. corrosion protection is highly dependent on the medium)	• Releases fine dust • Coatings are not compliant with RoHS • Use of SVHC-relevant substances (e.g. boric acid, Co salts)
	Economic		
		• Limited part service life • High costs • Limited part size (as a result of complex pre-treatment) – space and investment problem	

		• As a result of the partially insufficient quality of the coatings, other products are also influenced in the entire value-added chain. Substituting the coating significantly impairs the usability of these products (companies' experience)	
Laser and welding technologies	**Chromgrün**		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
	• No restrictions in terms of heat (laser, ESD/ESA) • Post-treatment is not necessary (laser)	• Suitable for repair	
	Economic		
	No information	No information	
	TURI (2006)		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
	Economic		
	No information	No information	
	HCAT		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
	Economic		
	No information	No information	
	Assessment and experiences of VECCO members		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
	Experience from evaluation of technology and practical experience of customers/competition: • Comparison of laser build-up welding with HVOF: - powder requirement and coating similar to HVOF	• Partial combustion of carbides • Risk of cracking and thermal overload for the base material (at high deposition rates) • Part failure (safety problem) • The thinner the coating, the slower the coating process (technical reasons, owing to weld beads)	

	- laser instead of flame as the energy source • Advantage: - better adhesion than HVOF - can also be used for the original moulding		
	Economic		
		- Costs not competitive	
		Experiences in the market show that customers that have developed the method independently return to hard chromium coating.	
Heat treatment	**Chromgrün**		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
		• Only for heat-resistant materials • Not for repair	
	Economic		
	No information	No information	
	TURI (2006)		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
	Economic		
	No information	No information	
	HCAT		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
	Economic		
	No information	No information	
	Assessment and		

	experiences of VECCO members		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
		• Precision coating is impossible • Coating only works in combination with the base material • Insufficient corrosion protection • Topographies cannot be controlled • After abrasion of a thin bonding layer there is a loss of anti-adhesion and friction coefficient • High temperature restricts substrates	
	Economic		
		Economic: • Vacuum chamber required: limited part size	
Electroless nickel	**Chromgrün**		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		• Several electrolytes are RoHS-relevant • Ni compounds toxic • Nanoparticles are used in some cases
	• No microcracks • Sufficient hardness	• Greater demand for electrolyte maintenance • Additional heat treatment required for wear resistance	
	Economic		
	• Overall costs lower than Cr(VI) process • Simple use as established process that is similar to electroplating		
	TURI (2006)		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
	Is not assessed because a critical substance		
	Economic		
	No information	No information	
	HCAT		

	Advantage	Disadvantage	Risk assessment
	Technical		
	Is not assessed because a critical substance		
	Economic		
	No information	No information	
	Assessment and experiences of VECCO members		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
		• Low hardness • Low anti-adhesion • Low wear protection • Friction coefficient is too high • Coatings that are greater than 50 µm thick are problematic • Inferior adhesion • Amagnetic • Minimal lubricant reservoir capacity • Too inaccurate in the coating thickness distribution • Reflectivity too high • Not resistant to sulphur compounds or nitrous gases • Topographies cannot be controlled	• Ni salts are SVHC relevant • Release of high-risk fine dust (regrinding)
	Economic		
		• Use is highly product-dependent • Cost-intensive	

Technology	Advantage	Disadvantage	Risk assessment
Chromium (III)-based decorative	**Chromgrün study – decorative**		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		

	• Higher cathode efficiency • Higher throwing power • Fewer burn marks • No white spots • Tolerant to power fluctuations • Higher power yields • Lower carry-over • Lower metal load • No air treatment is required • Double chromium plating • Lower temperature • No foaming • Simple waste water treatment • Various colour shades	• Different visual appearance • Different, reproducible colours • Sensitive to manual welding • Lower hardness and wear protection • No passivating • Lower corrosion protection • Highly sensitive to embedded foreign metal • Multiple bath analyses are required • Complex electrolyte properties (membrane separation)	• Generally low toxicity, however, some processes require SVHC-relevant substances (e.g. boric acid) • No specific occupational safety measures are necessary • No PFOS-based additives
	Economic		
	• More cost-effective containers can be used • Higher assembly density of the framework • No separate storage of Cr(VI) needed • More cost-effective waste treatment and disposal • Lower anode costs • Lower maintenance costs • Higher production rates • Lower scrap • Less energy required	• Higher chemical costs • Electrolyte maintenance is more complex, therefore additional equipment required (e.g. re-dosing) • Additional investment e.g. air supply	
	Assessment and experiences of VECCO members		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		• Use of boric acid (treated as a SVHC substance)
		Functional • Low mechanical resilience (bending/torsion) • High abrasion, for example in contact with shoe soles • Nickel release ➔ Exclusion criterion for parts for medical technology and those with subsequent skin contact e.g. vehicle interiors, musical instruments, furniture industry • Coating thickness is too thin • Lower corrosion protection • Topography not adjustable	

	Advantage	Disadvantage	Risk assessment
		• Not stable in the long term **Optics** • No black • Light reflection not adjustable • Colour stability of the deposited chromium coatings not guaranteed: ➔ darkening ➔ inadequate colour reproduction in the coating process • Streak formation on coating	
	Economic		
		• Substantially higher production costs • The geometry of the part that can be coated is limited • Specialist anodes are required which can vary greatly in terms of cost. • Unstable electrolytes and an extremely elaborate bath management. • Long-term stability is currently only possible with expensive membrane technology • High proportion of chelating chemicals. This means that the waste water treatment is more problematic than for solutions containing Cr(VI) • No possibility of building upon due to colour variations	
Chromium optics	**Chromgrün study – decorative**		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		• No use of heavy metals
	• Prevention of embrittlement and cracks • Any colouring possible	• Not yet widely used	
	Economic		
	No information	No information	
	Assessment and experiences of VECCO members		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
		• Low mechanical stress possible, therefore only short periods that the part is under stress • Lower corrosion protection	

	Advantage	Disadvantage	Risk assessment
		• Low distribution • Surface structure defective (orange peel)	
	Economic		
		• Significantly more expensive • Lack of certification or lack of customer approval	

Vapour deposition (PVD/CVD)	**Chromgrün study – decorative**		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
	• Higher hardness • High colour variation is possible • Higher wear resistance	• Different colouring • Higher failure in the event of overload	
	Economic		
	No information	No information	
	Assessment and experiences of VECCO members		
	Advantage	**Disadvantage**	**Risk assessment**
	Technical		
		• Effectiveness is dependent upon base substrate • Eggshell effect (large difference in hardness coating – substrate) • Corrosion resistance too low • Cannot be used universally • Only fulfils a few properties simultaneously	• Releases fine dust
	Economic		
		• Lack of certification • Niche product • Trial and pilot project stage • Very limited fields of application • Part service life must be guaranteed • Vacuum chamber required: limited part size	

4.1 List of possible alternatives/parallel technologies

In the following, using the function matrices developed in section 2, we present the selected alternatives with the functions of surface treatment with chromium (VI) solutions.

The comparative requirements (current use of chromium(VI) electrolytes) always form the blue outer circle. The alternatives are shown in red.

In the vast majority of cases, the diagrams indicate that many of the required functions are not described or do not exist for the different technologies. Similarly, the data of the chromium (VI) applications cannot often be achieved.

4.1.1 Chromium plating; functional, decorative, black chromium

1. **Substance alternative: electroplating coatings based on Cr(III) salts**
   Alternatives for: decorative, black chromium plating
   The essential properties and their importance are compared in the following function matrices:

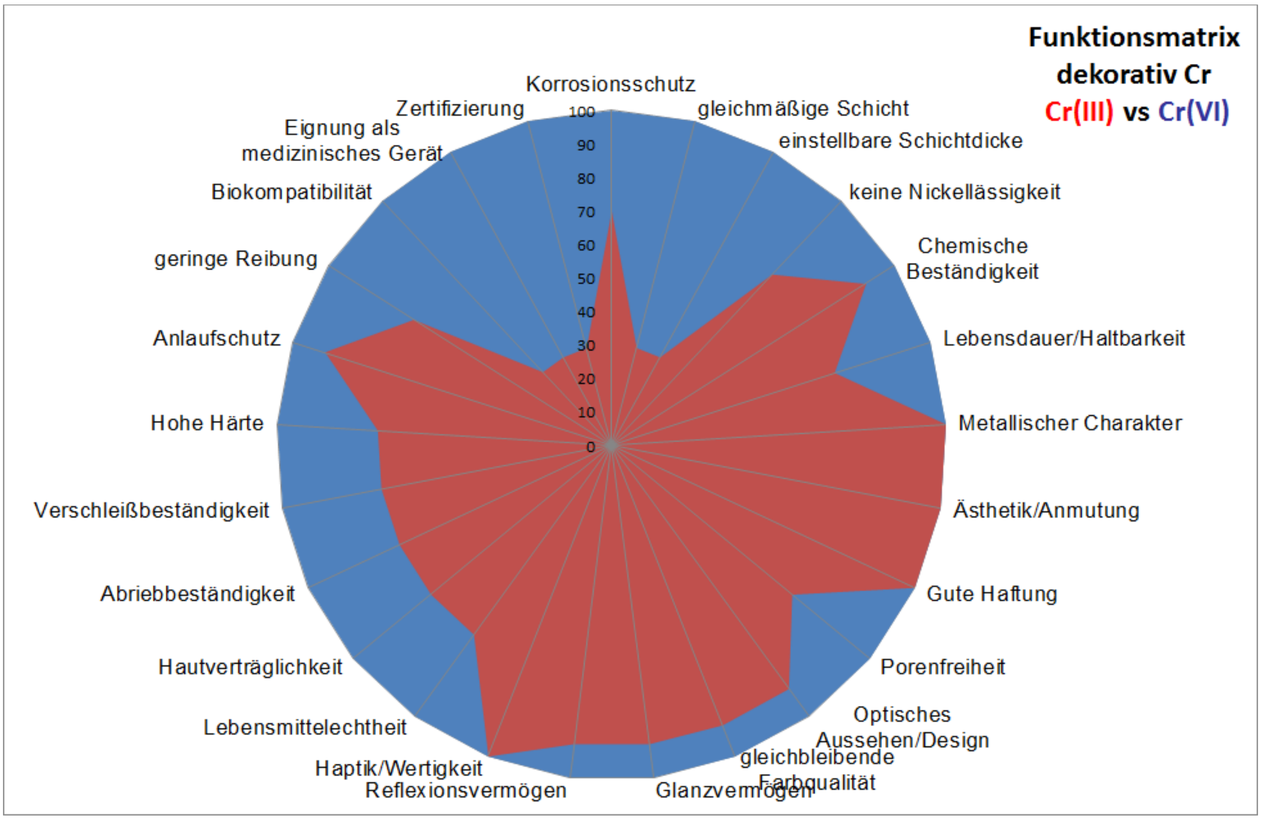

Figure 20: function matrix to compare decorative chromium coatings deposited from Cr(III) electrolytes and Cr(VI) electrolytes

Funktionsmatrix dekorativ Cr	**Function matrix decorative Cr**
Cr(III) vs Cr (VI)	Cr(III) vs Cr(VI)
Korrosionsschutz	Corrosion protection
gleichmäßige Schicht	Uniform coating
einstellbare Schichtdicke	Adjustable coating thickness
keine Nickellässigkeit	No nickel release
Chemische Beständigkeit	Chemical resistance

Lebensdauer/Haltbarkeit	Service life/durability
Metallischer Charakter	Metallic character
Ästhetik/Anmutung	Aesthetics/appearance
Gute Haftung	Good adhesion
Porenfreiheit	Non-porosity
Optisches Aussehen/Design	Visual appearance/design
gleichbleibende Farbqualität	Consistent colour quality
Glanzvermögen	Shine
Reflexionsvermögen	Reflectivity
Haptik/Wertigkeit	Haptics/valence
Lebensmittelechtheit	Food safety
Hautverträglichkeit	Skin tolerance
Abriebbeständigkeit	Abrasion resistance
Verschleißbeständigkeit	Wear resistance
Hohe Härte	High degree of hardness
Anlaufschutz	Tarnish protection
geringe Reibung	Low friction
Biokompatibilität	Biocompatibility
Eignung als medizinisches Gerät	Suitability as a medicinal device
Zertifizierung	Certification

The only substance-specific alternative that is possible in theory is the depositing of chromium coatings from chromium (III) electrolytes. In a very comprehensive study from 2006, the Massachusetts Toxics Use Reduction Institute – TURI /1/ showed that the deposits from electrolytes containing Cr(III) should, in principle, result in the same coatings as the deposits from solutions containing Cr(VI) and noted that this requires more in-depth research, which is strongly supported by the United States Environmental Protection Agency.

Furthermore, however, the study puts into perspective the possibilities of applying the Cr(III)-based electrolytes and presents a considerably more complex process management. Current research work in Germany substantiates this result. For instance, Bohnet in his dissertation /14/ describes that the properties of the resulting coatings are highly dependent on the electrolytes used and also the use of the electrolytes is significantly more complex than the handling of the Cr(VI)-based electrolytes. In addition, it is only in rare individual cases that the required coating properties can be achieved.

Richtering /15/ also shows, based on investigations into the corrosion protection properties of the coatings deposited from Cr(III) electrolytes, that despite intensive developments, these have not reached the level of the coatings deposited from Cr(VI).

The implementation of Cr(III)-based methods cannot be foreseen. Corresponding electrolytes have been highly developed since the end of the twentieth century. Several applications have also been implemented in production already. However, the functions achieved are often reduced and are only sufficient or acceptable in isolated cases; the reproducibilities of properties achieved in particular are not yet satisfactory.

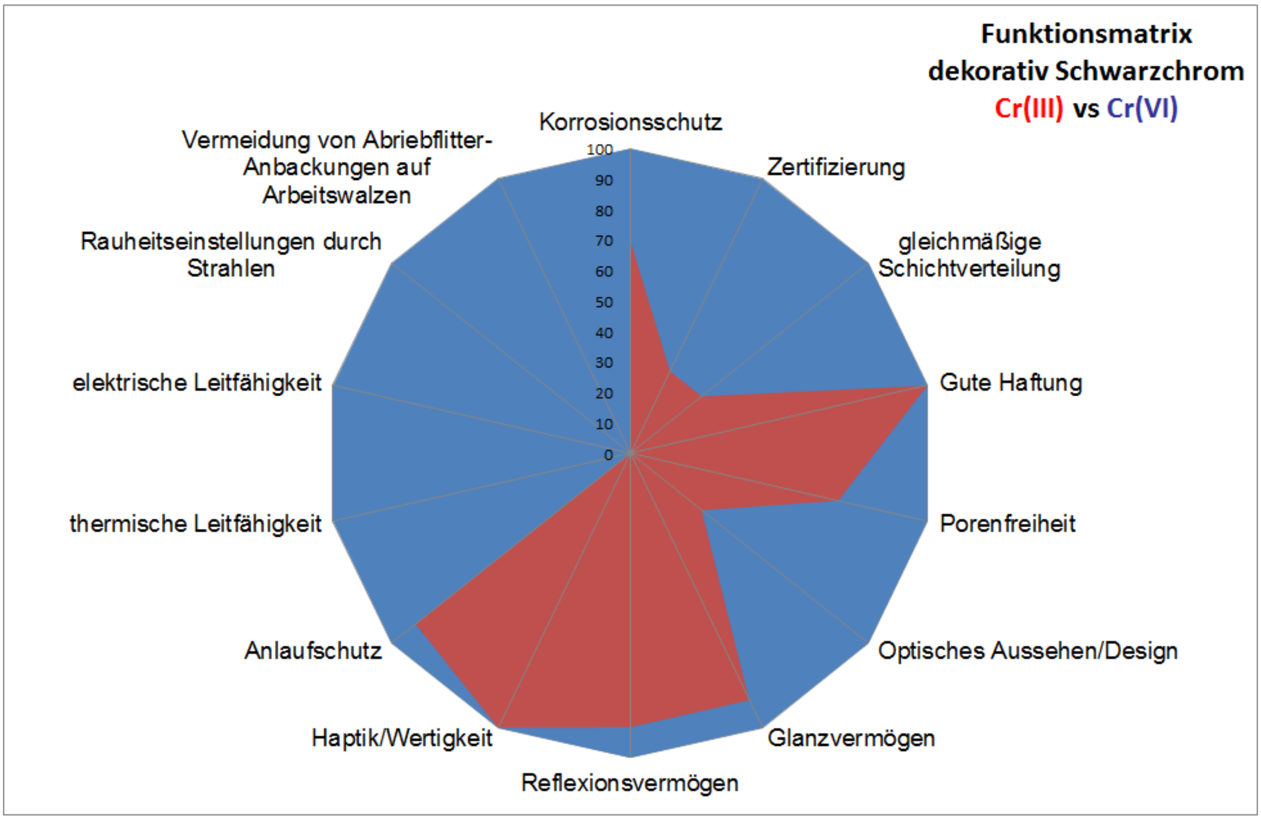

Figure 21: function matrix to compare decorative black chromium coatings deposited from Cr(III) electrolytes and Cr(VI) electrolytes

Funktionsmatrix dekorativ Schwarzchrom	**Function matrix decorative black chromium**
Cr(III) vs Cr (VI)	Cr(III) vs Cr(VI)
Korrosionsschutz	Corrosion protection
Zertifizierung	Certification
gleichmäßige Schichtverteilung	Uniform coating distribution
Gute Haftung	Good adhesion
Porenfreiheit	Non-porosity
Optisches Aussehen/Design	Visual appearance/design
Glanzvermögen	Shine
Reflexionsvermögen	Reflectivity
Haptik/Wertigkeit	Haptics/valence
Anlaufschutz	Tarnish protection
thermische Leitfähigkeit	Thermal conductivity
elektrische Leitfähigkeit	Electrical conductivity
Rauheitseinstellungen durch Strahlen	Roughness adjustment by means of blasting
Vermeidung von Abriebflitter-Anbackungen auf Arbeitswalzen	Prevention of abrasion flash build-up on work rolls

A project of the German association FGK [*Fachverband Galvanisierte Kunststoffe*], a field trial 'comparative studies on surfaces coated with chromium (III) and chromium (VI) electrolytes' has been conducted since 2012. As part of this project, sample parts coated using the chromium (III) method are being extensively tested at present (2015) and the quality of the coated parts assessed /16/. The current results (2015) show that reliable production methods do not yet exist.

The following response was formulated /17/: **'The trial results have shown a significant variation of the methods both in corrosion resistance and in colour consistency directly after deposition and after the field test and so it would be sensible to limit the types of methods. Otherwise the procurement processes of automotive manufacturers would no longer be manageable.'**

In principle, the coating with metallic chromium using other methods could also be considered a substance alternative. As, however, a parallel technology is required as the basis, this alternative is also considered when assessing the technology alternatives.

Risk assessment

- The critical factor continues to be the necessary use of boric acid to stabilise the electrolytes.
- The increased risk of a diffusion of nickel substances of the nickel coating, which is required as a bonding agent, to the surface is similarly an increased risk.

Outlook

- The chromium coatings from chromium (III) electrolytes do not yet achieve the required properties. The automotive sector in Germany, in particular, requires improved corrosion protection. Applications in Europe and internationally have difficulties with the stability of the required functions. An extensive use is therefore not foreseen in the decorative field either.
- Work has now begun to normalise or standardise the process. However, this can only begin once a reliable process has been developed. The related fields are the application in the food sector, the sanitary industry, the furniture industry and the automotive industry.
- There are comparable experiences in the black chromium field.
- No application is foreseen in the functional/hard chromium plating field.

2. Alternative technology replacement

Based on the framework conditions discussed in section 2.2, only the technologies that are possible under the accepted risk assessments shall be discussed.

a. WC/Co by thermal spraying

Alternatives for: functional chromium

The coatings produced using thermal spraying have been used as a parallel technology for functional chromium plating for many years. This is particularly successful in the area of wear protection for the adapted components.

However, a universal use comparable to that of chromium coatings is not possible. This technology is highly dependent upon the product and cannot be used in principle as an alternative technology by a contract coater or surface-finishing service provider.

The following function diagram clearly shows that the majority of properties achieved by chromium coatings cannot be fulfilled by the thermal spraying method.

The assessment is problematic because there is frequently no available data for the parameters being compared. The following function matrix therefore shows areas in which it is not possible to make a comparison as a result of a lack of data. However the fact is still clear that it is not possible to substitute the technology based on the current data situation.

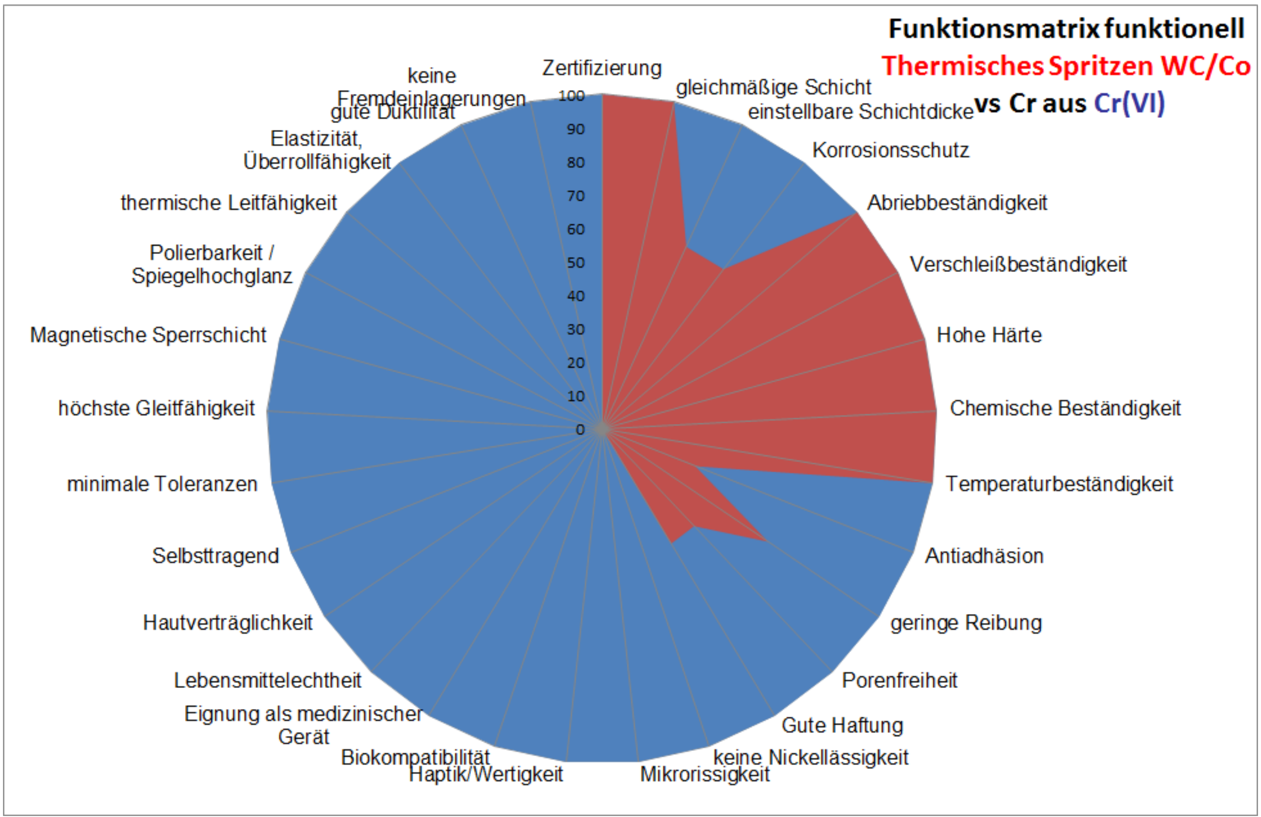

Figure 22: function matrix to compare functional chromium coatings, deposited from Cr(VI) electrolytes with WC/Co thermal spray coatings

Funktionsmatrix **funktionell** **Thermisches Spritzen WC/Co vs Cr aus CR(VI)**	**Function matrix** **Functional** **Thermal spraying WC/Co vs Cr from Cr(VI)**
Zertifizierung	Certification
gleichmäßige Schicht	Uniform coating
einstellbare Schichtdicke	Adjustable coating thickness
Korrosionsschutz	Corrosion protection
Abriebbeständigkeit	Abrasion resistance
Verschleißbeständigkeit	Wear resistance
Hohe Härte	High degree of hardness
Chemische Beständigkeit	Chemical resistance
Temperaturbeständigkeit	Temperature resistance
Antiadhäsion	Anti-adhesion
geringe Reibung	Low friction
Porenfreiheit	Non-porosity
Gute Haftung	Good adhesion
keine Nickellässigkeit	No nickel release
Mikrorissigkeit	Microcracking
Haptik/Wertigkeit	Haptics/valence
Biokompatibilität	Biocompatibility
Eignung als medizinisches Gerät	Suitability as a medicinal device

Lebensmittelechtheit	Food safety
Hautverträglichkeit	Skin tolerance
Selbsttragend	Self-supporting
minimale Toleranzen	Minimum tolerances
höchste Gleitfähigkeit	Maximum slippage
Magnetische Sperrschicht	Magnetic barrier
Polierbarkeit / Spiegelhochglanz	Polishability/high-shine mirror finish
thermische Leitfähigkeit	Thermal conductivity
Elastizität Überrollfähigkeit	Elasticity, roll-over capacity
gute Duktilität	Good ductility
keine Fremdeinlagerungen	No foreign substances

Risk assessment

- According to the explanation in the literature /6, 7/ the risk is comparable with chromium plating from Cr(VI) electrolytes.
- The spray additive that is not involved in creating the coating needs to be exhausted and disposed of separately.
- Spray powders that include chromium compounds are frequently used. In the course of the coating process these produce chromium (VI) compounds, which causes increased exposure.
- The German trade association for wood and metal observes that ultrafine particles, agglomerates and aggregates are formed with a particle size of less than 0.1 µm (< 100 nm), which are produced as undesirable by-products, for example as a result of thermal processes such as welding, thermal cutting, thermal spraying or brazing /18/. Primarily as part of the hazard assessment, the substance-specific occupational limit values specified in the TRGS 900 and the general dust limit value (A and E fraction) must be complied with. According to the TRGS 905, the classifications of substances as carcinogenic, mutagenic or toxic for reproduction must be considered and their concentration minimised in the workplace.

Outlook

- The method was introduced many years ago and was not able to replace functional chromium plating either technically or economically.
- We do not expect a broad scale replacement of metallic chromium coatings.
- The use is not technically possible for an electroplating contract coater
- The technology is established and has replaced the use of hard chromium coatings in some areas. Similarly to the use of chromium coatings, entire systems have increasingly been developed for which the substrate to be coated and the coating are coordinated in terms of function.
- It is expected that thermal spraying and functional chromium plating will experience a further parallel development and adjustment of functions.
- Long-standing experience of some companies in the market (more than 10 years) shows that as a result of the high maintenance effort (for example, piston rods, shafts, calender rollers, printing rollers, etc.) and chipping, increasing numbers of end customers reject these finishes and return to the more reliable hard chromium coatings.

b. PVD Cr

Alternative for: decorative chromium

A comparable situation is given for this technology. It is also successfully used in various fields in which specific and individual requirements are needed (e.g. Ropal method /19/ or to manufacture headlight reflectors).

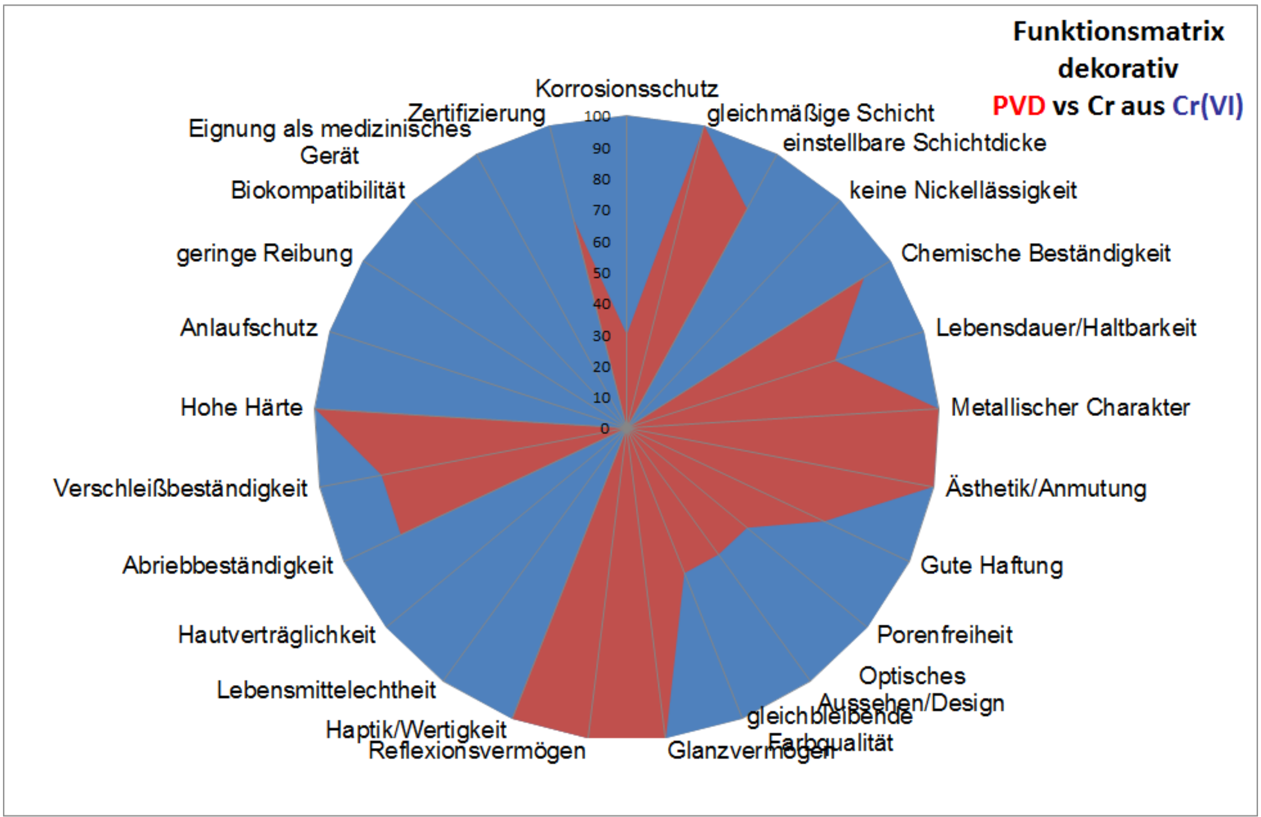

Figure 23: function matrix to compare decorative chromium coatings, deposited from Cr(VI) electrolytes with chromium coatings produced by PVD methods

Funktionsmatrix **dekorativ** **PVD vs Cr aus Cr(VI)**	**Function matrix** **Decorative** **PVD vs Cr from Cr(VI)**
Korrosionsschutz	Corrosion protection
gleichmäßige Schicht	Uniform coating
einstellbare Schichtdicke	Adjustable coating thickness
keine Nickellässigkeit	No nickel release
Chemische Beständigkeit	Chemical resistance
Lebensdauer/Haltbarkeit	Service life/durability
Metallischer Charakter	Metallic character
Ästhetik/Anmutung	Aesthetics/appearance
Gute Haftung	Good adhesion
Porenfreiheit	Non-porosity
Optisches Aussehen/Design	Visual appearance/design
gleichbleibende Farbqualität	Consistent colour quality
Glanzvermögen	Shine

Reflexionsvermögen	Reflectivity
Haptik/Wertigkeit	Haptics/valence
Lebensmittelechtheit	Food safety
Hautverträglichkeit	Skin tolerance
Abriebbeständigkeit	Abrasion resistance
Verschleißbeständigkeit	Wear resistance
Hohe Härte	High degree of hardness
Anlaufschutz	Tarnish protection
geringe Reibung	Low friction
Biokompatibilität	Biocompatibility
Eignung als medizinisches Gerät	Suitability as a medicinal device
Zertifizierung	Certification

Risk assessment

- According to the explanations in the literature the risk is comparable with chromium plating from Cr(VI) electrolytes /6, 10/.
- Synthesising the necessary chromium to manufacture the target produces a considerable chromate load /10/.

Outlook

- The technology is established and has replaced the use of chromium coatings (primarily in the decorative-functional field) in some areas. Similar to the use of chromium coatings, entire systems have increasingly been developed for which the substrate to be coated and the coating are coordinated with each other in terms of function.
- The method was introduced many years ago and was not able to replace functional chromium plating (specialist fields) or decorative chromium plating either technically or economically.
- We do not expect a broad scale replacement of metallic chromium coatings.
- The use is not technically possible for electroplating contract coaters.
- It is expected that the vacuum method and chromium plating will experience a further parallel development and adjustment of functions.
- Replacement of chromium coatings is conceivable, though not expected in the next 10 years.

c. DLC coatings

Alternative for: functional chromium

These coating systems complement the other methods and display comparable characteristics.

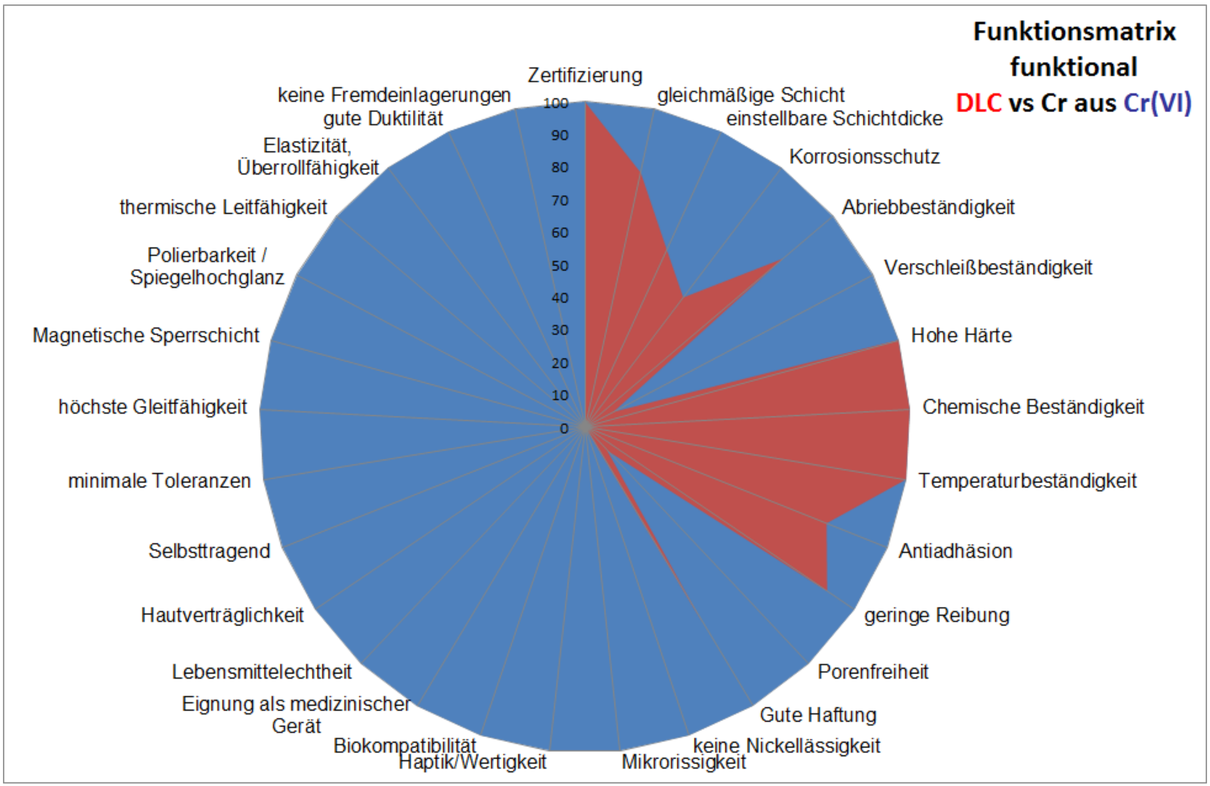

Figure 24: function matrix to compare functional chromium coatings, deposited from Cr(VI) electrolytes with DLC coatings

Funktionsmatrix funktional DLC vs Cr aus Cr(VI)	**Function matrix Functional DLC vs Cr from Cr(VI)**
Zertifizierung	Certification
gleichmäßige Schicht	Uniform coating
einstellbare Schichtdicke	Adjustable coating thickness
Korrosionsschutz	Corrosion protection
Abriebbeständigkeit	Abrasion resistance
Verschleißbeständigkeit	Wear resistance
Hohe Härte	High degree of hardness
Chemische Beständigkeit	Chemical resistance
Temperaturbeständigkeit	Temperature resistance
Antiadhäsion	Anti-adhesion
geringe Reibung	Low friction
Porenfreiheit	Non-porosity
Gute Haftung	Good adhesion
keine Nickellässigkeit	No nickel release
Mikrorissigkeit	Microcracking
Haptik/Wertigkeit	Haptics/valence
Biokompatibilität	Biocompatibility
Eignung als medizinisches Gerät	Suitability as a medicinal device
Lebensmittelechtheit	Food safety

Hautverträglichkeit	Skin tolerance
Selbsttragend	Self-supporting
minimale Toleranzen	Minimum tolerances
höchste Gleitfähigkeit	Maximum slippage
Magnetische Sperrschicht	Magnetic barrier
Polierbarkeit / Spiegelhochglanz	Polishability/high-shine mirror finish
thermische Leitfähigkeit	Thermal conductivity
Elastizität Überrollfähigkeit	Elasticity, roll-over capacity
gute Duktilität	Good ductility
keine Fremdeinlagerungen	No foreign substances

Risk assessment

- According to the explanation in section 1, the risk is comparable with chromium plating from electrolytes containing chromium trioxide.

Outlook

- The technology is established and has found its use in specialist fields.
- The method was introduced many years ago and could not replace functional chromium plating either technically or economically.
- We do not expect a broad scale replacement of metallic chromium coatings.
- The use is not technically possible for an electroplating contract coater.
- This method is consistently unsuitable as a replacement for chromium coatings.

d. Painting

Alternative for: decorative black chromium

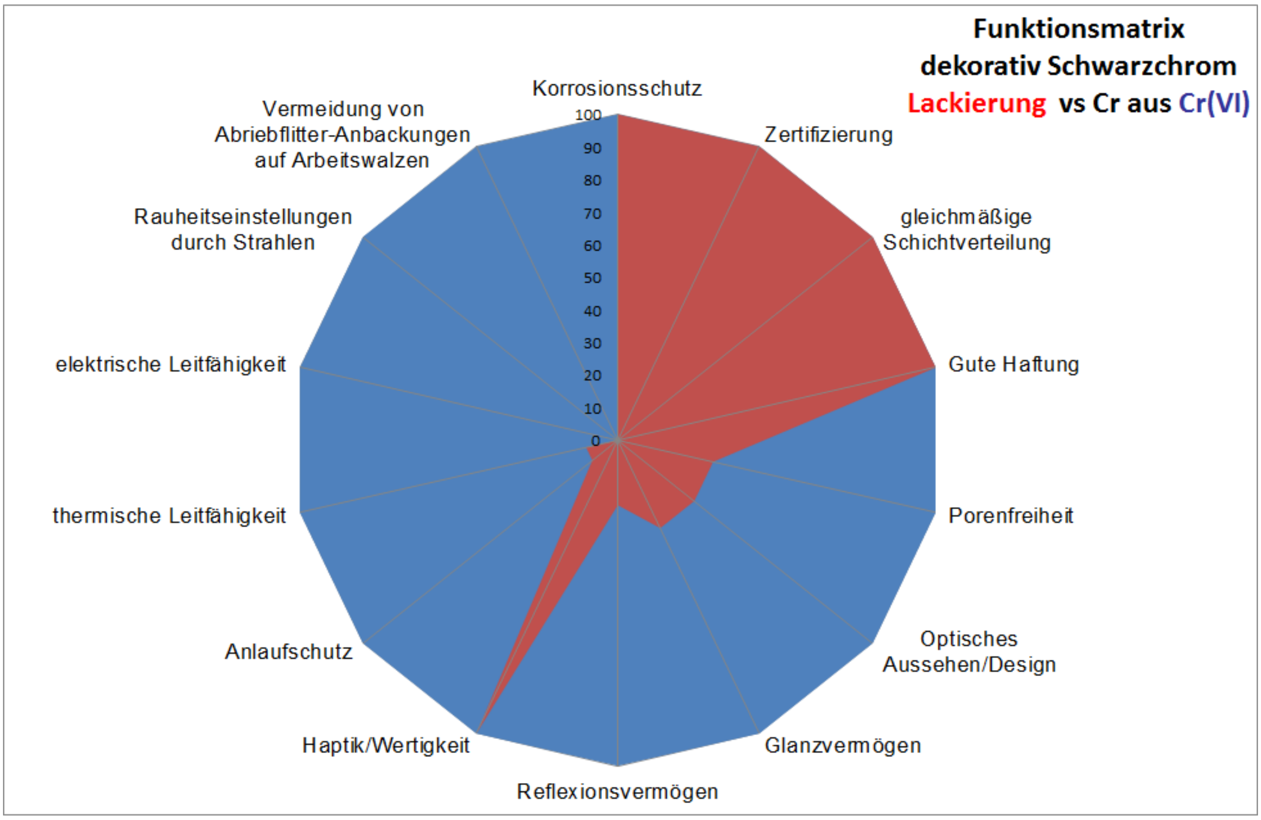

Figure 25: function matrix to compare decorative-functional black chromium coatings, deposited from Cr(VI) electrolytes with painting

Funktionsmatrix **dekorativ** **Schwarzchrom Lackierung vs Cr aus Cr(VI)**	**Function matrix** **Decorative** **black chromium coating vs Cr from Cr(VI)**
Korrosionsschutz	Corrosion protection
Zertifizierung	Certification
gleichmäßige Schichtverteilung	Uniform coating distribution
Gute Haltung	Good adhesion
Porenfreiheit	Non-porosity
Optisches Aussehen/Design	Visual appearance/design
Glanzvermögen	Shine
Reflexionsvermögen	Reflectivity
Haptik/Wertigkeit	Haptics/valence
Anlaufschutz	Tarnish protection
thermische Leitfähigkeit	Thermal conductivity
elektrische Leitfähigkeit	Electrical conductivity
Rauheitseinstellungen durch Strahlen	Roughness adjustment by means of blasting
Vermeidung von Abriebflitter-Anbackungen auf Arbeitswalzen	Prevention of abrasion flash build-up on work rolls

Risk assessment

- Use of organic solvents and potentially critical paint ingredients.

Outlook

- As a result of the diversity of the functions required, painting is not yet mature enough to replace chromium plating.
- There is no method that is ready for application. The optical properties in particular are not adequate.
- Further technical development is needed.

e. Heat treatment/hardening

Alternative for: functional chromium plating

Using elevated temperatures and the addition of reactive gases, reactions are initiated between the base material and the gases. The coatings show increased roughness and low dimensional precision.

Tests performed by users from VECCO give the following results:

- After nitriding, the users surveyed (members of VECCO e.V.) detected a greatly reduced level of shine and high discolouration.
- The surface hardness was not significantly increased.
- A reduction in corrosion protection was detected.
- As a result of high thermal distortion, a precision coating was not possible.
- Adequate corrosion protection can only be achieved if the base material (steel) already contains at least 13% Cr.

Risk assessment

- Not known

Outlook

- User tests show that this method is unsuitable.

  Based on these results, several end customers have transitioned to precision chromium plating.
- The method is technically unsuitable as an alternative.

f. Laser methods and build-up welding techniques

Alternative for: functional chromium plating

The applications are very limited and thus only specialist companies have experience.

The experiences of these companies in the market show that customers that have developed the method independently return to hard chromium coating.

Furthermore, literature studies /20/ show that the method is very extensive and the coatings only correspond to limited requirements.

Risk assessment

- Not known

Outlook

- No application prospects
- Technically unsuitable as an alternative

g. Currentless nickel plating (SVHC relevant)

Alternative for: functional chromium plating, decorative chromium plating, black chromium plating

The method is based on electroplating. Substitution in production is possible.

Tests performed by individual users (members of VECCO e.V.) show the following results:

- hardness, anti-adhesion, shine and wear protection are too low
- friction coefficient is too high
- the methods are significantly more expensive (about 50%)
- the electromagnetic properties are inferior, particularly the magnetic properties
- reflectivity too high
- not resistant to sulphur compounds or nitrous gases
- only smaller components can be coated
- tendency to ‘seize’

Risk assessment

- SVHC relevant: the boric acid and other boron compounds required for a use are being discussed for inclusion in Annex XIV.
- At present it is being discussed whether to regulate the use of nickel metal and nickel salts with limit values.
- Risk of carcinogenicity.

Outlook

- Already used for specialist applications and so there is sufficient experience.
- Not considered any further because of the high risk.

4.1.2 Electropolishing

The methods discussed as replacements can be used depending on the substrate. They are based on using acids and highly corrosive chemicals. Consideration is also given to the possibility of mechanical treatment.

A key point that is not achieved is the protection of the base material by means of passivating, particularly steel, and cleaning particle contamination as a result of the oxidation potential of the chromate.

No chromate remains on the surface of the treated workpiece.

The essential properties and their importance are compared in the following function matrices. Electrochemical polishing with current flow in Figure 26 and mechanical polishing in Figure 27 are compared with electrochemical polishing in chromium (VI) electrolytes.

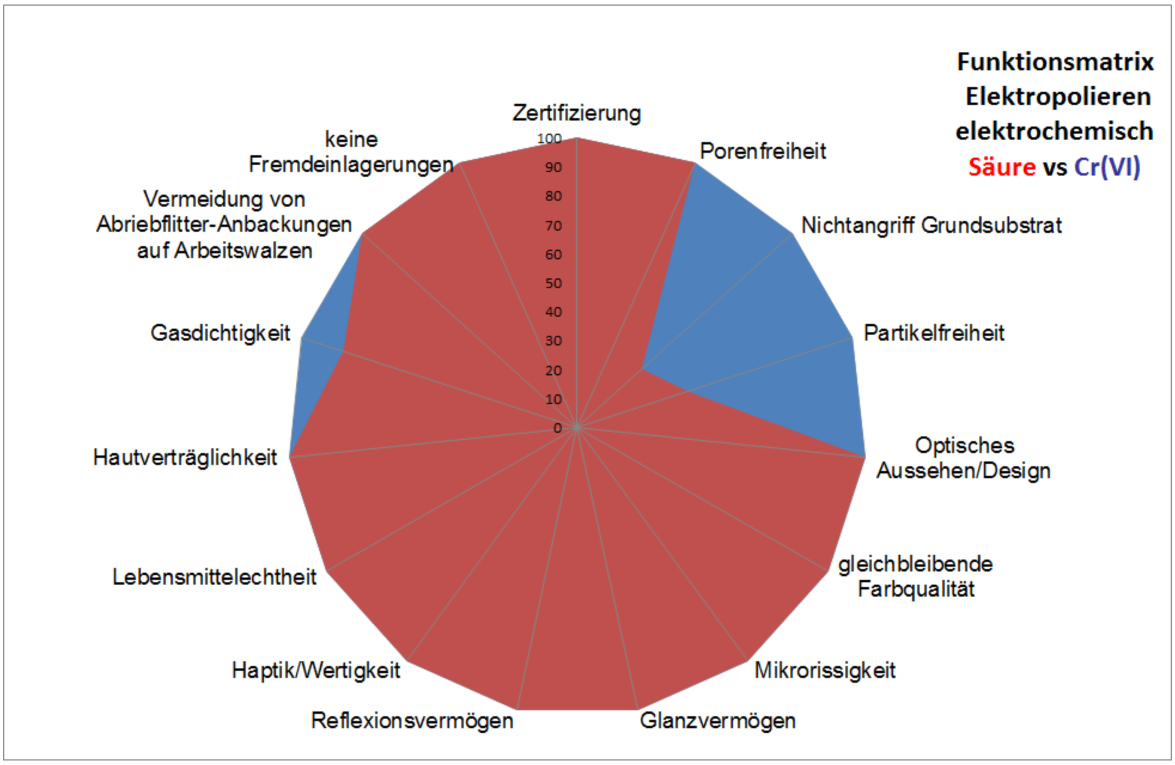

Figure 26: function matrix to compare electropolishing with current flow using acids with chromium (VI) electrolytes

Funktionsmatrix Elektropolieren elektrochemisch Säure vs Cr(VI)	**Function matrix Electropolishing Electrochemical Acid vs Cr(VI)**
Zertifizierung	Certification
Porenfreiheit	Non-porosity
Nichtangriff Grundsubstrat	Does not attack base substrate
Partikelfreiheit	Particle free
Optisches Aussehen/Design	Visual appearance/design
gleichbleibende Farbqualität	Consistent colour quality
Mikrorissigkeit	Microcracking
Glanzvermögen	Shine
Reflexionsvermögen	Reflectivity
Haptik/Wertigkeit	Haptics/valence
Lebensmittelechtheit	Food safety
Hautverträglichkeit	Skin tolerance
Gasdichtigkeit	Impermeability to gas
Vermeidung von Abriebflitter-Anbackungen auf Arbeitswalzen	Prevention of abrasion flash build-up on work rolls
keine Fremdeinlagerungen	No foreign substances

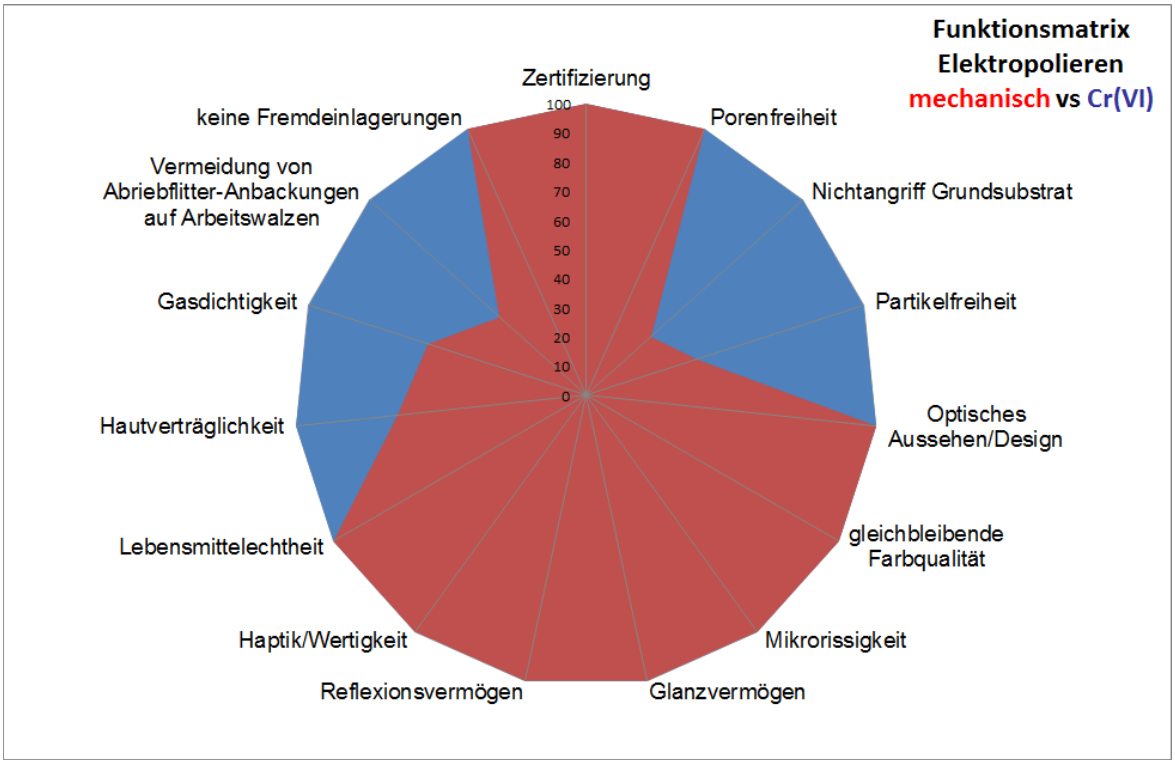

Figure 27: function matrix to compare electropolishing, mechanical polishing and the electrochemical method using chromium (VI) electrolytes

Funktionsmatrix Elektropolieren mechanisch vs Cr(VI)	**Function matrix Electropolishing Mechanical vs Cr(VI)**
Zertifizierung	Certification
Porenfreiheit	Non-porosity
Nichtangriff Grundsubstrat	Does not attack base substrate
Partikelfreiheit	Particle free
Optisches Aussehen/Design	Visual appearance/design
gleichbleibende Farbqualität	Consistent colour quality
Mikrorissigkeit	Microcracking
Glanzvermögen	Shine
Reflexionsvermögen	Reflectivity
Haptik/Wertigkeit	Haptics/valence
Lebensmittelechtheit	Food safety
Hautverträglichkeit	Skin tolerance
Gasdichtigkeit	Impermeability to gas
Vermeidung von Abriebflitter-Anbackungen auf Arbeitswalzen	Prevention of abrasion flash build-up on work rolls
keine Fremdeinlagerungen	No foreign substances

Risk assessment

- Strong acids used for electrochemical or chemical polishing
- Dust formation in mechanical polishing (risk of respirable dust)

Outlook

- Mechanical methods can be used for substrates that do not need to be treated with precision.

4.1.3 Stripping

The methods that are specified in electropolishing are discussed.

A key point that is not achieved is the protection of the base material, particularly steel, and cleaning particle contamination as a result of the oxidation potential of the chromate.

No chromate remains on the surface of the treated workpiece.

Risk assessment

- Strong acids used for electrochemical or chemical polishing
- Dust formation in mechanical polishing (risk of respirable dust)

Outlook

- Methods that protect the base material are not known.
- No alternative is known that achieves the required passivation effect.

4.1.4 Plastic pickling

As a result of development in the field of plastics, methods have long been developed for processing the polymers used.

As a result of the necessary oxidative attack, other technologies are similarly high risk.

At the same time it must be ensured that the subsequent coatings are highly adhesive. Debonding of the deposited metallic coatings represents a risk of injury to the (end) user.

No chromate remains on the surface of the treated workpiece.

The following methods under development have the greatest potential use.

- Sulphonation using sulphonic acid (Figure 28)
- Oxidative methods, e.g. use of permanganate (Figure 29)

Risk assessment

- The specified methods also use high-risk substances. For instance, permanganate is classified as carcinogenic.

Outlook

- At present there are no methods on a laboratory scale that are promising for practical implementation.
- No releases have yet been issued by customers.
- Based on development in polymer technology, further intensive development is assumed.
- Approvals from authorities and end customers are essential.
- The methods cannot be used at present.
- The industry is working on implementation, however there needs to be a reliable technology before it can be implemented on a production scale.

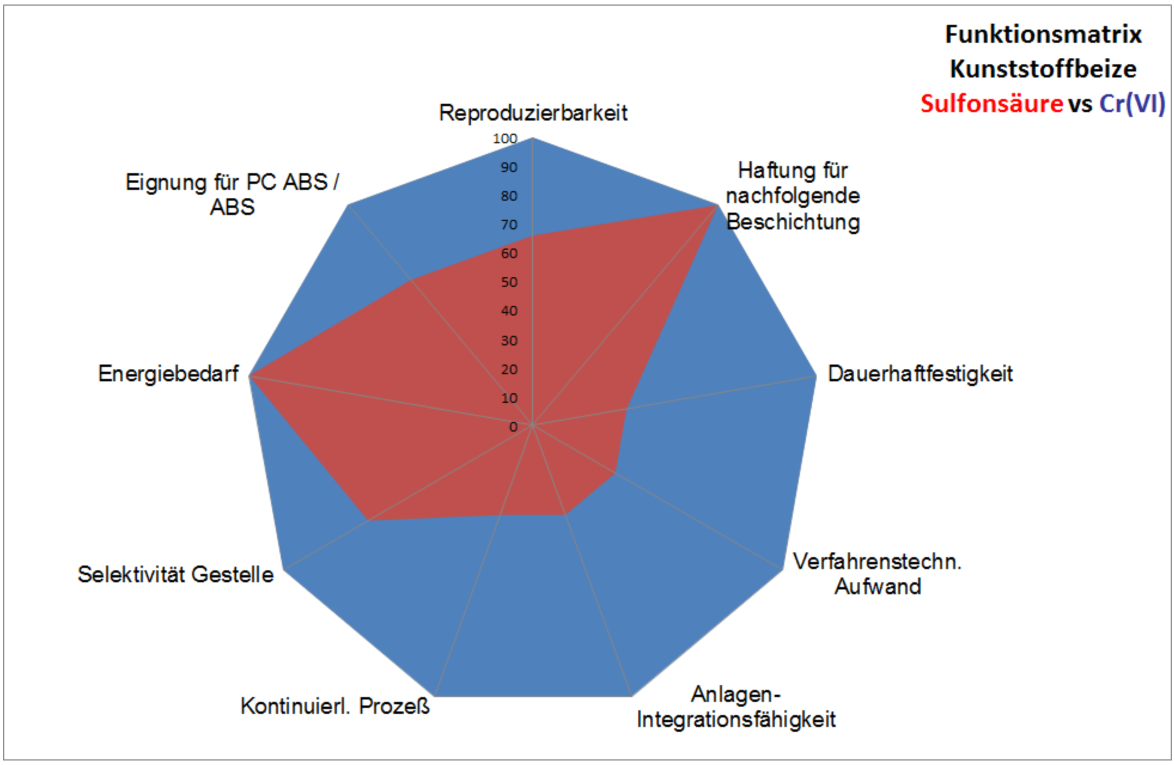

Figure 28: function matrix to compare plastics pickles: sulphonation method compared with the electrochemical method using chromium (VI) electrolytes

Funktionsmatrix **Kunststoffbeize** **Sulfonsäure vs Cr(VI)**	**Function matrix** **Plastics pickle** **Sulphonic acid vs Cr(VI)**
Reproduzierbarkeit	Reproducibility
Haftung für nachfolgende Beschichtung	Adhesion for subsequent coating
Dauerhaftfestigkeit	Long-term adhesive strength
Verfahrenstechn. Aufwand	Process engineering outlay
Anlagen-Integrationsfähigkeit	Plant integration capacity
Kontinuierl. Prozeß	Continuous process
Selektivität Gestelle	Selectivity framework
Energiebedarf	Energy requirement
Eignung für PC ABS/ ABS	Suitability for PC ABS/ABS

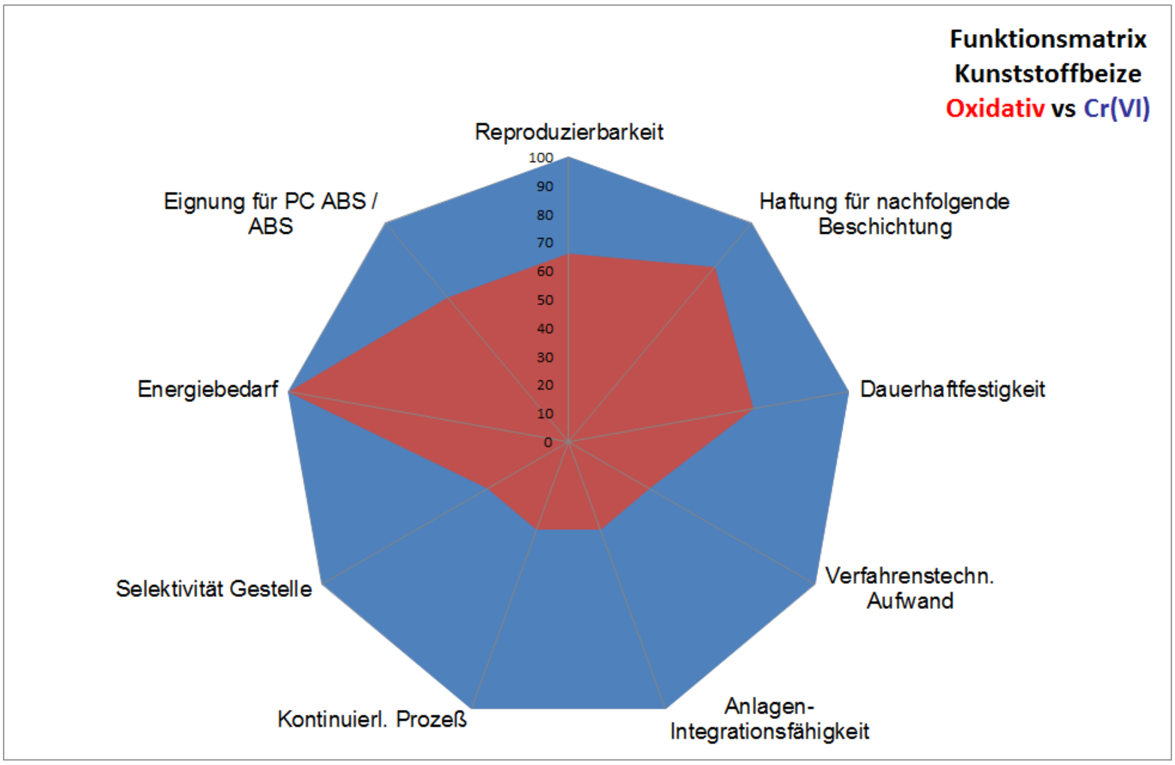

Figure 29: function matrix to compare plastics pickles: Oxidative process compared with the electrochemical process using chromium (VI) electrolytes

Funktionsmatrix Kunststoffbeize Oxidativ vs Cr(VI)	**Function matrix Plastics pickle Oxidative vs Cr(VI)**
Reproduzierbarkeit	Reproducibility
Haftung für nachfolgende Beschichtung	Adhesion for subsequent coating
Dauerhaftfestigkeit	Long-term adhesive strength
Verfahrenstechn. Aufwand	Process-engineering outlay
Anlagen-Integrationsfähigkeit	Plant integration capacity
Kontinuierl. Prozeß	Continuous process
Selektivität Gestelle	Selectivity framework
Energiebedarf	Energy requirement
Eignung für PC ABS/ ABS	Suitability for PC ABS/ABS

4.1.5 Anodising (hard anodising)

As a result of the primary use of aluminium materials in the aviation industry, the sector is working hard to develop other methods. Methods have been successfully developed that can achieve suitable thin coatings in the µm range as preparation for subsequent coating (e.g. painting). The developments of chromate-free methods to prepare hard anodising coatings have not been successful, as various research projects show (e.g. /21/).

The critical points are hardness, roughness and subsequent certification.

In-depth studies show that using acids results in a highly roughened product surface, in which case the necessary precision cannot be guaranteed /22/.

No chromate remains on the surface of the treated workpiece.

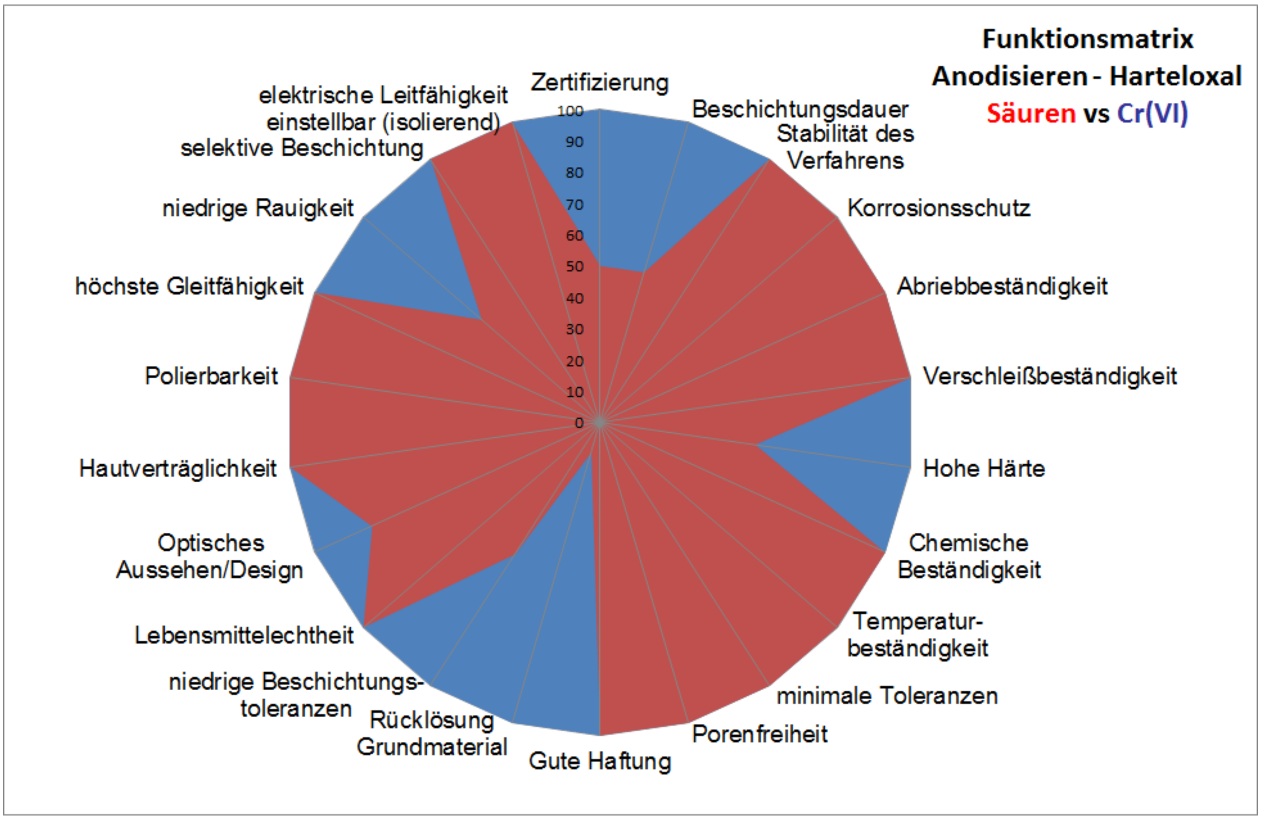

Figure 30: function matrix to compare anodising: use of acids compared with the electrochemical process using chromium (VI) electrolytes

Funktionsmatrix **Anodisieren – Harteloxal** **Säuren vs Cr(VI)**	**Function matrix** **Anodising – hard anodising** **Acids vs Cr(VI)**
Zertifizierung	Certification
Beschichtungsdauer	Coating duration
Stabilität des Verfahrens	Stability of the method
Korrosionsschutz	Corrosion protection
Abriebbeständigkeit	Abrasion resistance
Verschleißbeständigkeit	Wear resistance
Hohe Härte	High degree of hardness
Chemische Beständigkeit	Chemical resistance
Temperaturbeständigkeit	Temperature resistance
minimale Toleranzen	Minimum tolerances
Porenfreiheit	Non-porosity
Gute Haftung	Good adhesion
Rücklösung Grundmaterial	Dissolution of base material
niedrige Beschichtungstoleranzen	Low coating tolerances
Lebensmittelechtheit	Food safety
Optisches Aussehen/Design	Visual appearance/design
Hautverträglichkeit	Skin tolerance
Polierbarkeit	Polishability

höchste Gleitfähigkeit	Maximum slippage
niedrige Rauigkeit	Low roughness
selektive Beschichtung	Selective coating
elektrische Leitfähigkeit einstellbar (isolierend)	Adjustable electrical conductivity (insulating)

Risk assessment

- Use of acids

Outlook

- An alternative for preparing hard anodised coatings cannot be identified.

4.1.6 Stainless steel dyes (form functional, thin passive coatings)

The methods discussed are those that are specified for electropolishing or stripping. No chromate remains on the surface of the treated workpiece.

A key point that is not achieved is the protection of the base material as well as precision. Steel, in particular, cannot therefore be treated by other methods.

Build-up methods such as painting create a coating that is too thick.

Risk assessment

- No known alternatives

Outlook

- No known alternatives

4.1.7 Comparison of technologies discussed in literature

In accordance with the explanations in section 1.5.2, the following materials are used:

- Synthesis studies

  These generally consist of the results discussed in the literature. They may be used as an initial source of information, however, they do not enable the applicability to be assessed. Frequently, the results presented cannot generally be used.

The following materials are not used:

- Marketing /23/

  Presents possible positive properties in the run-up to the market launch. No objective consideration is desired or intended.
- Patent searches:

  Qualification can only be evaluated to a limited extent as generally only the first studies are published.

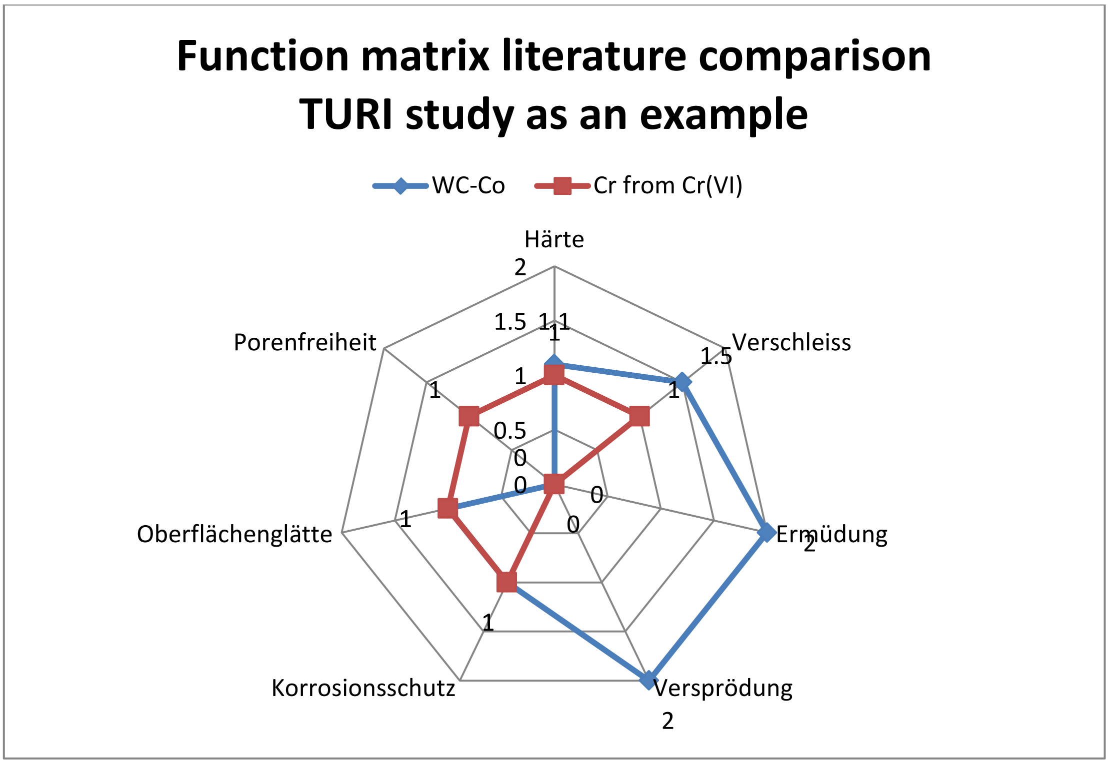

Figure 31: function matrix to assess the results of the literature

Funktionsmatrix Literaturvergleich Studie TURI als Beispiel	**Function matrix literature comparison TURI study as an example**
WC-Co	WC-Co
Cr from Cr(VI)	Cr from Cr(VI)
Härte	Hardness
Verschleiss	Wear
Ermüdung	Fatigue
Versprödung	Embrittlement
Korrosionsschutz	Corrosion protection
Oberflächenglätte	Surface slip
Porenfreiheit	Non-porosity

The data in the literature was assessed in the same way via function matrices.

A key result is that the assessment criteria of the studies only partly match the requirements of the different types of chromium plating. In both the decorative and the functional field only specific and selected parameters are considered and they do not permit an overall picture.

The following figure shows that the key parameter ‘porosity’ is not taken into account, while fatigue and embrittlement are only regarded as being partially relevant in practice.

Result

A great deal of attention must be paid to the use for the end products and the functions required by the customer. Consequently, the results of the literature studies are only partially suitable for assessing the specific use by surface finishers.

4.1.8 Evaluation of potential risks of alternatives – risk assessment

a. The literature only provides partial data on assessing the potential risk of the considered alternatives. Various review articles, for example /6, 24, 25 and references in these were evaluated.

For instance, a study by the German Association of Thermal Sprayers stated that when using the thermal spraying method, requirements relating to safety and the environment need to be taken into account, but no further details are given /6, 7/.

In particular, the respirability of nanoparticles in the field of thermal spraying methods and the PVD method should be viewed critically because no suitable filtration systems exist yet. The discussion is comparable to the discussions on fine particulate pollution.

A dose-response relationship is currently being worked hard on, however the relevant properties cannot be clearly identified /e.g. 26/ and therefore the potential risk minimisation measures are also unknown.

For the PVD field, reference is made to the risks already outlined in the IZT study /10/.

b. Further assessment is problematic:
   - at present, the risks posed by nanoparticles are being assessed in depth /27/. Consequently, nanoparticles are not yet clearly classified /26/.
   - Frequently, there is no differentiation between the risk of a technology and a chemical substance.

Result

The risk potential in the use is therefore estimated as being comparable for all technologies.

This is also supported by the fact that production in the surface-finishing industry is conducted under comparable conditions.

Overall it should be stressed that the available information does not permit a transparent and clear assessment.

4.1.9 Evaluation of economic relevance of alternatives/parallel technologies

The literature also only permits limited statements on this topic.

This is essentially due to the different state of development of the technologies. The electroplating surface-finishing industry is a technology that has been used for a long time. There is a great deal of experience and a close link with the finished products. Consequently, no quantum leaps are expected in this field. However, there is also continuous further development, which in recent decades has particularly focused on close links with the end customers.

For instance, the deposition of chromium coatings from Cr(III) electrolytes has been studied and developed for many years. However, no methods that make economic sense could yet be brought to the market.

This is also confirmed by international research and development projects.

For example, the following presents the result of the EU project ‘ecochrome’ (2006), which was worked on in collaboration with the international consortium HCAT (Hard Chrome Alternatives Team). Further studies confirm this perspective /28/.

The results of the ecochrome project on using Cr(III) electrolytes are summarised as follows /29/:

Start of quotation:

Advantages

- Environmentally friendly: Cr(VI)-free electrolyte
- Satisfying microhardness: better than Cr(VI) after HT
- Satisfying appearance BUT depending on pH, flow rate, thickness.
- Satisfying adhesion and tribological properties (wear, coefficient of friction,…) (Quite the same as Cr(VI))
- Possible to control and maintain the chemical composition of the bath

Drawbacks:

- Macrocracks and porosity
  - low corrosion resistance on carbon steel
  - corrosion resistance can be improved with Ni underlayer.
- Limited plated thickness: 60–100 µm (intermediate rectification must be necessary for higher thickness)
- Low throwing power: problems with holes and complex geometries
- Black areas in borders
- Need frequent analysis of the bath: expensive
- Cl_2 gas evolution; other anodes to test
- Bad cohesion; problems with cross sections

End of quotation

Result

In many cases, information in the literature still cites a high development potential of the methods discussed as alternatives.

Methods that have already proven their marketability are used in the fields in which they achieve the required functions. A general replacement of chromium coatings is neither technically nor economically possible.

A generally accepted estimation of the economic outlay is not possible from a technological perspective.

4.2 Description of efforts made to identify possible alternatives/parallel technologies

Analysing the supply chains and customer-supplier relationships that exist in surface engineering results in two basic types of positions within the supply chain. The details are presented in the SEA.

1. Type 1 = 1:1

   This type of positioning within the supply chain is characterised in that for the surface-finishing operation of the customer that manufactures or further processes the part, a clear specification is given for treating the relevant part. This 1:1 relationship is typical of long-term, static business relationships that are generally associated with specialised plants and/or processes. The logical conclusion here is subject to selecting a possible alternative – for instance one that is technically and economically feasible – at the component processors or client of the contract company that is performing the surface treatment. The company acts as an ‘extended workbench’ without being able to influence the choice or development of the technology. This situation is typical of the automotive and aerospace industries. Component manufacturers frequently reserve the right to select the technology.

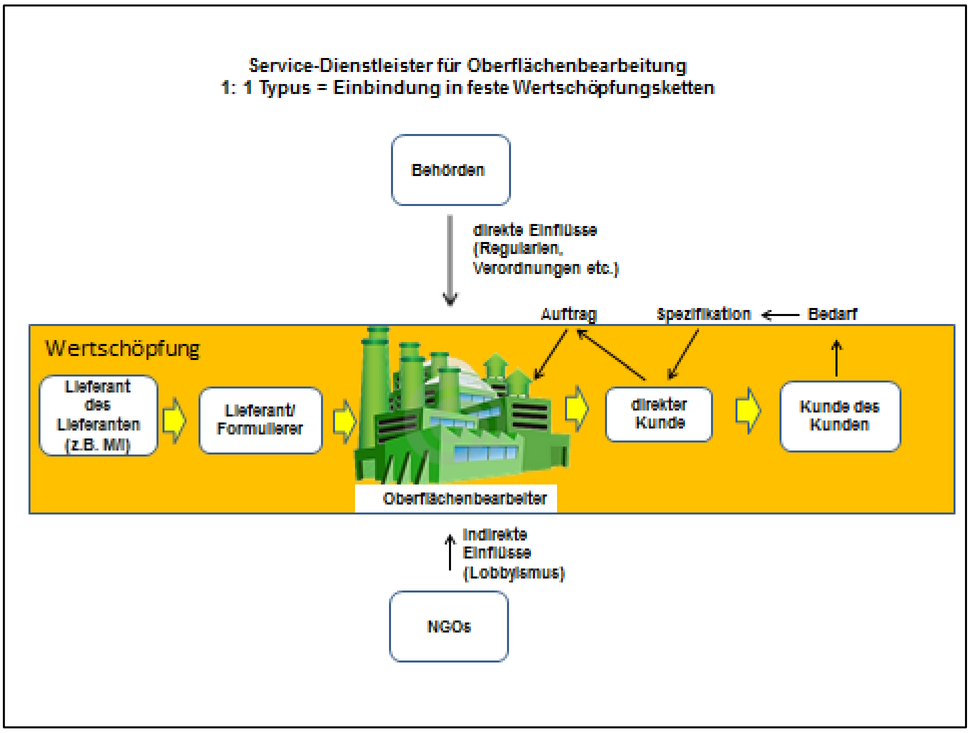

Figure 32: illustration of the situation of a surface-finishing company that has processed a selected product for many years

Service-Dienstleister für Oberflächenbearbeitung **1: 1 Typus = Einbindung in feste Wertschöpfungsketten**	**Surface-finishing service provider** **1: 1:1 type = inclusion in fixed value-added chains**
Behörden	Authorities
direkte Einflüsse (Regularien, Verordnungen etc.)	Direct influences (rules, regulations, etc.)
Auftrag	Order
Spezifikation	Specification
Bedarf	Requirement
Wertschöpfung	Added value
Lieferant des Lieferanten (z.B. M/I)	Supplier of the supplier (e.g. M/1)
Lieferant/ Formulierer	Supplier/formulator
Direkter Kunde	Direct customer
Kunde des Kunden	Customer of the customer
Oberflächenbearbeiter	Surface processor
indirekte Einflüsse (Lobbyismus)	Indirect influences (lobbying)
NGOs	NGOs

2. Type 2 = 1:n

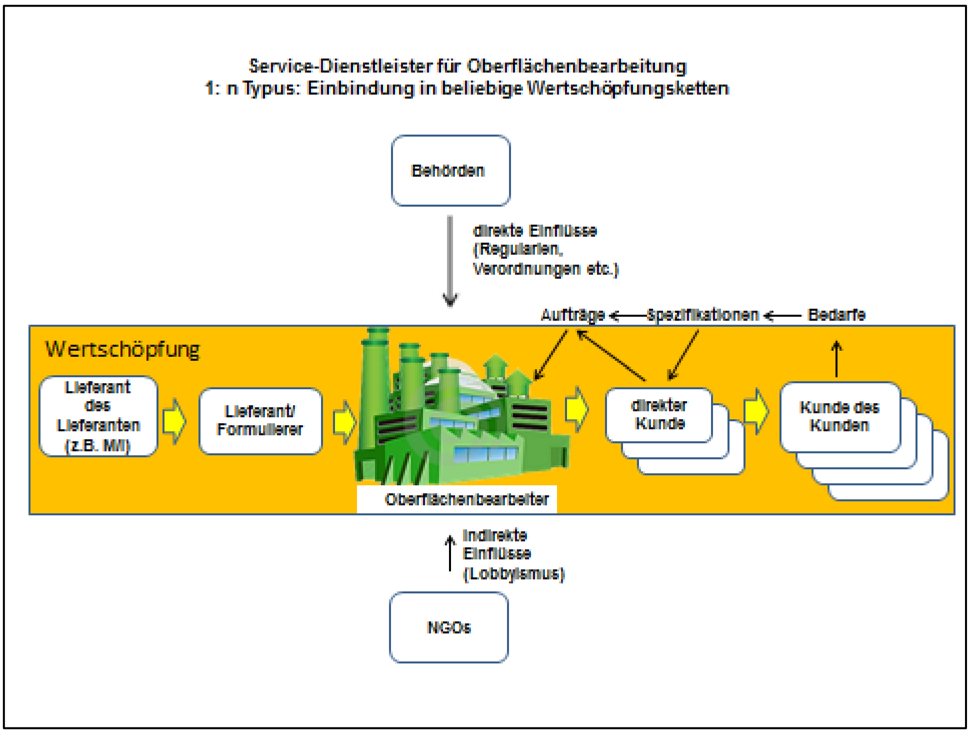

Figure 33: illustration of the situation of a surface-finishing company that processes a multitude of products in short time frames

Service-Dienstleister für Oberflächenbearbeitung **1: n Typus = Einbindung in beliebige Wertschöpfungsketten**	**Surface-finishing service provider** **1:n type = inclusion in any value-added chains**
Behörden	Authorities
direkte Einflüsse (Regularien, Verordnungen etc.)	Direct influences (rules, regulations, etc.)
Aufträge	Orders
Spezifikationen	Specifications
Bedarfe	Requirements
Wertschöpfung	Added value
Lieferant des Lieferanten (z.B. M/I)	Supplier of the supplier (e.g. M/1)
Lieferant/ Formulierer	Supplier/formulator
Direkter Kunde	Direct customer
Kunde des Kunden	Customer of the customer
Oberflächenbearbeiter	Surface processor
indirekte Einflüsse (Lobbyismus)	Indirect influences (lobbying)
NGOs	NGOs

In this case, the processing company acts as a service provider that offers surfaces with pre-defined properties. Customers choose the service if the surface treatment offered corresponds to their requirements. Consequently the processing company is part of any number of supply chains and value-added chains. They vary constantly and on a daily basis. Often, the surface-finishing company does not know the use of the components that they need to finish, frequently they are not even aware of the end customer and therefore they cannot influence the design and selection.

This type is characterised by short-term, often one-off business relationships, a lack of specifications (because they themselves bring the properties of the surface treatment to the market in the same way as a catalogue of properties). It is key to note that it is essential for the 1:n company to be able to offer all the properties of surface treatments (see diagram p. 27). Otherwise their 'range of properties' would be limited and the number of their potential customers would drop. In addition, they are also specialised in specific surface treatments and therefore a specific clientèle. Their service corresponds to their profession and therefore their professional training.

4.2.1 Research and development

The 1:1 companies directly support the endeavours of the contracting part manufacturer if they so desire. Generally, all studies are performed – in some cases together with process chemistry suppliers – once there is a framework agreement and a longer term commitment. At this point, the preliminary investigations reached the definitive conclusion that the contractually agreed surface processing, in the present case the Cr(VI)-based treatment, creates the necessary surface properties of the part in the manner required by the customer. During series manufacture, the surface-finishing company's only obligation is to maintain the agreed processes without modification and at the attainable level of process safety.

It is a similar situation for 1:n companies. Each customer has selected the processing option based on the properties that can be achieved and that they require. The surface-finishing company itself offers this service and the customer accepts the offer. Consequently, the R&D of the 1:n company generally relates to optimising its professional service, however, not fundamentally replacing this.

Nevertheless, both types of companies are always interested in further developing their technical expertise. Generally, new technologies or approaches at the preliminary stages of a series or before the initial order are discussed and sampled; in many cases, companies are involved with parallel technologies. The customer selects their preferred solution. For many years, owing to the corresponding technical and/or economic suitability this may not have been chromium plating. However, experience has shown that both chromium plating and other surface-processing methods experience a parallel growth and are therefore necessary.

Result of the R&D approach

- **The users are not able to perform or implement research and development.**
- **The users expect the upstream suppliers to carry out this development and present the results to the users.**
- **The users need to frequently test the developments of upstream suppliers under application conditions in their plants.**
- **Finally, the end customers test the results and convert the results into standards and certifications**
- **The users join together to intensify their efforts and perform joint development projects.**

4.2.2 Data searches

Electroplating technology has continued to develop for more than 100 years. This also applies to Cr(VI)-based processes. In this case, both improved processes and parallel technologies are developed that differ in some cases slightly in their properties, however above all, differ massively in process management, suitability for specialist requirements, applicability to different part sizes and materials, and in the process costs. The parallel technologies, which are not based on electroplating process management, are generally performed by other companies because they require other professional qualifications.

Even at the start of electroplating technology it was organised across Europe in associations and organisations /30/, in which working permanently on technological development and the distribution of relevant information among their member companies is part of the statutory tasks. Similarly, they hold regular events in person to exchange experiences. Examples in Germany are the *Oberflächentage* [surface finishing conference], *Berliner Fachseminar* [Berlin technical seminar] up to 2013, *Ulmer Gespräche* [Ulm discussions], Chrom 2020, *DGO-Bezirksgruppentreffen* [regional group meeting of the German Society for Electroplating and Surface Technology], *Leipziger Fachseminar* [Leipzig technical seminar], *Norddeutscher Galvanotag* [North German electroplating conference], *Stuttgarter Automobiltag* [Stuttgart automotive conference], O&S, *Hannover-Messe* with *Welt der Oberfläche* [International trade fair for surface treatments and coatings at Hanover exhibition centre with surface world] (programmes in the references /31/). Relevant events are held across Europe by the national associations, for example in Austria (AOT-*Jahrestagung* – AOT annual meeting) and the Czech Republic and Slovenia.

New processes or process variations are always presented at these events. Similarly, comparisons with parallel technologies are a permanent fixture of these technical exchanges.

The end customers use these events to learn about new approaches or to obtain confirmation for their choice of technology.

Formulators and suppliers get in contact with their customers from the surface-processing circle, to offer new processes or process optimisations, to sample these and, where applicable, employ these in the first applications.

Furthermore, for decades these events have produced R&D networks with specific issues for further technological development /32/ and interdisciplinary collaboration /33/.

4.2.3 Consultations – surveys

Specific investigations as part of preparing the application for the present authorisation took place in the form of diverse studies and literature studies. Compelling examples of these are specified in the references /9, 34/.

The applicants have prepared a separate questionnaire /12/ as part of their association work in VECCO e.V., which was revised with customers from the most diverse industries. More than 100 extensive interview results meant that findings could be obtained for and by the members of VECCO e.V., although the findings should not be regarded as being representative of the entire sector. Nevertheless, they do describe the technical and economic possibilities of the individual VECCO member and their (regular) customers.

Collaborative work:

- Literature studies and roadmaps.
- Surveys with personal interviews: VECCO survey with direct customer-supplier discussions.
- Cooperation with associations and institutions with common interests (ZVO, DGO, CETS, Ni Institute, etc.).

Own work:

- Discussions with suppliers to identify new systems. These systems are not necessarily alternatives, however they may be used to meet the requirements of the end customers.
- Discussions with customers of the surface-finishing companies (VECCO survey [12])

- Conferences /31/

  including *Oberflächentage*, *Berliner Fachseminar* until 2013, *Ulmer Gespräche*, Chrom 2020, *DGO-Bezirksgruppentreffen*, *Leipziger Fachseminar*, *Norddeutscher Galvanotag*, *Stuttgarter Automobiltag*, O&S, *Hannover-Messe* with *Welt der Oberfläche*.
- Networks: regional business development (IHK – Chamber of Industry and Commerce), Networks WEGANET, Reonet /32/.
- Possible uses of research programmes,

  e.g. Horizon2020, EUREKA, EEN, ZIM.

5 SUITABILITY AND AVAILABILITY OF POSSIBLE ALTERNATIVES/parallel technologies

5.1 General remarks

The search for alternative possibilities gave two options. Firstly, replacing Cr(VI) compounds with other chromium compounds, keeping the electroplating technology as far as possible (i.e. a substance-related substitution) and secondly, the use of entirely different technologies that have nothing in common with electroplating.

Various studies have published information on the substance substitution, which agree on the following statements /1, 14, 15, 29/:

- The +3 oxidation state is the only oxidation state from which technically usable chromium compounds can be obtained for electroplating (Cr(III)).
- Cr(III)-based technologies to manufacture functional, so-called hard chromium coatings do not exist (see discussion in the section on the alternatives).
- Cr(III)-based technologies for decorative-functional surfaces only fulfil the required properties in individual applications; various studies in the automotive and sanitary field showed serious deficiencies, predominantly in nickel release, scratch resistance and colour consistency.

As the replacement of Cr(VI) compounds with compounds of other Cr oxidation states has not been successful, parallel technologies are being increasingly discussed whose technical possibilities allegedly enable Cr(VI) replacement. The following facts should be established in these regard.

In many cases an entire technology is compared with a specialist individual coating (in this case using Cr(VI) compounds). This approach is not appropriate. For example, replacement with thermal spraying needs to be discussed for the entire electroplating technology. Otherwise, detailed explanations would have to be given of which powder composition would be suitable for which specific application /1, 12/ (see also Table, section 4)

5.1.1 Economic feasibility [1]

Based on the experience and data of VECCO members we have attempted to evaluate the economic feasibility.

We have only addressed a few typical cases because the approach and the key results are comparable for the other applications addressed in this dossier.

[1] Link to Section 3.2: Economic impacts of the socio-economic analysis (SEA) format.

Influential parameters include:

1. Process data (processing time, coating quantity, work shifts, etc.)
2. Technical data (surfaces, coating thicknesses, etc.)
3. Investment to change the technology
4. Running costs (material, disposal etc.)
5. Staff outlay (operator and additional services such as analysing the chemicals and materials)
6. Environmental and energy costs

1. **Evaluating coatings from Cr(III) electrolyte with coatings from Cr(VI) electrolyte**

   A survey of VECCO members was conducted to investigate the suitability of the substance alternative Cr(III) electrolyte. This revealed that replacement with a Cr(III) technology would cause the costs of coating to double per square metre.

   Estimations in the literature, in contrast, lead to the conclusion that the use of Cr(III) technology would result in a reduction in costs of around 50%.

   However, these estimations do not take into account the increased plant outlay as a result of the more complex composition of the electrolyte, for example for managing the cycle of the required boric acid. There is still little experience on this.

   The analysis shows that in the literature the ongoing waste treatment is essentially presented as a difference which, as a result of the unnecessary reduction of the waste water containing Cr(VI) is actually lower. The estimations discussed in the literature are also based on figures from 1988, when there was little experience.

   Current assessments show that the number of relevant parameters is too large and too individual for a reliable estimation.

   As a result, it should be noted that the economic feasibility can only be partially assessed using the cost factors. The key influencing parameters are:

   - The running costs are dependent on the services of the upstream suppliers and essentially on the capacities of the plant.
   - With a comparable capacity, the coating costs of both methods per square metre are comparable.
   - The robustness of the methods differ, in which case the influence on the production method is significantly different.
   - The experience of consistent process management also differs.
   - A comparison of investment costs is only useful if a new plant is constructed.
   - Incalculable reworking costs and high scrap rates as a result of colour fluctuations.

2. **Technology comparison: thermal spraying and chromium plating**

   Unambiguous results on the unit costs are not available. Various publications, including by the German Thermal Sprayers Association, provide some data /35, 36/.

   An illustrative calculation is as follows:

   - calculation of the surface area for TS: rotary cylinder 1 m long, 30 cm diameter
   - efficiency TS: 70% /36/
   - comparative values /35, 36/:
     thermal spraying: EUR 1.70/dm^2
     hard chromium: EUR 1.50/dm^2 and 300 µm or EUR 0.15/dm^2 at 30 µm

In this case as well the unit costs are nominally comparable. The key differences here are also

- turnaround time and thereby the number of products that can be coating in a unit of time
- necessary mechanical reworking with thermal spraying
- robustness of the methods
- various set-up times
- simplicity of the methods and also maintenance by various qualified professionals

3. **Technology comparison: chromium plating using PVD and electrolytic chromium plating from Cr(VI) electrolytes.**

   The data situation is evaluated based on the literature data, e.g. /37, 38 /.

   An illustrative calculation for decorative chromium plating is as follows:

   - calculation of the surface area for PVD: according to /37/: TiN moulded parts, d = 3 cm, l =10 cm
   - coating thickness PVD: 1–5 µm assumed for the deposition of headlight reflectors with Al (Ref. http://www.patent-de.com/19980430/DE19644207A1.html)
   - efficiency PVD: 60% /37, 38//
   - comparative values /37/:

     PVD EUR 7.80/dm^2

     chromium plating: about 10% of the PVD unit costs

   The study /37/ shows that the results of other methods are comparable. For instance, it demonstrates comparable unit costs for a DLC coating and the PVD method.

   In this comparison, clear differences in the unit costs are consistently shown. It is therefore expected that a decision on the application of the technology is only partially determined by the unit costs in production and that other cost components or added values are decisive in the application chain.

The following statements can be derived as key results

1. Calculating an investment only takes into account the period of depreciation. The real service life of the coating plants is significantly longer. For instance, an electroplating plant can be used perfectly well for 20 years and thus risk minimisation measures can easily be continuously improved.
2. A key parameter is the throughput of the treatment or the surface area treated per time unit, which is significantly different for the various methods. Consequently, the surface area treated is more significant for a contract company and less significant is the cost per surface area.
3. The efficiency of the direct coating is of key importance, i.e. how much material is actually used for coating and how much is lost.
4. The direct material costs are comparable and not the significant parameters.

Overall result of the analysis

- **The overall result of the analysis of economic feasibility means that the technical processes are also critical to economic feasibility.**
- **The costs per surface area or per quantity of coating material are not meaningful on their own.**

- **There are also secondary effects such as a method's influence on cleaning the parts being coated. While when using a chromium (VI) electrolyte a high proportion of this can be performed in the electrolyte itself as a result of its oxidative effect, this needs to be a separate process in the other methods.**
- **Economic feasibility based on the multitude of specific parameters can only be considered and assessed meaningfully in individual cases.**

5.1.2 Time factor for possible implementation

To assess the necessary time frames to implement the alternatives discussed, different processes are relevant:

1. feasibility analyses
2. development at a laboratory scale
3. pilot plant process
4. implementation in production
5. field trials
6. certifications
7. market launch

Points 1 and 2 provide the initial indications of whether the method is physicochemically possible. This time frame is essentially filled with research-oriented projects by research institutes or large research companies.

Points 3 and 4 are relevant for the implementation. However, the commercial potential needs to be clarified. This is the point where many alternatives that have potential (points 1 to 2), fail.

Preparation for market launch is addressed by points 4 and 5. From experience, the field trials open up a number of questions that need to be clarified before the alternative is accepted by the customer and this customer can then prepare for certification for their customers.

The time frames are different for each of the alternatives discussed. However, in general it should be said that prompt implementation of an unreliable physicochemical method is impossible.

It should also be stressed that the contract companies themselves do not have the resources for implementation and are currently dependent on the upstream suppliers, and so have no influence on the time frames.

There is no collaborative development structure and this needs to be developed along the value-added chain.

Overall, this analysis requires an existing physicochemical feasibility on a laboratory scale and successful pilot plant studies to classify an alternative as relevant. However, neither is it possible in this case to promptly employ the alternatives. This also applies to the use of Cr(III)-based methods.

In summary, it should be stated that many alternatives of the various applications discussed are at the pilot plant stage.

The methods that are implemented at a production level and which have already completed successful field trials, have already been introduced to the market.

A typical process is presented in the following video. It should be emphasised that in this case, all feasibility studies and production developments were available.

https://www.youtube.com/watch?v=_NaJP4q_HI8&feature=share

(Perfect shine and durability: Thoma in Heimertingen finishes metals – Thoma MV)

5.1.3 Reduction of overall risk due to transition to the alternatives/parallel technologies[2]

- See section 4.1.8 for more information.
- It needs to be emphasised that the electroplating contract companies have no option of reducing the risk by switching technology.
- However, it is possible for them to optimise their own plant.

5.1.4 Availability [3]

- The majority of assessed alternatives are at the development stage.
- Methods that have already been developed are established in the market in specialist fields.
- Limited availability as a result of patent law, for example, is not expected. However, the availability of information for assessment may be restricted by this.
- The tried and tested alternatives that are already on the market were not able technically or economically to replace the use of electrolytes containing chromium trioxide.

5.1.5 Conclusion on suitability and availability for alternatives/parallel technologies

The results of the HCAT project emphasise that implementing the applications is highly dependent on the products:

Keith Legg concludes the following as a result of the HCAT project /39/

> **The advantage of chrome is that it is a single material and deposition method that can be used for a wide variety of applications. The advantage of HVOF is that it is a single technology, with a wide variety of materials that can be used to achieve just the right combination of properties for any purpose.**
>
> **Our data thus far shows HVOF coatings, particularly the tungsten carbides, to be equal in performance to hard chrome in all of their measured properties, and significantly better than hard chrome in fatigue and wear.**
>
> **The HCAT program is in the process of acquiring all of the data necessary for the validation and broad acceptance of HVOF coatings for OEM and O&R use. At the same time, commercial users are adopting the technology for their specific applications in landing gear and other aerospace systems.**

And further /40/

> **Hard chromium plating has been around for decades. The finish reduces wear and corrosion. The problem is not with the finish but with the plating process. Chromium metal is inert and is used on everyday items such as prosthetic implants. However, the EPA and OSHA have decided to limit and heavily regulate its use, forcing platers to look for alternatives to the process. There is no drop-in solution, and there is no solution that can completely replace a hard chromium finish; however, the industry continues its research and development on alternatives.**

There is widespread agreement that close collaboration is required between surface finishers and end customers for modern product development. The required functions of the end users are reflected in the development of the surface processes, which are further linked to the base

[2] Link to Section 3.1: Human health and environmental impacts of the socio-economic analysis (SEA) format.
[3] Link to Section 3.2: Economic impacts of the socio-economic analysis (SEA) format.

substrates being used. Consequently, in virtually all metal-processing industries, adaptations to the coating and substrate were developed. When replacing surface treatment, all affected products would need to be redeveloped, which is neither technically nor economically sensible.

6 OVERALL CONCLUSIONS ON THE SUITABILITY AND AVAILABILITY OF POSSIBLE ALTERNATIVES – Summary

The following table summarises the evaluations presented in the preceding sections. To give an overview, the individual points are illustrated using a point system from 0 to 10.

The score 10 corresponds to an alternative or parallel technology that can be used immediately and the score 0 to one that only exists in theory or is undergoing initial laboratory experiments.

The following criteria are summarised and evaluated accordingly:

0–6:	Red	Cannot be used at present
6–8:	Yellow	Can be partially used or needs further development
8–10:	Green	Can be used

1.	Technical function	10	high		0	low
2.	Risk assessment	10	low		0	high
3.	Needs development	10	low		0	high
4.	Available on the market	10	Yes		0	No
5.	Requirements: customers/DIN/agreements	10	none		0	mandatory
6.	Time frame for implementation	10	1 year		4	10 years
		9	2 years		3	17 years
		8	4 years		2	15 years
		7	6 years		1	18 years
		6	8 years		0	20 years
		5	9 years			
7.	Investment for implementation	10	low	0	0	high

The possible courses of action for an electroplating coater/user are shown.

1. **Chemical:** Change in the chemical composition of the used electrolytes, i.e. a **chromium (III)-based electrolyte or acids for the other applications**.
2. **Technological:** Use of another **coating or processing technology**
3. **Optimisation** of their own process to minimise exposure.

Furthermore, differentiation is made between what is possible for a contract coater/user with a large range of products to be processed with a multitude of functions (1:n) and what is possible for a specialist coater/user with a specific product and a specific range of functions (1:1).

The difficulty of a conclusion is reflected by the fact that if a specific function is required, the remaining criteria would permit an alternative, but that the alternative is prevented through not fulfilling this function.

This shows that a full evaluation, as shown in the last column, does not lead to a satisfactory conclusion. This is particularly clear in the field of stripping.

Anwendung	Paralleltechnologie																																			Bewertung
	Chemisch Substanzersatz							**Technologisch Neue, unterschiedliche Verfahren**																												Potenzial + Zeit + Risklevel + Invest / Anzahl max: 10 * 7 = 70 Wert / max Anzahl grün: 80 - 100 gelb: 60 - 80 rot: < 60
	Funktionalität	Risk-level	Entwicklungs-bedarf	Verfügbar auf Markt	Forderungen / DIN Kunden	Zeitbereich zur Umsetzung	Investment zur Umsetzung	Funktionalität	Risk-level	Entwicklungs-bedarf	Verfügbar auf Markt	Forderungen / DIN Kunden	Zeitbereich zur Umsetzung	Investment zur Umsetzung	Funktionalität	Risk-level	Entwicklungs-bedarf	Verfügbar auf Markt	Forderungen / DIN Kunden	Zeitbereich zur Umsetzung	Investment zur Umsetzung	Funktionalität	Risk-level	Entwicklungs-bedarf	Verfügbar auf Markt	Forderungen / DIN Kunden	Zeitbereich zur Umsetzung	Investment zur Umsetzung	Funktionalität	Risk-level	Entwicklungs-bedarf	Verfügbar auf Markt	Forderungen / DIN Kunden	Zeitbereich zur Umsetzung	Investment zur Umsetzung	
1. technisch-funktionelles Verchromen 200-400g/l Chromtrioxid	Cr(III)							Thermisches Spritzen							PVD							Nickel							Thermisches Härten							
1:n, Servicedienstleister	0	3	0	0	0	0	5																													11%
1:1, Spezialanwendungen	3	3	0	0	0	7	5																													26%
1:n, Servicedienstleister								0	5	0	5	2	4	4																						29%
1:1, Spezialanwendungen								10	5	2	10	7	10	8																						74%
1:n, Servicedienstleister															3	7	3	6	5	4	4															46%
1:1, Spezialanwendungen															10	7	2	10	8	10	6															76%
1:n, Servicedienstleister																						5	1	7	9		7	2								44%
1:1, Spezialanwendungen																						10	1	7	9		7	2								51%
1:n, Servicedienstleister																													5	1	8	9	2	10	2	53%
1:1, Spezialanwendungen																													10	1	8	9	8	10	2	69%
2. dekorativ-funktionelles Verchromen (inkl. Schwarzchrom)	Cr(III)							Thermisches Spritzen							PVD (zB. Chromoptics)							Nickel							Lackierung							
1:n, Servicedienstleister	5	3	5	5	5	5	5																													47%
1:1, Spezialanwendungen	6	3	6	5	5	5	5																													50%
1:n, Servicedienstleister								0	5	5	6	2	4	5																						39%
1:1, Spezialanwendungen								2	5	4	6	6	10	7																						57%
1:n, Servicedienstleister															3	7	5	6	2	4	5															46%
1:1, Spezialanwendungen															10	7	4	6	6	10	5															69%
1:n, Servicedienstleister																						5	1	8	9	6	7	4								57%
1:1, Spezialanwendungen																						10	1	8	9	6	7	4								64%
1:n, Servicedienstleister																													5	5	5	9	6	10	2	60%
1:1, Spezialanwendungen																													10	5	8	9	6	10	2	71%
3. Elektropolieren	Elektroplieren Cr(VI) frei							Chemisches Beizen / Polieren							Mechanisches Polieren																					
1:n, Servicedienstleister	4	5	10	10	4	7	10																													71%
1:1, Spezialanwendungen	4	5	10	10	4	7	10																													71%
1:n, Servicedienstleister								4	5	10	4	4	8	10																						64%
1:1, Spezialanwendungen								4	5	10	4	4	8	10																						64%
1:n, Servicedienstleister															4	5	10	4	4	8	10															64%
1:1, Spezialanwendungen															4	5	10	4	4	8	10															64%
1:n, Servicedienstleister																																				0%
1:1, Spezialanwendungen																																				0%
4. Entschichten	Laserverfahren							Stripping (Anodised Aluminium) Sodium Hydroxide							Deoxidation (Anodised Aluminium) Nitric Acid							Natronlauge / Salzsäure														
1:n, Servicedienstleister	4	10	8	8	4	8	7																													70%
1:1, Spezialanwendungen	4	10	8	8	4	8	7																													70%
1:n, Servicedienstleister								2	7	10	10	10	8	10																						81%
1:1, Spezialanwendungen								2	7	10	10	10	8	10																						81%
1:n, Servicedienstleister															4	5	10	4	4	8	10															64%
1:1, Spezialanwendungen															4	5	10	4	4	8	10															64%
1:n, Servicedienstleister																						4	5	10	10	4	8	10								73%
1:1, Spezialanwendungen																						4	5	10	10	4	8	10								73%

	Paralleltechnologie																																			Bewertung
Anwendung	Chemisch Substanzersatz							Technologisch Neue, unterschiedliche Verfahren																												Potenzial + Zeit + Risklevel + Invest / Anzahl max: 10 * 7 = 70 Wert / max Anzahl grün: 80 - 100 gelb: 60 - 80 rot: < 60
	Funktionalität	Risk-level	Entwicklungs-bedarf	Verfügbar auf Markt	Forderungen / DIN Kunden	Zeitbereich zur Umsetzung	Investment zur Umsetzung	Funktionalität	Risk-level	Entwicklungs-bedarf	Verfügbar auf Markt	Forderungen / DIN Kunden	Zeitbereich zur Umsetzung	Investment zur Umsetzung	Funktionalität	Risk-level	Entwicklungs-bedarf	Verfügbar auf Markt	Forderungen / DIN Kunden	Zeitbereich zur Umsetzung	Investment zur Umsetzung	Funktionalität	Risk-level	Entwicklungs-bedarf	Verfügbar auf Markt	Forderungen / DIN Kunden	Zeitbereich zur Umsetzung	Investment zur Umsetzung	Funktionalität	Risk-level	Entwicklungs-bedarf	Verfügbar auf Markt	Forderungen / DIN Kunden	Zeitbereich zur Umsetzung	Investment zur Umsetzung	
5. Kunststoffbeizen	Alkalipermanganat							Natrium THF							Säuren							Sulfonierung														
1:n, Servicedienstleister	4	10	8	8	4	4	10																													69%
1:1, Spezialanwendungen	4	10	8	8	4	4	10																													69%
1:n, Servicedienstleister								2	5	5	8	5	4	4																						47%
1:1, Spezialanwendungen								2	5	5	8	5	4	4																						47%
1:n, Servicedienstleister															4	5	10	4	4	8	10															64%
1:1, Spezialanwendungen															4	5	10	4	4	8	10															64%
1:n, Servicedienstleister																						4	5	10	10	4	8	10								73%
1:1, Spezialanwendungen																						4	5	10	10	4	8	10								73%
6. Anodisieren / Alle Alternativen spezielle Entwicklungen	Selga-Coat Beschichtung mit CrVI-frei Elektrolyt (Schwefelsäure/Oxalsäure Elektrolyt) (in Entwicklung - prototyp Stadium)							Hartanodische Beschichtung; Harteloxal							Mischsäure-Anodisation (für Schichten im µm Bereich)																					
1:n, Servicedienstleister	4	10	8	8	4	5	10																													70%
1:1, Spezialanwendungen	4	10	8	8	4	5	10																													70%
1:n, Servicedienstleister								2	10	10	10	5	2	10																						70%
1:1, Spezialanwendungen								2	10	10	10	5	2	10																						70%
1:n, Servicedienstleister															7	7	10	10	8	8	10															86%
1:1, Spezialanwendungen															7	7	10	10	8	8	10															86%
1:n, Servicedienstleister																																				0%
1:1, Spezialanwendungen																																				0%
7. Passivieren (dünn), inkl. Edelstahlfärben / Alle Alternativen spezielle Entwicklungen"	Tauchlackierung							Schwarznickel							Pulverbeschichtung							Säurepassivierung														
1:n, Servicedienstleister	0	8	7	10	4	3	10																													60%
1:1, Spezialanwendungen	0	8	7	10	4	3	10																													60%
1:n, Servicedienstleister								0	1	10	10	4	5	10																						57%
1:1, Spezialanwendungen								0	1	10	10	4	5	10																						57%
1:n, Servicedienstleister															0	8	5	10	4	8	10															64%
1:1, Spezialanwendungen															0	8	5	10	4	8	10															64%
1:n, Servicedienstleister																						6	7	8	10	0	5	10								66%
1:1, Spezialanwendungen																						6	7	8	10	0	5	10								66%

Paralleltechnologie	Parallel technology
Anwendung	Application
Chemisch Substanzersatz	Chemical substance replacement
Technologisch Neue, unterschiedliche Verfahren	Technological New, different methods
Bewertung	Assessment
Funktionalität	Functionality
Risk-level	Risk level
Entwicklungsbedarf	Needs development
Verfügbar auf Markt	Available on the market
Forderungen / DIN Kunden	Requirements/DIN customers
Zeitbereich zur Umsetzung	Time frame for implementation
Investment zur Umsetzung	Investment for implementation
Potenzial + Zeit + Risklevel + Invest / Anzahl	Potential + time + risk level + investment/number
max: 10 * 7 = 70	max: 10 * 7 = 70
Wert / max Anzahl	value/max. number
grün: 80 – 100	green: 80–100
gelb: 60 – 80	yellow: 60–80
rot: < 60	red: < 60
technisch-funktionelles Verchromen 200-400g/l Chromtrioxid	technical-functional chromium plating 200–400 g/l chromium trioxide
dekorativ-funktionelles Verchromen (inkl. Schwarzchrom)	decorative-functional chromium plating (incl. black chromium)
Elektropolieren	Electropolishing
Entschichten	Stripping
Kunststoffbeizen	Plastics pickling
Anodisieren / Alle Alternativen spezielle Entwicklungen	Anodising/all alternatives specific developments
Passivieren (dünn), inlk. Edelstahlfärben / Alle Alternativen spezielle Entwicklungen	Passivating (thin), incl. stainless steel dyes/all alternatives specific developments
1:n, Servicedienstleister	1:n, service provider
1:1, Spezialanwendungen	1:1, special applications
Cr(III)	Cr(III)
Thermisches Spritzen	Thermal spraying
PVD	PVD
Nickel	Nickel
Thermisches Härten	Thermal hardening
PVD (zB. Chromoptics)	PVD (e.g. chromium optics)
Lackierung	Painting
Elektroplieren Cr(VI) frei	Electropolishing Cr(VI) free
Chemisches Beizen / Polieren	Chemical pickling/polishing
Mechanisches Polieren	Mechanical polishing
Laserverfahren	Laser methods

Stripping (Anodised Aluminium) Sodium Hydroxide	Stripping (Anodised Aluminium) Sodium Hydroxide
Deoxidation (Anodised Aluminium) Nitric Acid	Deoxidation (Anodised Aluminium) Nitric Acid
Natronlauge / Salzsäure	Sodium hydroxide/hydrochloric acid
Alkalipermanganat	Alkaline permanganate
Natrium THF	Sodium THF
Säuren	Acids
Sulfonierung	Sulphonation
Selga-Coat Beschichtung mit CrVI-frei Elektrolyt (Schwefelsäure/Oxalsäure Elektrolyt) (im Entwicklung – prototyp Stadium)	Selga-coat coating with Cr(VI)-free electrolyte (sulphuric acid/oxalic acid electrolyte) (at the development – prototype stage)
Hartanodische Beschichtung; Harteloxal	Hard anodic coating; hard anodising
Mischsäure-Anodisation (für Schichten im µm Bereich)	Mixed acid anodisation (for coatings in the µm range)
Tauchlackierung	Dip coating
Schwarznickel	Black nickel
Pulverbeschichtung	Powder coating
Säurepassivierung	Acid passivating

7 Roadmap for future developments

7.1 Technical reduction of exposure

The companies involved in this authorisation will optimise their plants in such a way to reduce the exposure as far as possible.

The exposure scenarios will be continuously adjusted.

7.2 Active further developments of the companies referred to in this authorisation

The companies are supported and accompanied in the active development.

The authorisation submitted covers various categories of applications of the use and is aimed at a service-oriented use of the substance to process third-party products. For this reason, many measures, operating conditions and exposure scenarios are covered at the same time and described using universal framework conditions.

1. The applicant, HAPOC, undertakes, together with the companies that refer to the approval, to develop actively reproducible methods to assess exposure scenarios that are binding for the companies.
2. Regular monitoring of exposure

   As a minimum, annual measurements will be taken under defined conditions at defined manufacturing positions. This may take place in collaboration with the employers' liability insurance associations. however it is not dependent on their willingness to take measurements.
3. Regular bio-monitoring of workers

   The exposed workers will be offered annual testing to test the Cr(VI) content in their blood and urine. The results are reported anonymously.
4. Active development work

   The notifying companies commit to active participation and implementation of development projects on the issue of possible substitutions or optimisations of the exposure situation.

VECCO e.V. acts as a centre for collaboration. Practical implementation takes place by EUPOC GmbH and eiffo eG using the pre-established eiffo platforms (example network Reo.net).

7.3 Basis of the development

In the past ten years, structures have been established that permit the contract coaters/users to carry out joint further development. This may occur together with customers or with other contract coaters/users.

Topic areas are

- Identification of R&D topics from the perspective of what is possible for SMEs
- Specification of the R&D approaches
- Implementation options as part of, for example national or European research projects (Horizon2020, EUREKA, ZIM, etc.)
- Market launch

The following structures or R&D projects are already active:

1. WeGaNet network (since 2010)

   Focus on new coating systems and their implementation in production
2. REOnet network (since 2013)

   Focus on resource efficiency and the optimisation of production processes
3. EU project MEMAN (since 2015)

   Focus on describing the collaboration in the supply chain
4. EU network EUREKA: Focus on identifying relevant projects and implementation options within the EU

8 Application for granting an authorisation in accordance with the REACH Regulation

for the

Use of chromium trioxide in solid form and in aqueous solution of any composition to modify the properties of surfaces made of metal or plastic, with or without current flow, at a maximum risk level of 2:100.

taking into account the applications

1. The impact of solutions in accordance with the requested *use* on surfaces to deposit chromium layers, principally for technical and functional purposes. *(Abbreviated to: 'functional chromium plating')*
2. The impact of solutions in accordance with the requested *use* on surfaces principally for decorative and functional purposes. *(Abbreviated to: 'decorative chromium plating')*
3. The impact of solutions in accordance with the requested *use* on surfaces to electropolish metallic surfaces. *(Abbreviated to: 'electropolishing')*
4. The impact of solutions in accordance with the requested *use* on surfaces to strip any components from substrate surfaces for the partial or complete removal. *(Abbreviated to: 'stripping')*
5. The impact of solutions in accordance with the requested *use* on surfaces for pickling and activating plastic parts, particularly those made of ABS (acrylonitrile butadiene styrene) or PC/ABS (polycarbonate/acrylonitrile butadiene styrene). *(Abbreviated to: 'plastics pickle')*
6. *The impact of solutions in accordance with the requested use on surfaces for anodising, particularly aluminium, magnesium or titanium or components coated with these metals. (Abbreviated to: 'anodising')*
7. The impact of solutions in accordance with the requested *use* on surfaces for the oxidative modification of surfaces of components made of stainless steels, particularly corrosion-resistant chromium-nickel steels. *(Abbreviated to: 'stainless steel dyes')*

The present application shows the lack of alternatives for this use that are technically and economically feasible. In addition it shows the possibility of reliably and reasonably keeping the risk of using the SVHC, chromium trioxide, at a very low level in accordance with the above definition of use. In addition, in its socio-economic analysis, the application shows that the benefits of the use scenario for European society outweigh the statistically expected economic expenditure from the welfare costs resulting from the risk of illness.

The application is aimed at the approval of technical implementations that take into account the above use, that fall under a specific risk limit – the statistical first case limit defined in the application – and that demonstrate regular monitoring of key parameters.

Authorisation is requested for companies with no more than 40 regularly exposed workers, with a term of 12 years until the next review. The statistical first case limit in this case is 50 years, about four times the requested term.

APPENDICES

Literature

1 Five Chemicals – Alternatives Assessment Study, The Massachusetts Toxics Use Reduction Institute – TURI , University of Massachusetts Lowell, 2006

2 *Statistisches Bundesamt* [German Federal Statistical Office], Technical Series 4, Series 3.1, 2013, last revised 4 July 2014
https://www.destatis.de/DE/Publikationen/Thematisch/IndustrieVerarbeitendesGewerbe/Konjunkturdaten/ProduktionJ2040310137004.pdf?__blob=publicationFile
German Federal Statistical Office, Technical Series 4, Series 3.1, 2014, last revised 27 April 2015
https://www.destatis.de/DE/Publikationen/Thematisch/IndustrieVerarbeitendesGewerbe/Konjunkturdaten/ProduktionJ2040310147004.pdf?__blob=publicationFile

3 'Analysis of the German electroplating and surface technology industry', *Zentralverband Oberflächentechnik* [central association for surface technology] ZVO 2006

4 'Surface engineering, industry report', *Deutsche Industriebank* [German Industrial Bank] IKB Information: May 2005;
'Industry report on surface finishing and heat treatment', *Sparkassen Finanzgruppe* [Savings Bank Finance Group] September 2008

5 'A Review of Human Carcinogens. C. Metals, Arsenic, Fibres and Dusts – Part Nickel and Nickel compounds', IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 100 (C); International Agency for Research on Cancer (IARC), 2012

6 *Thermisches Spritzen – Potentiale, Entwicklungen, Märkte* [Thermal spraying– potentials, developments, markets]; DVS reports volume 245, ISBN 978-3-87155-251-9, Düsseldorf 2007

7 *Neue Methoden und Anwendungen des Thermischen Spritzens* [New methods and applications of thermal spraying], Christian Rupprecht; postdoctoral thesis TU Chemnitz, 2013

8 Replacement of Chromium Electroplating on Helicopter Dynamic Components Using HVOF Thermal Spray Technology, ENVIRONMENTAL SECURITY TECHNOLOGY CERTIFICATION PROGRAM U.S. Department of Defense, 2009

9 Research on the Technical Feasibility and Economic Evaluation of Alternative Substances and Technologies as Substitutes for CrO_3 and other Chromium (VI)-Compounds in Surface Treatment, Final Report; March 2012, Chromgruen Gmbh & Co. KG, on behalf of the *Bundesanstalt für Arbeitsschutz und Arbeitsmedizin* [Federal Institute for Occupational Safety and Health, BAuA]

10 *Umweltstandards für thermische Solarkollektoren unter besonderer Berücksichtigung der selektiven beschichtung ihrer Absorberoberflächen* [Environmental standards for thermal solar collectors taking into account the selective coating of their absorber surfaces], *Institut für Zukunftsstudien und Technologiebewertung* [Institute for Futures Studies and Technology Assessment], Workshop Report No 97, Berlin 2009

11 'A Review of Human Carcinogens. C. Metals, Arsenic, Fibres and Dusts – Part Chromium (VI) Compounds', IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 100 (C); International Agency for Research on Cancer (IARC), 2012

12 Analytical summary of the VECCO questionnaire

13 Annex XV report 'PROPOSAL FOR IDENTIFICATION OF A SUBSTANCE AS A CMR CAT 1 OR 2, PBT, vPvB OR A SUBSTANCE OF AN EQUIVALENT LEVEL OF CONCERN – Substance Name: Chromium trioxide', ECHA August, 2010

14 *Entwicklung eines Verfahrens zur Abscheidung technischer Chromschichten aus Chrom(III)-Elektrolyten* [Development of a method to strip technical chromium layers from chromium(III) electrolytes], J. Bohnet; dissertation, University of Stuttgart 2009

15 *Korrosionsuntersuchungen an Chromüberzügen aus dreiwertigen Chromelektrolyten für den Einsatz im Automobil* [Corrosion analysis of chromium coatings from trivalent chromium

electrolytes for automotive use] , P. Hartmann, P. Wachter, C. Donner, W. Richtering (Atotech Deutschland GmbH, Berlin), ZVO Ulmer Gespräch, Neu Ulm, Germany, 8.5.2014
16 http://www.f-g-k.org/chrom-iii-statt-chrom-vi.html (accessed 30.07.2015)
17 http://www.f-g-k.org/chrom-iii-empfehlung.html (accessed 30.07.2015)
18 http://www.bghm.de/arbeitsschuetzer/fachinformationen/gefahrstoffe-und-biologische-arbeitsstoffe/nanopartikel-und-ultrafeine-partikel.html (accessed 30.07.2015)
19 Product sheet for 'Chrombase', CWS Powder Coating, http://cws-powder.de/produkte/chrombase (30.06.2015)
20 *Informationsinitiativen Oberflächentechnik* [Surface engineering information initiatives], studies of the German Association of Engineers, Technology Centre – VDI TZ Düsseldorf *Forschungsagende Oberfläche – Analyse des Innovations- und Nachhaltigkeitspotenzials im Bereich der Oberflächenbehandlung* [Surface research agendas – analysis of the potential innovation and sustainability in the field of surface treatment], K. Roths, J. Gochermann, *Deutsche Forschungsgesellschaft für Oberflächenbehandlung* [German Research Association for Surface Treatment – DFO e.V.], Neuss 2007
21 *Optimierung der Modifizierung von Anodisierschichten auf Aluminiumwerkstoffen durch chemische Nanotechnologie und industrielle Anpassung des Verfahrens* [Optimisation of the modification of anodised coatings on aluminium materials using chemical nanotechnology and industrial adaptation of the method] final report AiF project 321 ZBG, DECHEMA research institute and Fraunhofer-IKTS, 2012
22 *Werkstoff Aluminium und seine anodische Oxidation* [Aluminium and its anodic oxidation], M. Schenck, A. Francke AG Verlag, Bern, 1948
23 Product sheets
   1. Savroc Ltd: http://www.savroc.com/
   2. Faraday Technology, Inc.: http://www.faradaytechnology.com/PDF%20files/Industrial%20Coatings%20&%20Fuel%20Cells/FARADAYIC%28R%29%20Process%20for%20Chromium%20Plating%20from%20a%20Trivalent%20Bath.pdf
   3. Company presentation Ropal Europe AG; http://www.ropal.eu/pdf/unternehmenspraesentation.pdf
24 Mechanisms of chromium toxicity, carcinogenicity and allergenicity: Review of the literature from 1985 to 2000, A.D. Dayan and A.J. Paine; *Human & Experimental Toxicology* (2001) 20, 439-451
25 *Thermal Spray Fundamentals - From Powder to Part*, Authors: Pierre L. Fauchais, Joachim V.R. Heberlein, Maher I. Boulos, Springer Verlag 2014
26 Analysis of the influence of cell heterogeneity on nanoparticle dose response; M.J. Ware et al., *ACS Nano*. 2014 Jul. 22;8(7), 6693
27 *nano.DE-Report 2013 – Status quo der Nanotechnologie in Deutschland* [Status quo of nanotechnology in Germany], *Bundesministerium für Bildung und Forschung* [German Federal Ministry of Education and Research], Germany, 2013
28 Project *Machbarkeitsstudie über die Abscheidung von Funktionalchrom aus neuartigen, käuflich nicht erwerbbaren Cr(III)-Verbindungen* [Feasibility study on the deposition of functional chromium from novel, commercially unavailable Cr(III) compounds], 2003/2004, Hesse
29 ECOCHROM; A Growth-IMS project; Eco-efficient hard chrome chromium process; PowerPoint presented at ECOCHROM, Jan. 24-26, 2006, San Diego
30 Websites:
   1. VECCOe.V.; http://www.vecco.info/
   2. ZVO e.V; http://zvo.org/
   3. CETS AISBL; http://www.cets-surface.eu
31 Programmes of the *Oberflächentage* – http://www.oberflaechentage.de/
   1. Programmes of the *Berliner Fachseminar* up to 2013 – http://www.dgo-online.de/veranstaltungen.html
   2. Programmes of the *Ulmer Gespräche* – http://www.dgo-online.de/veranstaltungen.html

3. Programmes of the *DGO-Bezirksgruppentreffen* – http://www.dgo-online.de/veranstaltungen.html
4. Programmes of the *Leipziger Fachseminar* – http://www.dgo-online.de/veranstaltungen.html
5. Programmes of the *Norddeutscher Galvanotag* – http://www.dgo-online.de/veranstaltungen.html
6. Programmes of the *Stuttgarter Automobiltag* – http://www.dgo-online.de/veranstaltungen.html
7. Programmes of the O&S (International trade fair for surface treatments & coatings) – http://www.ounds-messe.de/
8. Programmes of the Hanover exhibition halls with 'Welt der Oberfläche' – http://zvo.org/welt-der-oberflaeche.html

32 *Werterhaltung in der Galvanotechnik* – WeGaNet [Preserving value in electroplating]: http://www.weganet.org
Ressourceneffizienz in der Oberflächentechnik – REOnet [Resource efficiency in surface engineering]: http://www.reonet.de/

33 *Zentrales Innovationsprogramm Mittelstand* [The Central Innovation Programme for SMEs] – ZIM, http://www.zim-bmwi.de/

34 'Report on inclusion of chromium trioxide (CrO3) in Annex XIV', H. Holeczek, S. Kölle, M. Metzner, Fraunhofer IPA, Stuttgart 2011

35 Economic Considerations with respect to HVOF spraying, R. Schwetzke, W. Krömmer, P. Heinrich, Conference proceedings 7th HVOF Colloquium, 2006

36 *Innovative Oberflächenpanzerungen für hochwertigen Verschleißschutz in der Kunststoffverarbeitung und Extrusionstechnik* [Innovative surface platings for high-quality wear protection in plastics processing and extrusion technology], Ino J. Rass, *Fachtagung Verschleiß und Verschleißschutz an Kunststoffverarbeitungsmaschinen* [Symposium on wear and wear protection for plastics processing machines], 10-11 April 2013 in Würzburg

37 G. Grundmann, W. Blau; *Modellrechnungen anhand von Fallbeispielen* [Model calculations based on case examples]; Surface engineering information initiative, VDI-TZ, Düsseldorf 2002

38 *Praxishandbuch moderne Beschichtungen* [Handbook of advanced surface coatings], K.M. Mertz, H.A. Jehn, Hanser Verlag 2001

39 'Hard Chrome Alternatives Team Update – Improving Performance While Reducing Cost', Keith Legg, Rowan Technology Group, Chicago, IL and Bruce Sartwell, Naval Research Laboratory, Washington, OC; 2004

40 'What to do about Hard Chromium', article from: Products Finishing, Beverly Graves , Editor from Products Finishing, posted on: 2/1/2005; http://www.pfonline.com/articles/what-to-do-about-hard-chromium (accessed on 12.06.2015)