# ANALYSIS OF ALTERNATIVES

# and

# SOCIO-ECONOMIC ANALYSIS

## Non-confidential Report

**Legal name of applicant(s):** *ZF Friedrichshafen AG*

**Submitted by:** *ZF Friedrichshafen AG*

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

**Use title:** *Functional chrome plating of piston rods for automotive and rail applications*

**Use number:** *1*

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| ACEA | European Automobile Manufacturer’s Association |
| AfA | Application for Authorisation |
| AoA | Analysis of Alternatives |
| ASTM | American Society for Testing and Materials |
| Cr(III) | Trivalent Chromium |
| Cr(VI) | Hexavalent Chromium |
| CSR | Chemical Safety Report |
| CT | Car Chassis Technology Division of the ZF Group |
| CTAC | Chromium Trioxide Authorisation Consortium |
| CVD | Chemical Vapour Deposition |
| DIN | Deutsche Industrie Norm (German Industry Norm) |
| DLC | Diamond Like Carbon |
| ECHA | European Chemicals Agency |
| EEA | European Economic Area |
| EFTA | European Free Trade Association |
| EN | European Norm |
| EU | European Union |
| EOP | End of Production |
| HV | Vickers Hardness |
| HVOF | High Velocity Oxygen Fuel |
| ISO | International Organisation for Standardisation |
| MVE | Monetisation of Health Impacts to the General Public |
| NSS | Neutral Salt Spray |
| NUS | Non-Use Scenario |
| OEM | Original Equipment Manufacturer |
| PE-CVD | Plasma Enhanced Chemical Vapour Deposition |
| PVD | Physical Vapour Deposition |
| R&D | Research and Development |
| REACH | Registration, Evaluation, Authorisation and Restriction of Chemicals |
| SDS | Safety Data Sheet |
| SEA | Socio Economic Analysis |
| SOP | Start of Production |
| SST | Salt Spray Test |
| SVHC | Substance of Very High Concern |
| US | Uncertainty Scenario |
| WCS | Worker Contributing Scenario |
| ZF | ZF Friedrichshafen AG |

# GLOSSARY

| Term | Definition |
|---|---|
| Adhesion | Parameter describes the tendency of dissimilar particles or surfaces to cling to one another (for example adhesion of coating to substrate) |
| Alternative | Potential alternative to functional chrome plating using chromium trioxide |
| Automotive | “Automotive” is used as a general term for commercial and passenger vehicles.<br>Commercial vehicles: trucks, buses, tractor, etc.<br>Passenger vehicles: cars, moto cycle, etc. |
| Bath | Typical method for surface treatment of parts. May also be referred to as dipping or immersion. |
| C35, C45, ST52-3 | Steel grades used at ZF Friedrichshafen AG as substrates for piston rods. |
| Coating | A coating is a covering that is applied to the surface of an object, usually referred to as the substrate. The purpose of applying the coating may be decorative, functional, or both. |
| Corrosion protection | Means applied to the metal surface to prevent or interrupt oxidation of the metal part leading to loss of material. The corrosion protection provides corrosion resistance to the surface. |
| Electroplating | Electroplating is forming a metal coating on the part by an electrochemical method in an electrolyte containing metal ions and the part is the cathode, an appropriate anode is used and an electrical current is applied. |
| Etching | Process changing surface morphology as well as removing material. This is a pre-treatment step of the process chain activating the surface before subsequent plating. |
| Functional chrome plating | An industrial use, meaning the electrochemical treatment of surfaces (typically metal) to deposit metallic chromium using a solution containing chromium trioxide (amongst other chemicals), to enhance wear resistance, tribological properties, corrosion resistance in combination with other important functional characteristics. Process characteristics are closed loop processing, high speed, flexibility in size, plating of inner surfaces, low process temperature, surface can be machined, assemblability.<br>Functional chrome plating may include use of chromium trioxide in pre-treatment and surface deposits unlimited in thickness but typically between 2 µm and 5,000 µm. |
| Implementation | After having passed qualification and certification, the third step is to implement or industrialize the qualified material or process in all relevant activities and operations of production, maintenance and the supply chain. |
| Main treatment | The main treatment, functional chrome plating using chromium trioxide, occurs after the pre-treatment and before the post treatment. |
| Metallic chrome coating | Resulting coating layer of the functional chrome plating process. |

| | |
|---|---|
| Plating | Electrolytic process that applies a coating of metal on a substrate. |
| Post-treatment | Post-treatment processes do not involve chromium trioxide and are performed after the main functional chrome plating process. |
| Pre-treatment | Pre-treatment process using chromium trioxide to remove contaminants (e.g. oil, grease, dust), oxides and scale. The pre-treatment process must also provide chemically active surfaces for the subsequent treatment. (See also: Etching). |
| Process chain | A series of surface treatment process steps. The individual steps are not stand-alone processes. The processes work together as a system, and care should be taken not to assess without consideration of the other steps of the process. In assessing candidate alternatives for chromium trioxide, the whole process chain has to be taken into account. |
| Qualification | Original Equipment Manufacturer's (OEM) validation and verification that all material, components, equipment or processes meet or exceed the specific performance requirements. |
| Rail vehicle | Rail vehicle is used as a general term for trains, trams, etc. |
| Tribological properties | Tribological properties relate to friction, lubrication and wear on surfaces in relative motion and are important for moving machine parts. |
| Wear resistance / abrasion resistance | The ability of a coating to resist the gradual wear caused by abrasion and friction. |

# DECLARATION

We, ZF Friedrichshafen AG, request that the information blanked out in the "public version" of the Analysis of Alternatives and Socio-economic analysis is not disclosed. We hereby declare that, to the best of our knowledge as of today (12.05.17) the information is not publicly available, and in accordance with the due measures of protection that we have implemented, a member of the public should not be able to obtain access to this information without our consent or that of the third party whose commercial interests are at stake.

Signature:

Uwe Gehringer

Director Car Chassis Technology

ZF Friedrichshafen AG

Date, Place:

Schweinfurt, 12.05.2017

# SUMMARY

## <u>Introduction</u>

The Analysis of Alternatives (AoA) and the Socio-Economic Analysis (SEA) form part of the Application for Authorisation (AfA) for the usage of chromium trioxide in functional chrome plating of piston rods for automotive and rail vehicle applications at ZF Friedrichshafen AG at the production sites in Schweinfurt and Eitorf.

The piston rods manufactured by ZF are part of automotive and rail vehicle damper systems which represent one of the most important components of vehicle chassis. “Automotive” is a general term and is used for the combination of passenger vehicles (cars, moto cycles, etc.) and commercial vehicles (trucks, buses, tractor, etc.). Consequently, the term “rail vehicle” is used for the combination of trains, trams, etc. (see Figure 1).

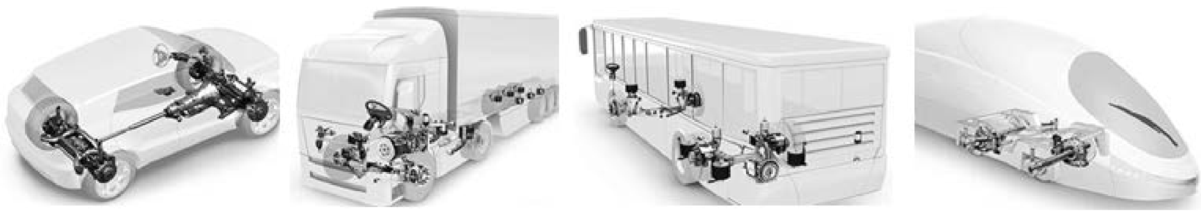

**Figure 1: Examples for the application fields of ZF’s piston rods**

The unrestricted functionality of the damper unit is crucial as it is an important safety relevant component. As the piston rod forms a central part of the damper unit, excellent mechanical wear and corrosion resistance as well as sliding properties (low coefficient of friction) are mandatory. These attributes are all achieved by functional chrome plating using chromium trioxide, a special process step for depositing a layer of metallic chromium on the functional surface of the piston rods, consisting of non-alloyed and low-alloyed steels. Piston rods coated with metallic chromium satisfy high requirements such as high temperature loads, mechanical impact and repetitive wear due to the unique tribological properties of the chromium layer.

Functional chrome plating can be divided in two sub-processes: **pre-treatment** and **main process**. The **pre-treatment** is a surface activation step, necessary for the deposition of the chromium layer in the **main process** (see Figure 2). <u>Both</u> sub-processes require the usage of chromium trioxide.

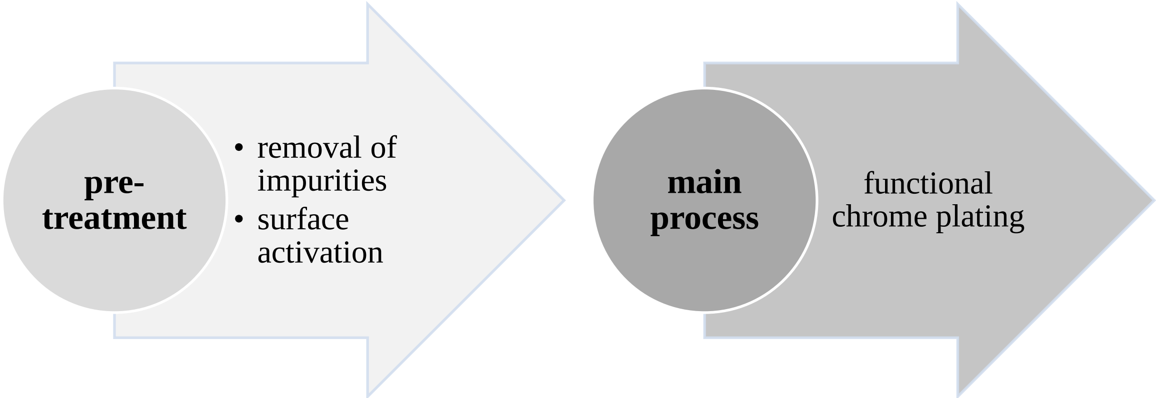


**Figure 2: Simplified scheme of the different process steps that are involved in functional chrome plating using chromium trioxide**

The characteristics of chromium trioxide, a detailed description of the plating process and the key functionalities of the plated piston rods are discussed in Chapter 2.

**Functional chrome plating of piston rods**

Functional chrome plating is a well-established and commonly used method among engineering companies from different industry sectors. In particular suppliers of the automotive and rail vehicle industry use this method to provide products with excellent properties such as component lifetime and safety aspects. Functional chrome plating of piston rods using chromium trioxide offers unique technical benefits in comparison to potential alternatives which include:

- ➢ excellent tribological properties:
    - wear and abrasion resistance combined with hardness leading to longevity
- ➢ mechanical strength
- ➢ adequate layer thickness
- ➢ corrosion resistance
- ➢ machinability
- ➢ design features

**The automotive and rail vehicle sectors and their dependence on chromium trioxide**

ZF Friedrichshafen AG produces piston rods for automotive and rail vehicle damper systems in varying sizes according to different fields of application.

- Eitorf: piston rods with diameters of 9 - 32 mm [redacted]
- Schweinfurt: piston rods with diameters of 9 - 32 mm [redacted]

ZF Friedrichshafen AG is a major player in the production of piston rods and covers around [redacted] % of the EEA-market for passenger car applications ([redacted] % worldwide) and [redacted] % of the EEA-market for truck and rail applications ([redacted] % worldwide). In general, the demand for high quality piston rods is increasing worldwide and slightly increasing in Europe.

ZF Friedrichshafen AG and their position in this competitive market are highly dependent on the continuous use of functional chrome plating using chromium trioxide as development, validation and implementation of an alternative method is time-consuming and cost-intensive. A detailed description of the complex development process is presented in Chapter 2.6.

With regard to both, the highly complex nature of supply chains (see Chapter 2.5.9) in the automotive and rail vehicle industry and the different lifetime of vehicles, planning reliability is crucial. If contractual obligations concerning part supply and/or quality are in danger because of a chromium trioxide prohibition, customers will source their parts from non-EEA markets.

**Identification of possible alternatives**

In this AoA four alternative technologies for the substitution of functional chrome plating using chromium trioxide are described in detail (see Chapter 3.4) and a full technical and semi-quantitative economic assessment was conducted by ZF. However, none of these technologies were found to be suitable to replace state-of-the-art functional chrome plating. In Table 1 an overview including color-coded technical assessment criteria of these alternatives is presented.

**Table 1: Most promising alternatives with color-coded technical assessment criteria**

| Alternative Method | Technical key functionalities of piston rods | | | | | |
|---|---|---|---|---|---|---|
| | Wear resistance | Corrosion resistance | Hardness | Coefficient of friction | Process conditions | Additional criterion: Microstructure |
| Case Hardening (Nitrocarburzation) | | | | | | not relevant |
| | | | | | | |
| Physical Vapour Deposition (PVD) | | | | | | not relevant |
| | | | | | | |
| Chemical Vapour Deposition (CVD) | | | | | | not relevant |
| | | | | | | |
| Trivalent Hard Chrome Plating | | | | | | |

Red = not sufficient; Yellow = cannot be determined; Green = sufficient; Colourless = no data;

Additionally, ZF Friedrichshafen AG was involved in the R&D of various alternative methods for functional chrome plating using chromium trioxide. However, due to significant technical limitations, these alternative approaches have been discarded in an early stage of their individual development process. The methods and related exclusion criteria are presented in Chapter 3.3.

In 2015, the company started to work on four additional and promising projects for the substitution of chromium trioxide based functional chrome plating (see Chapter 3.5). However, as the R&D progress on these methods is still in a very early stage, no data on technical and economic feasibility was available until now.

**Research and development timeline**

The R&D process for Cr(VI)-free piston rods at ZF is separated in four phases presented in Figure 3 and sufficiently described in Chapter 2.6.

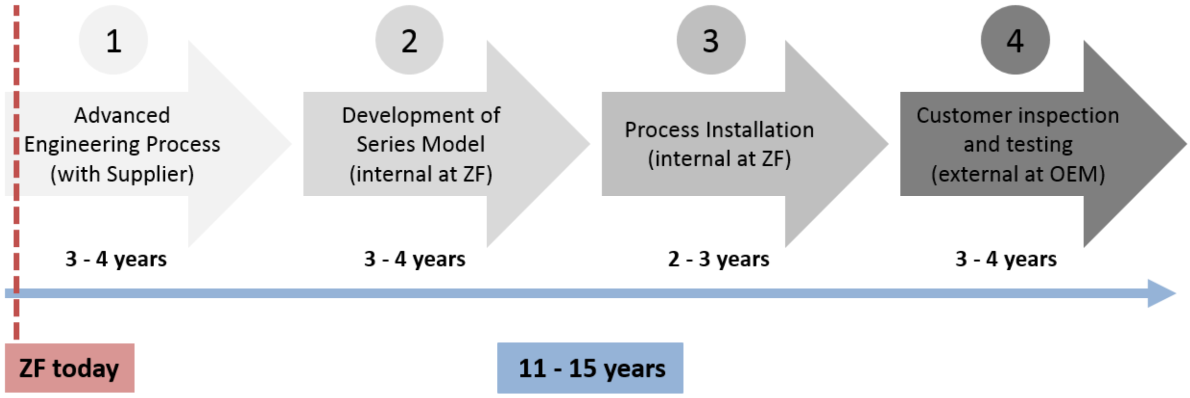


**Figure 3: R&D phases for Cr(VI)-free piston rods at ZF**

**Review period**

ZF conducted extensive R&D on different alternatives for functional chrome plating using chromium trioxide. However, these alternatives have been excluded due to significant technical limitations but the company is constantly searching for new promising R&D projects concerning the substitution of chromium trioxide. Due to the unique functionalities and performance of the chromium trioxide based plating, it is a challenging and complex task to replace this special process used for the refinement of automotive and rail vehicle piston rods. Until now, none of the technologies were able to compete with the performance of functional chrome plating using chromium trioxide.

For the derivation of the review period needed to enable sustainable replacement of functional chrome plating, the following factors were taken into account by the applicant (see Chapter 5.2 for a more detailed description):

- The risk characterized for the continued use of chromium trioxide can be considered as low;
- The benefits of continued use outweigh the risks by a considerable ratio of at least 1:23 [redacted]

- To date, no technical and economical feasible alternative is available on the market that can be implemented by the sunset date.
- ZF was proactive in the R&D of potential alternatives for many years but did not succeed in finding a suitable one and there is no indication that R&D and implementation success can be expected before 2038.
- Even if an alternative was to become available, the phase out of Cr(VI) used for over [redacted] different parts (differences in type of connection, length, thickness, stability, etc.) at ZF is a long process. This is supported by the fact that a phase out is directly dependent on the acceptance by the OEMs.
- Design changes for running series are not possible, due to safety reasons.
- The dominance of Cr(VI) plated products over a long time, alongside the continued availability of Cr(VI) plated imports if no authorisation is granted, suggests that any alternative must at least match the performance and price characteristics of Cr(VI) plated products. Therefore, return of investment can only be achieved if the implementation of a new technology is considered technically and economically acceptable for the OEMs under these aspects.

As a result, a review period of **at least 21 years** was selected because it coincides with best case scenario estimated by ZF for the schedule required to industrialize an alternative for the substance chromium trioxide and the corresponding processes (including pre-treatment) for refining piston rods for ZF's applications. In the calculation of the review period, contracts with [redacted] were not taken into account.

# 1 AIMS AND SCOPE OF THE ANALYSIS

## 1.1 Aims

The following substance is subject to this AoA and SEA:

**Table 2: Substance of this AfA**

| # | Substance | Intrinsic property(ies)[1] | Latest application date[2] | Sunset date[3] |
|---|---|---|---|---|
| 1 | Chromium trioxide, $CrO_3$<br>EC No: 215-607-8<br>CAS No: 1333-82-0 | Carcinogenic (category 1A)<br>Mutagenic (category 1B) | 21 March 2016 | 21 September 2017 |

[1] Referred to in Article 57 of Regulation (EC) No. 1907/2006
[2] Date referred to in Article 58(1)(c)(ii) of Regulation (EC) No. 1907/2006
[3] Date referred to in Article 58(1)(c)(i) of Regulation (EC) No. 1907/2006

Chromium trioxide is categorized as a Substance of Very High Concern (SVHC) and is listed on Annex XIV of Regulation (EC) No 1907/2006. Chromium trioxide is an inorganic salt based on hexavalent chromium (Cr(VI)). Adverse effects are evaluated in detail in the chemical safety report (CSR). The substance was included in the list of substances subject to authorisation (Annex XIV) in the course of the third recommendation of ECHA for the inclusion of substances in Annex XIV from 20th December 2011. Furthermore, chromium trioxide is categorised as a non-threshold substance and therefore the socio-economic analysis (SEA) route is foreseen under REACH.

The applicant ZF applies for authorisation to continue the use of chromium trioxide for functional chrome plating of piston rods. Piston rods form integral parts of dampers for the automotive and rail industry produced by the applicant. The Chemical Safety Report (CSR) prepared as part of this application of authorisation (AfA) is referenced here to provide context for the SEA part of this document.

The aim of this combined AoA + SEA is to demonstrate that no feasible alternatives to chromium trioxide **will be available before 2038** and that the socio-economic benefits associated with the continued use of chromium trioxide by the applicant outweigh the remaining risks to human health associated with prevalent use conditions.

## 1.2 Scope - uses of chromium trioxide

ZF performs chrome plating of piston rods in two facilities in Germany, Eitorf and Schweinfurt. The piston rods that are plated in Eitorf and Schweinfurt are then also used in the manufacturing of dampers at the facilities in Ahrweiler (Germany), Candiolo (Italy), Levice (Slovakia) and Lezama (Spain). It is important to emphasise that chrome plating only takes place in Eitorf and Schweinfurt.

The assessment takes into account economic, social and health impacts linked to a non-granted authorisation. Further impacts which cannot be quantified at this stage are described qualitatively.

The scope of analysis concentrates geographically on the location of the two ZF production sites in Eitorf and Schweinfurt which are involved with the functional chrome plating of piston rods. Thus, the impact assessment covers these areas specifically as part of the European Economic Area (EEA).

For the purpose of this SEA, an assessment period of **21 years** was defined. Because the sunset date for chromium trioxide is in 2017, the period of time covered by the SEA runs **from 2018 to 2038** (taking 2017 as a base year for calculations).

It is important to mention that ZF is covered under CTAC for the same use described in this application, with a recommended review period of 7 years.

## 1.3 Purpose and benefits of chromium trioxide usage for surface treatment of piston rods

ZF Friedrichshafen AG produces piston rods for automotive and rail vehicle damper systems in varying sizes according to the field of application and the occurring loads within these applications. The production takes place in two sites in Germany:

- Eitorf: production of piston rods for passenger cars with diameters between 9 - 32 mm [redacted];
- Schweinfurt: production of piston rods for passenger cars, commercial vehicles and rail vehicles with diameters between 9 - 32 mm [redacted].

The company offers a broad product range of different damper systems for the following applications:

- Passenger vehicles (cars, moto cycle, etc.);
- Commercial vehicles (trucks, buses, tractor, etc.);
- Rail vehicles (trains, trams, etc.).

In general, functional chrome plating provides excellent surface properties for piston rods. The mechanical and thermal loads occurring in damper system piston rods make chromium trioxide based plating indispensable for this application. The requirements for their functionality are not only particularly high but also constantly increasing to meet the advancing customer requirements in terms of service life, performance and of course safety. For example, the damper unit and all its components are designed to fulfil their unrestricted function over the life cycle of a vehicle (> 17 years). Furthermore, it is technically not possible to change only the piston rod when it is damaged, but instead the whole damper system must be replaced. This aspect emphasizes the need for robust piston rods with additional criteria regarding maintenance cost for clients and also environmental sustainability.

When facing these challenges, the use of chromium trioxide has multifunctional advantages, mainly based on the characteristics of the hexavalent chromium compound. The following desirable properties of metallic chrome coatings produced from chromium trioxide have made this compound the state of the art substance for refining piston rods surfaces for several decades. The beneficial properties are:

- excellent tribological properties:
    - wear and abrasion resistance combined with hardness leading to longevity
- mechanical strength
- adequate layer thickness
- corrosion resistance
- machinability
- design features

Another great benefit of functional chrome plating using chromium trioxide is process reliability, which is necessary for providing products with constant quality and worldwide availability; which is indispensable for ZF’s customers from the automotive and rail industry.

Although chromium trioxide is used in functional chrome plating of piston rods, **no chromium trioxide residues are present on the chrome plated article** and therefore **no risk hazard arises from the finished product**. Indeed, this is in compliance with EU Directive 2000/53/EG on end-of-life vehicles.

# 2 “APPLIED FOR USE” SCENARIO

Surface treatment of metals with varying compositions is a complex and stepwise process in many industry sectors. For the application of high performance surfaces in demanding environments, the use of chromium trioxide in metallic chrome coating components is mandatory to ensure quality and safety of the final product over decades. Surface treatments are essential for influencing the properties of a substrate in a way that the finished product performs adequately under the conditions of use. Different chemicals and operating conditions are specified for each individual plating process in order to effectively treat different substrates and / or confer specific performance criteria (e.g. layer thickness) to the treated article.

Functional chrome plating of piston rods can be divided in two sub-processes which require the use of chromium trioxide: **pre-treatment** and **main process**. During the pre-treatment, the surface of the substrate is exempt from impurities and simultaneously activated (etching). In the main process the actual chromium coating is created on the piston rod’s surface (see Figure 4). **Pre-treatment** and **main-process** are performed in two subsequent Cr(VI) containing plating baths.

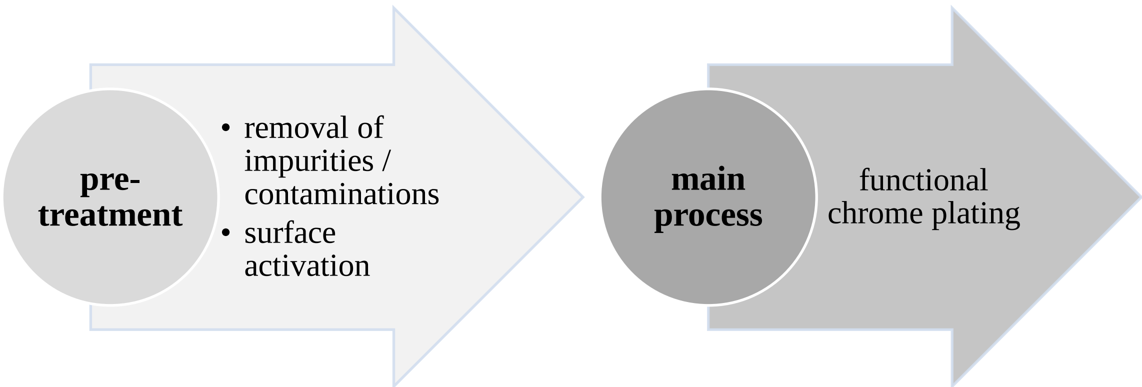


**Figure 4: Simplified scheme of the different process steps that are involved in functional chrome plating using chromium trioxide**

It is of great importance that only this combination of pre-treatment and main process step ensures the manufacturing of piston rods with well-prepared surface qualities, providing the necessary key requirements according to their field of application as descripted in Chapter 2.3.4.2.

Although pre-treatment and main process can be assessed individually, they cannot be seen as stand-alone processes but as part of the whole process chain. Consequently, when assessing alternatives for chromium trioxide-based surface treatment of piston rods, the whole process chain and the performance of the end product must be taken into account. It is crucial to consider that any change of even a single step in the process chain of surface treatments, will require (re)qualification before it can be implemented into the supply chain.

For a thorough assessment of replacement technologies, it is mandatory to include the whole process chain (including pre-treatment) while considering that for all steps involved, chromium trioxide-free solutions must be developed, which in combination result in technically equivalent performance compared to the current chromium trioxide containing treatments.

Please also note that ZF Friedrichshafen AG specifically decided to apply for the combined use of chromium trioxide in the pre- and main treatment process for two reasons. First, both process steps are performed in a closed system were no additional waste water is generated due to the pre-treatment process. Second, the chromium trioxide based pre-treatment process is absolutely crucial for the quality of surface coating applied to the piston rod in the main-treatment process.

**ZF Friedrichshafen AG regularly conducts worldwide bench mark investigations to stay well informed about the current R&D status at competitors concerning chromium trioxide alternatives. However, no alternative to state-of-the-art chromium trioxide based functional chrome plating is available on the market or used at any of ZF's competitors up to date.**

## 2.1 Hard chrome plating process description

Functional chrome plating of piston rods takes place at the production facilities in Eitorf and Schweinfurt. The production process is similar at both sites and involves the following steps:

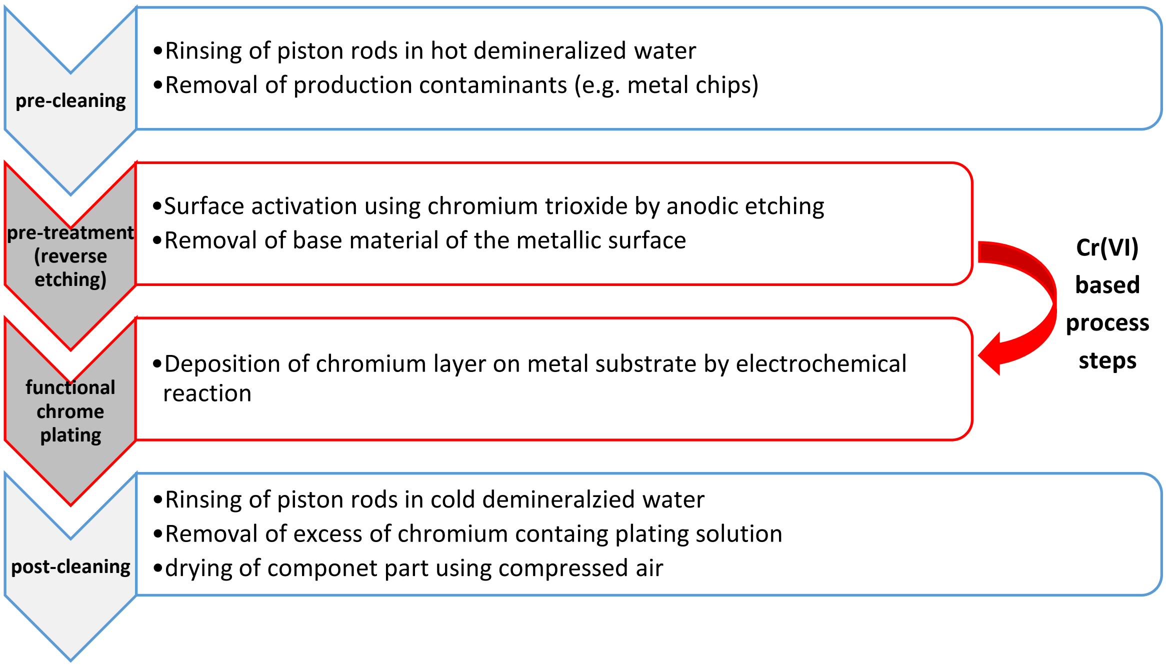


**Figure 5: Process steps used for functional chrome plating using chromium trioxide**

In the overall process only the reverse etching (anodic etching) and the actual plating process require the use of chromium trioxide. All other process steps and the surface of the finished piston rod are completely Cr(VI)-free.

Importantly, ZF uses two kinds of chromium plating lines with different Cr(VI) exposure levels to the workers:

- Encapsulated plating line ([redacted])
- Semi-closed plating line ([redacted])

[redacted].

The process description presented below covers the most relevant and critical process steps during functional chrome plating of piston rods. In general, both sub-processes (reverse etching and functional chrome plating) require the usage of chromium trioxide and involve immersion of the component in the two process baths for reverse etching and chromium plating.

In Chapter 2.2 pre-cleaning and reverse etching are summarized as overall pre-treatment process.

Detailed descriptions of the key performance parameters and the sector specific minimum requirements of the metallic chrome coating on piston rods are provided in Chapter 2.3.4.

## 2.2 Process steps

### 2.2.1 Pre-treatment processes

In this chapter, the pre-cleaning and reverse etching step (although these are single process steps; see Figure 5) are summarized as pre-treatment processes.

For functional chrome plating of piston rods, two pre-treatment steps are necessary to prepare the surface of the substrates for the subsequent plating process steps as adequate preparation of the base metal is a prerequisite: adhesion between the metallic chrome coating and the substrate depends on the force of attraction at an atomic level. Therefore, the surface of the metal must be absolutely free of contaminants, corrosion and other residuals until the plating process is finished.

**Pre-cleaning** is the removal of pre-production contaminants like metal chips and water-soluble contaminants from the metal surface of the piston rod in a mechanical rinsing process.

Pre-cleaning is performed by rinsing the piston rods with hot, demineralized water and is crucial to remove pre-production contaminants such as metal chips and other particles sticking to the surface. Additionally, water-soluble contaminants (e.g. salts) are eliminated. It is of great importance that the subsequent treatment baths are not contaminated with foreign ions as these cause electro-chemical side reactions which are capable of deteriorating the surface quality of the plated piston rod. Therefore, the life cycle of the treatment baths is also extended.

**Etching** is defined as a surface activation step, performed by the removal of base material from a metal surface. The etching process uses chromium trioxide and creates a surface which is clean and free from defects or metal oxides, adequately preparing the piston rod's surface for the subsequent chromium plating process and providing very good adhesion.

Etching affects metal surfaces in an aggressive manner so that actual base material is removed. For example, during a 5 minutes etching step, 2-4 µm of the substrate is removed. In general, the exact removal rates depend on the base materials used (see Chapter 2.3.3).

In functional chrome plating of piston rods, a **reverse etching** process using an aqueous solution of chromium trioxide is used. Consequently, additional rinsing processes between the etching and plating steps are not required. Reverse etching is performed by the application of an anodic current to the metal substrate which increases the metal dissolution rate in aqueous solution. The etching process immediately slows down after the current stops and therefore its benefit is the high level of adjustability regarding etching parameters and metal dissolution. Chromium trioxide is necessary for controlling a moderate etch rate and to avoid over-etching.

Reverse etching is performed with a Cr(VI) bath concentration below 30 % [redacted] and a current density of 20-80 A/dm² [redacted] for both, the encapsulated and semi-closed system. In the encapsulated plating line a sulfuric acid bath concentration of below 2 % [redacted] and a bath temperature of 60 - 80 °C [redacted] is used. The semi-closed plating line operates with a sulfuric acid bath concentration of below 2 % [redacted] and a bath temperature of 40 - 70 °C [redacted].

After the etching process, the parts are transferred directly into the subsequent chromium plating bath. No rinsing processes are necessary because of the chemical compatibility between the treatment solutions. Another important advantage of the Cr(VI)-based etching is that the surface of the piston rods becomes resistant against air oxidation during the transfer between the treatment baths due to surface passivation. Oxidation of the activated surface would deteriorate the adhesion between chromium layer and substrate in the main plating process.

### 2.2.2 Main process of functional chrome plating

The metallic chrome layer is applied by electroplating based on the principle of electrolysis illustrated in Figure 6. The setup for electrolysis for plating piston rods consists out of the following elements:

- direct current source
  - ➔ providing electrical potential for reduction of Cr(VI) cations
- inert anode (positive pole)
  - ➔ only responsible for charge transfer (current flow)
- cathode (negative pole)
  - ➔ illustrated by piston rod
- electrolyte
  - ➔ contains Cr(VI) cations and additives (e.g. catalyst)

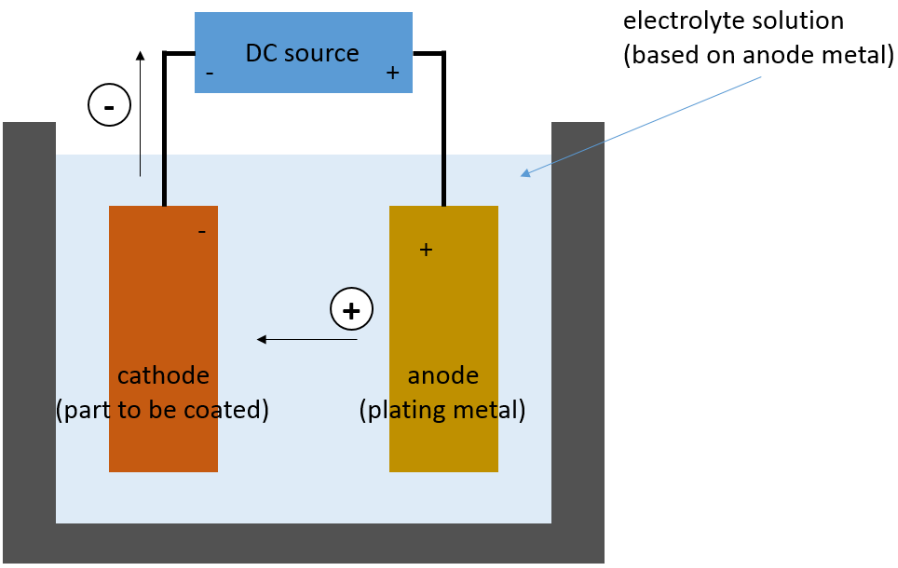


**Figure 6: Functional principle of electroplating**

During the functional chrome plating of piston rods, a coherent chromium coating forms on the surface of the component. The plating process is performed directly on the piston rod by applying an electrical current between the component (used as cathode) and anode. For the chromium plating the piston rod is immersed in the electrolytic plating solution containing Cr(VI) cations sourcing from dissolved chromium trioxide and additives. This aqueous solution forms the so-called electrolyte. The actual plating or layer build-up is based on the reduction of the Cr(VI) cations which takes place on the surface of the negatively charged piston rod (cathode).

The chromium layer is applied specifically to the functional surface (see Figure 13 in Chapter 2.3.3) of the piston rod whereas the end parts remain non-plated. This selective plating is achieved by immersion the piston rod only up to a specific immersion depth and masking the counterpart.

In the plating process of piston rods, the chromium trioxide solution used has a Cr(VI) concentration below 20 %. Additionally, sulfuric acid is contained in the treatment solution in a catalytic concentration below 2 % [redacted] in the semi-closed system and 2 % [redacted] in the encapsulated plating line. The plating process in the encapsulated plating line is conducted with a bath temperature of 60 - 80 °C [redacted] and a current density up to 250 A/dm² [redacted]. The semi-closed plating line operates with 20 - 80 A/dm² [redacted] current density and a temperature of 50 - 70 °C [redacted].

The properties of electrodeposited coatings depend strongly on the type and exact chemical composition of the electrolyte, the current density and the electrolyte temperature. In the case of chromium deposition, the special advantageous properties of functional chrome coatings like high hardness can only be achieved within a certain working window of electrolyte composition, current density and electrolyte temperature. The chemical properties of chromium trioxide play a crucial role in the generation of those properties.

**For visualization purposes, please find a detailed video of ZF's functional chrome plating process (encapsulated plating line) as an attachment to the application documents.**

### 2.2.3 Post-treatment process

**Post-cleaning** is the removal of excess plating solution containing Cr(VI) cations and additives after the actual plating process is finished.

Post-cleaning is performed by rinsing the piston rods with cold, demineralized water and is crucial for surface quality and to prevent unnecessary exposure of hexavalent chromium to the worker (e.g. during packaging process). After removal of plating solution excess the components are dried properly, supported by the usage of compressed air. [redacted]

In general, regarding the overall chrome plating process, very low amounts of Cr(VI), if at all, are released from wastewater treatment systems, where residual Cr(VI) is reduced to Cr(III). The resulting Cr(III) is then precipitated and disposed to licensed waste management companies. Because this is a fully automatic and enclosed process, there is no potential of inhalation exposure from the waste water treatment systems because sampling before discharging to public sewage system is a short-term activity and the concentration of Cr(VI) is very low (0.1 mg Cr(VI)/L).

## 2.3 Analysis of substance function

ZF Friedrichshafen AG produces piston rods for automobile and rail vehicle damper systems in varying sizes according to the field of application and the occurring loads within these applications. The production takes place at two sites in Germany:

- At the production facility in Eitorf piston rods for passenger cars with diameters between 9 - 32 mm [redacted] are produced;
- Piston rods with diameters between 9 - 32 mm [redacted] for passenger cars, commercial vehicles and rail vehicles are crafted at the production site in Schweinfurt.

The company offers a broad product range of different damper systems (see chapter 2.5.4) for the following applications:

- Passenger vehicles (cars, moto cycle, etc.);
- Commercial vehicles (trucks, buses, tractor, etc.);
- Rail vehicles (trains, trams, etc.).

In the following, the basic principle and setup of a damper system will be explained in detail. Moreover, the complex setup of the chassis of power-driven vehicles is explained to provide an overall understanding of the importance of accurate working damper systems and the role Cr(VI) plays in this context.

### 2.3.1 The chassis

The chassis forms the central part of power-driven vehicles. It consists out of many individual components such as brakes, steering, suspension and dampers and its general task is to provide with excellent handling characteristics. Therefore, it can be considered the most important safety relevant feature of different sorts of vehicles.
In this report only the function of the suspension, the damper and the associated piston rod will be explained in further detail as the following general description of the functional principle of these components can be related to passenger, commercial and rail vehicles (see chapters 2.3.2 & 2.3.3). Figure 7 gives an example of the varying chassis setup possibilities used in different applications. In rail vehicles, dampers have a second important task. As a non-chassis components, crash dampers are used for the non-destructive and smooth linking of rail vehicles. However, the functional principle remains the same.

**Please note that, only the piston rod is in the scope of this AoA. In the following, the functional principles of the suspension and the damper system are only explained to describe the complex interaction of these components.**

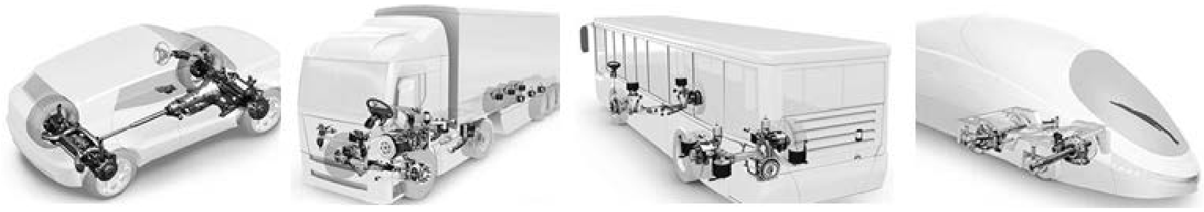

Figure 7: Varying chassis setups used in different applications

### 2.3.2 The suspension / damper system:

The suspension / damper system is an essential part of the chassis as it is the major connection piece between the wheel suspension on the bottom and the wheel arch on top (see Figure 8).

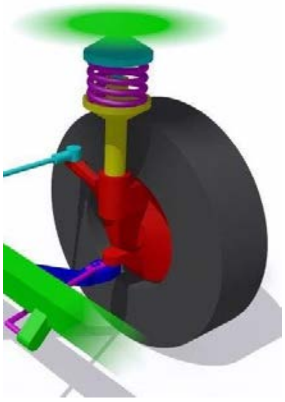

**Figure 8: Assembly situation of a suspension / damper system**

The damper system consists out of the following main three components (see Figure 9):

- damping tube
- piston rod
- piston with mechanical valves

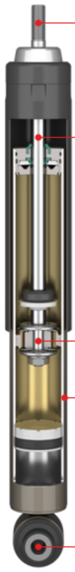


**Figure 9: Simplified setup of damper unit with bottom & top anchorage points**

*Functional principle*

The key functionality of the suspension is the absorption of bumps and shocks by converting them into mechanical oscillations of the vehicle body. In comparison with the damper, the suspension is more relevant for providing comfort than contributing as a safety relevant components. In fact, the suspension increases the need for dampers as these are mandatory for abating the oscillations of the vehicle body triggered by for example road bumpiness or change in direction. Without this functionality the spring borne mass, correlating with the vehicle body would remain in oscillation for an extended period of time which would decrease comfort and even more importantly handling characteristics of the appropriate vehicle. The absorption of the oscillation is based on the physical principle of transforming kinetic energy (oscillation energy) in thermal energy by liquid friction which occurs when in this case oil passes the valve openings on the piston inside the damping tube (see Figure 10). Due to this energy transformation the damper can reach temperatures between 100 and 120 °C.

During the energy transformation, almost all mechanical force occurring inside the damper unit is carried by the piston rod. Consequently, it is crucial that this component is built with high mechanical and wear resistance together with excellent corrosion resistance over the lifetime of the vehicles. Further key properties are a low coefficient of friction to prevent surface abrasion and thermal stability due to the high temperatures occurring in a damper under load.

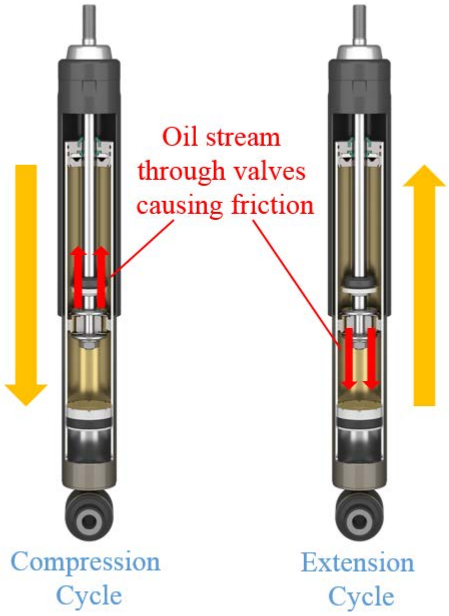


**Figure 10: Different phases of a damper under load**

### 2.3.3 The piston rod

**Please note that, for a thorough understanding of the importance of the piston rod the whole damper system has to be regarded but the scope of this AoA is limited to the piston rod.**

*Function*

The piston rods subject to this report are the central part of multi-component damper system described in detail in Chapter 2.3.2. The most demanding task of the piston rod is to transfer mechanic tractive forces between the vehicle body and the wheel suspension emerging during the retardation of movement caused by hydraulic oil passing the valve openings on the piston (see Chapter 2.3.2.). Additionally, it forms the upper anchorage of the damper unit to the vehicle body and it seals the pressure chamber by a tight contact to the sealing of the damping tube (see Figure 11).

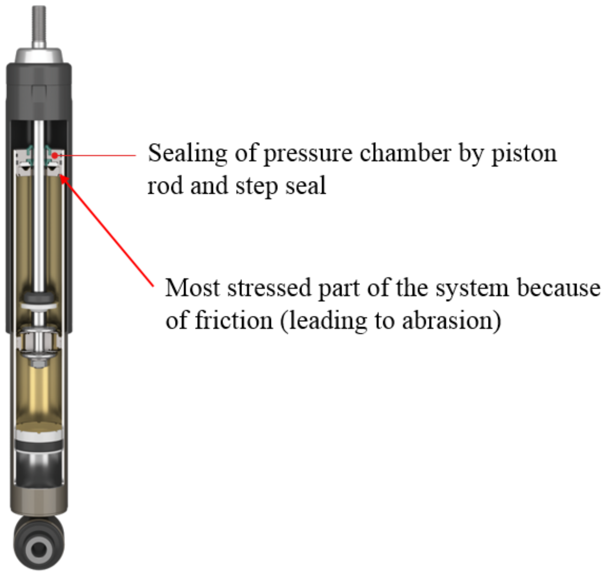


**Figure 11: Cross section of damper unit with illustration of the critical abrasion point (sealing / surface)**

As mentioned in Chapter 2.3.2, the work performed by the piston rod and the attached piston can be described as a simple upward and downward movement. These contrary actions result in high stress between the functional surface of the piston rod and the sealing of the damping tube because of mechanical friction (see Figure 11) which could cause abrasion and therefore weakening of the basis material (ferrous compound). The effecting forces on the whole damper system are of 3-dimensional nature (tractive and shearing forces) which additionally increases the stress on the piston rod (see Figure 12).

Due to these demanding requirements it is of utmost importance that the functional surface of the piston rod shows excellent wear and abrasion resistance and a low coefficient of friction in order to withstand the mechanical impact of friction (see ) and 3-dimensional forces (see Figure 12).

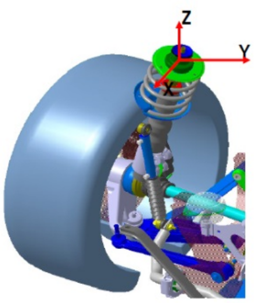


**Figure 12: Impact of 3D forces on damper unit**

Furthermore, an effective corrosion protection is necessary to prevent oxidation of the piston rod which could lead to degradation of the basis material. Another essential aspect of the functional surface is a sufficient layer thickness as no stressed component or material is completely free of wear. Even small scratches on the functional surface are a potential catalyst for corrosion of the substrate.

Together, the criteria mentioned above guarantee that a damper system has a [redacted] during its lifecycle. These are crucial thresholds which must not be exceeded because oil and gas levels are important for the damper unit to function.

This demanding combination of safety aspects can currently only be achieved by functional chrome plating of piston rods using chromium trioxide.

*Metal composition and functionalities*

ZF Friedrichshafen AG uses the following three different basis materials for their piston rods:

- C35 steel: non-alloy quality steel
- C45 steel: non-alloy quality steel
- ST52-3 steel: low-alloy quality steel

The piston rod is generally separated in three functional sections. The end sections can be described as fastening stem for the connection to the vehicle and stem for the piston valve inside the damper. The stem for the piston valve additionally contains the rebound stop groove for the rebound stop ring. The middle section is the functional sliding surface which is coated with a layer of chromium whereas the end sections remain chromium-free (see Figure 13). This selective treatment including adjustable properties for the treated product such as layer thickness are essential benefits of functional chrome plating using chromium trioxide.

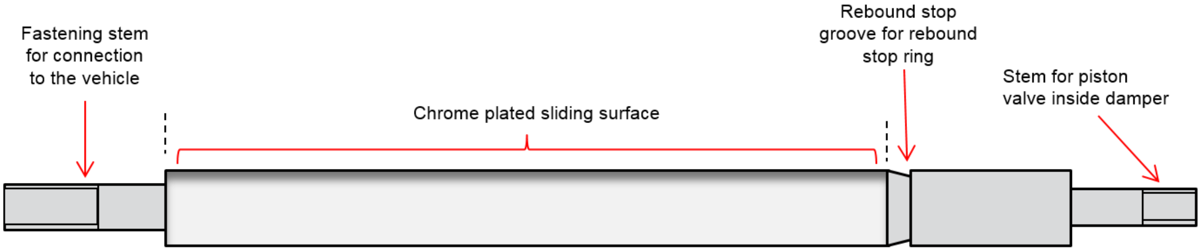


**Figure 13: Piston rod with functionalities: vehicle and valve connection points and chrome-plated sliding surface**

The piston rods treated with functional chrome plating by ZF Friedrichshafen are used in damper systems of passenger and commercial vehicles and rail applications. In accordance with their field of application they need to comply with different requirements such as layer thickness of the applied chromium coat and of course strength, size and diameter of the basis material which vary in their metal compositions. Functional chrome plating using chromium trioxide offers the possibility to apply a coating with unique properties to these different kinds of metal compounds. Table 4 provides an overview of the varying requirements relevant in the different application sectors.

### 2.3.4 Key functionalities of functional chrome plating of piston rods

The unique functionalities of chromium trioxide make it the ideal substance for refining metallic surfaces. Chrome coatings provide a unique combination of surface properties (key functionalities) which cannot be easily replaced. In this chapter, the key functionalities for piston rods will be presented and quantified, if applicable. These functionalities will be used for the assessment of alternatives in Chapter 3.4.

#### 2.3.4.1 Key functionalities of chromium trioxide-based surface pre-treatment

The pre-treatment process *etching* prepares the metallic surfaces of the piston rod for the subsequent main process step. In Table 3, selected key functionalities and relevant advantages of the etching process are listed. Chromium trioxide based pre-treatment ensures high quality products, mostly related to the unique functionality of the hexavalent chromium compound.

**Table 3: Key process functionalities of Cr(VI) based pre-treatment:** ***etching***

| Process | Key Process Functionality |
|---|---|
| **Etching** | Well-defined, adjustable moderate etch rate |
| | Sufficient surface activation to ensure coating adhesion |
| | Removal of base metal substrate / oxides |
| | Suitability for all piston rod base materials (non & low alloy steels) |
| | Chemical compatibility:<br>- no cross contamination to subsequent bath<br>- no rinsing steps necessary (waste water reduction)<br>- no re-oxidation during rinsing (no loss of surface activation) |
| | High level of automatization |
| | Long-time bath stability & simple bath maintenance |
| | Simple analytical method for process control |

#### 2.3.4.2 Key functionalities of the metallic chrome coating and process requirements

A non-exhaustive list on the requirements regarding performance of chromium plated piston rods is presented in Table 4. The key functionalities which have been identified to be the most relevant for the respective field of application and which are essential for the assessment of potential alternatives are descripted in more detail below.

Please note that in Table 4, *process conditions* is additionally added as assessment criterion, although this is no surface property of the metallic chrome coating itself. Furthermore, *process reliability*, as a general aspect of a production process, required by the industry is described below.

**Table 4: Key functionalities of the metallic chrome coating and process conditions**

| Quantifiable key functionality | Definition / Justification | Automotive | | Rail |
|---|---|---|---|---|
| | | **Passenger Vehicles** | **Commercial Vehicles** | **Rail Vehicles** |
| **Wear resistance** | Surface hardness needed to avoid any scratches or damages even at side loads.<br>Oil & gas tight at temperature range -40 to +200°C [redacted] | [redacted] | [redacted]. | [redacted] |
| **Corrosion resistance** | Minimum 240 hours salt spray resistance according to DIN EN ISO 9227 NSS | [redacted] | [redacted] | [redacted] |
| **Hardness** | Hardness test | > 800 HV 0.05* [redacted] | | |
| **Coefficient of friction** | Surface roughness: max. Rz ≤ 1 µm<br>Minimize wear of seal and rod bushing | [redacted] | [redacted] | [redacted] |
| **Process conditions** | Combination of critical process parameters: temperature, time and subsequent tempering. | Technical important criteria of a coating technology as piston rods consist of heat sensitive base materials (max. 300 °C) and therefore process temperature, process time and tempering is strictly limited. | | |
| | | | | |
| **Layer thickness** | Limited by internal stress, deformation, delaminating, deposition time | 5-40 µm [redacted] | | 5-40 µm [redacted] |

* 0.05 is the test force in kilopond (kp) applied to the piston rod during testing;

*Wear resistance*

Wear is the progressive metal loss from the surface of a solid compound triggered by mechanical impacts such as friction and side loads.

The wear resistance of piston rods used in automotive and rail applications is evaluated in a standard durability test (complete damper system) with additional side loads for determination of long-term performance in regards to abrasive wear, leakage and oil evaporation. To create realistic test conditions, the damper system is subjected to different static and / or dynamic (pulsing) side loads with a maximum of [redacted]. The requirement on the piston rod coating is that no visual detectable damages (e.g. scratches) occur after the durability test. Additionally, the validation criteria on the whole damper system are: [redacted]. After the durability test, the functional surface of the piston rod may not show any wear that could affect its function.

Piston rods are relevant safety components which are constantly under stress (mechanical and temperature loads). Usually, they are designed to withstand the life cycle of a vehicle (> 17 years) and therefore it is essential that they are built with high abrasion resistance which is achieved by high surface quality.

*Corrosion resistance*

Corrosion describes the process of oxidation of a metallic material due to chemical reactions with its surroundings, especially under the effect of humidity and oxygen. In this context, the parameter corrosion resistance relates to the ability of a metal to withstand gradual destruction by chemical reaction with its environment. It is crucial for longevity and safety as corrosion leads to the weakening of the piston rod basis material.

Corrosion resistance is important as the surface of the piston rod can get in contact with water, salt and other corrosive substances when the piston rod itself is out of the damping tube during the up- and down movement necessary for the damping function. A detailed description of the functional principle of a damper is provided in Chapter 2.3.2.

Components that inhibit corrosion can be categorized according to basic quality criteria which are inhibitive efficiency and versatility. Ideally, the component is compatible with subsequent layers and performs effectively on all major metal substrates. Furthermore it needs to guarantee product stability (chemically and thermally) and reinforce the requested coating properties.

The corrosion resistance test performed for piston rods for ZF's applications is the **Salt Spray Test (SST)** according to DIN EN ISO 9227 NSS. Minimum requirement is a corrosion resistance of 240 h.

*Hardness*

Hardness is defined as the resistance of solid matter to various kinds of permanent shape changes when a force is applied. The total hardness of the product is the combined result of the substrate hardness and coating hardness. Measuring Vickers hardness (HV) for metallic materials, ISO 6507-1, is the most common hardness test method and used for evaluation of alternative piston rod coatings. The minimum requirement for piston rods used in automotive and rail applications is **> 800 HV 0.05** [redacted]. Hardness is linked to the scratch and abrasion resistance. The amendment “0.05” is the test force in kilopond (kp) applied to the piston rods during the determination of the hardness value.

*Coefficient of friction*

Friction is the force resisting the relative motion of solid surfaces sliding against each other. The friction coefficient is low for functional chrome plated surfaces. The coefficient of friction can be determined by tribological testing.

ASTM D 4518 is a test method for static friction of coating surfaces and ASTM D 1894 is the standard test method for static and kinetic coefficients of friction of sheeting.

Equipping the surface of a piston rod with a low coefficient of friction ensures a high quality damper systems regarding both comfort and safety performance. However, the most important benefit is that a low coefficient of friction leads to low abrasion which leads to longevity and safety.

*Process conditions*

Process conditions combine the critical process properties temperature, time and subsequent tempering.

Process temperature and tempering are technical important criteria for potential alternative coating technologies because the base materials (see Chapter 2.3.3) used for piston rods are only heat resistant up to a maximum temperature of 300 °C without losing their specific metal properties. Functional chrome plating using chromium trioxide requires a relatively low process temperature of < 75 °C and subsequent tempering at [redacted] °C. Potential alternative coating technologies must not exceed this threshold of 300 °C, neither in the coating process itself nor in the follow-up process step tempering, if required.

Process time is mostly important as an economical factor. Functional chrome plating using chromium trioxide offers the possibility to treat large numbers of components in a [redacted]. Potential alternative technologies, even if the coating itself shows promising results, must have acceptable processing times to be practical on an industrial scale in order to satisfy the market requirements.

*Process reliability*

Process reliability is crucial for customers from the automotive and rail industry as they demand products with constant high quality over the contract period. Using immature technologies holds the risk of product failure which is associated with high costs due to recalls, especially in the automotive but also rail industry. Additionally, it is of great importance that the source materials used in the alternative method are constantly available worldwide to ensure product supplies.

*Layer thickness*

Layer thickness is an additional key functionality of the functional chrome plating process using chromium trioxide. The thickness of a chromium layer applied by functional chrome plating varies in accordance to the field of application the piston rods is used in (5-40 µm) [redacted] The minimum requirement for automotive vehicles is 5-40 µm [redacted] of thickness. For rail vehicles, the minimum layer thickness is 5-40 µm [redacted] In general, layer thickness can be regarded as a measure for corrosion protection. The thicker the achievable layer (by a specific method), the more corrosion protection can be expected. However, this is not a general case as different other factors such as oxygen permeability play a major role.

The layer thickness of piston rods is measured online and offline by a non-destructive magnetic inductive procedure according to DIN EN ISO 2178 and ASTM D7091.

**Layer thickness is not used as a criterion for assessment in individual alternatives presented in Chapter 3.4. The reason behind is that a layer thickness with a definite value is a chromium constant and cannot be applied or compared to alternatives using different processes and chemicals. In theory, a thinner layer ([redacted]) applied by an alternative can be sufficient to achieve adequate wear resistance. However, insufficient layer thickness is correlated to insufficient corrosion resistance and therefore mentioned as exclusion criteria for some alternatives, when applicable**.

## 2.4 Market and business trends including the use of the substance

- **The ZF Group is a major player in the damper market, Europe wide and globally.**
- **The company covers around [redacted] % of the EEA-market for passenger car applications ([redacted] % worldwide) and [redacted] % of the EEA-market for truck and rail applications ([redacted] % worldwide).**
- **Over the next years, [redacted].**
- **As of 2016, [redacted]. The portfolio of piston rods produced [redacted].**
- **Every single piston rod treated at ZF is chrome plated.**
- **ZF currently produces piston rods for damper systems used in [redacted] vehicle projects (parts differ in type of connection, length, thickness, stability, etc.).**
- **The contractual obligations include 7 years of serial production and that the supply with spare parts has to be guaranteed by the company at least for 10 years after End of Production (EOP) for every series produced now and in the future. Changing the technology is explicitly not allowed to not impair the function and the safety of the damper system.**

## 2.5 The ZF Group

### 2.5.1 The ZF Group financial and employment information

The ZF Group worldwide sales reached EUR 29 154 million in 2015. By the end of that year, 138 269 people were employed in 230 locations, thereunder [redacted], in 40 countries worldwide. Approximately EUR 1 290 million were invested in properties, plants and equipment while the investments in R&D consumed EUR 1 390 million in 2015.

The significant impact of the businesses managed by the ZF Group can also be observed by the number of firms involved in the ZF network and supply chain worldwide: 77 service companies and more than 650 service partners.

Figure 14 shows the worldwide presence of the ZF Group in terms of production, development, sales and service branches.

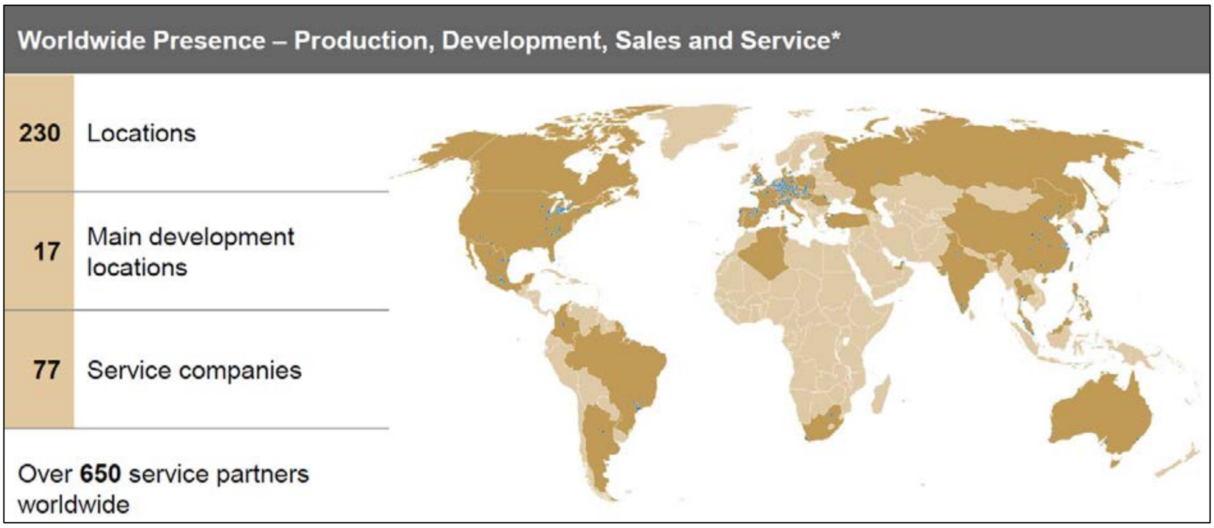


**Figure 14: ZF Group Worldwide presence (Status: December 2015)**

The ZF group is structured in technology divisions which themselves are organised in different business units. The businesses in the scope of this application are located in the car chassis technology division, more specifically in the suspension technology business unit. These are described in the following.

### 2.5.2 Car chassis technology division

The car chassis technology division of the ZF Group (CT) comprises three business units: chassis systems, chassis components and suspension technology. Figure 15 shows some examples of what is produced by each of the units of this division.

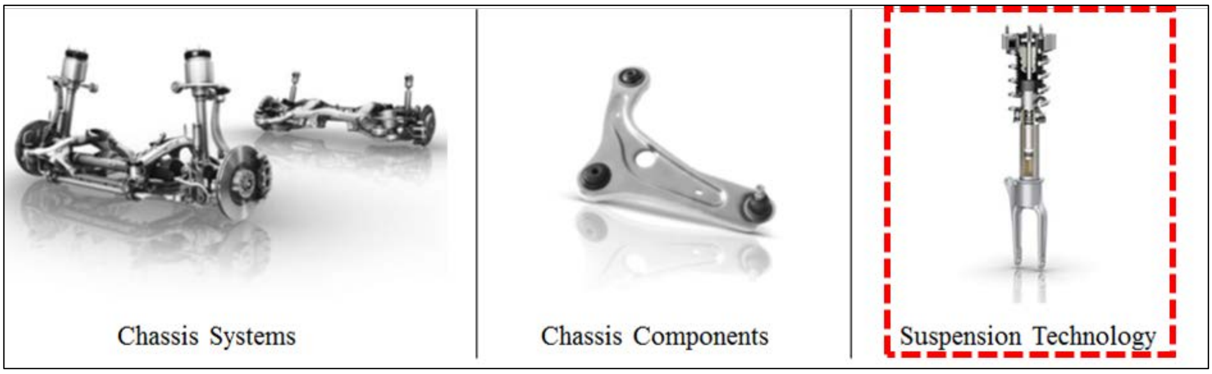


**Figure 15: Business units of the ZF Group car chassis technology division**

The division has more than 40 plants in 18 countries, 5 of them being development centres. The development centres are located in Dielingen (Germany), Schweinfurt (Germany), Eitorf (Germany), Northville (USA) and Shanghai (China).

### 2.5.3 Suspension technology business unit

Among the three business units (Figure 15) which compose the car chassis technology division, the suspension technology unit is the relevant one for the present AfA (see Figure 15). The product portfolio of this business unit includes damper modules and damping and levelling systems for the automotive and rail industry.

In 2015, the suspension technology business generated worldwide sales of [redacted]. In the same year, [redacted] were employed in the facilities shown in the Figure 16.


**Figure 16: Suspension technology business unit locations**

As it can be seen from Figure 16, there are 6 locations focused on suspension technology in the EEA - 3 in Germany (Schweinfurt, Eitorf and Ahrweiler), 1 in Italy (Candiolo), 1 in Slovakia (Levice) and 1 in Spain (Lezama). As stated before, only the sites in Schweinfurt and Eitorf are in the direct scope of this application for authorisation.

### 2.5.4 Description of directly affected sites in the EEA

- **Schweinfurt (Germany)**

The site in Schweinfurt is the global headquarter of ZF suspension technology. Out of the 6 locations of this business unit in the EEA, this is the one with the highest amount of revenues and number of employees. Schweinfurt had sales amounting to [redacted] in 2015. [redacted] workers are involved in the production of the piston rods, which are chrome plated with chromium trioxide and are a vital component of the dampers produced by ZF. The portfolio of piston rods produced in Schweinfurt includes different diameters ranging from 9 - 32 mm [redacted].

The facility produces active and semi-active damping systems ([redacted]), see Figure 17.

**Figure 17: Active and semi-active damping systems produced at the facility in Schweinfurt**

The dampers produced by the facility in Schweinfurt are supplied to firms from the automotive (including passenger cars, trucks and utility vehicles for agriculture) and rail industries.

- **Eitorf (Germany)**

Eitorf generated sales amounting [redacted] in 2015. [redacted] workers are employed in the production of chrome plated piston rods [redacted]. The facility produces piston rods in [redacted] different diameter sizes to be used in the assembling of dampers: diameters from 9 - 32 mm [redacted]

With regards to final products, the site produces twintube shock absorbers, twintube damping modules and levelling systems ([redacted]), see Figure 18.

**Figure 18: from left to right: twintube shock absorber, twintube damping module and levelling system produced at the facility in Eitorf**

### 2.5.5 Connection among the facilities in EEA

The facilities located in the EEA are connected to each other in regards to the supply of piston rods. [redacted]

### 2.5.6 The dampers market and market trends

As pointed out, the ZF Group is a major player in the damper market, Europe wide and globally. Regarding passenger cars, ZF holds approximately [redacted] % of the EEA market of conventional dampers and semi-active damping systems. Worldwide, the applicant estimates a market share of [redacted] % of the conventional dampers and semi-active damping systems. With respect to dampers for trucks, trains and utility vehicles for agriculture, ZF estimates to have [redacted] %, [redacted] % and [redacted] % of the European market respectively. Worldwide, ZF market shares in the same sectors are estimated to reach [redacted] %, [redacted] % and [redacted] % respectively. The current conventional and semi-active dampers market share distribution and the projection for 2018 both for Europe as worldwide are shown in Figure 19 and Figure 20.

[redacted]

**Figure 19: Conventional and semi-active dampers market share distribution in Europe**

[redacted]

[redacted]

**Figure 20: Conventional and semi-active dampers market share distribution worldwide**

[redacted]

[redacted]

**Figure 21: Leading suppliers of dampers in Europe (ZF competitors)**

[redacted]

### 2.5.7 International trade

The EU-5 biggest economies (Germany, France, the UK, Italy and Spain) imported approximately 1.3 billion EUR worth of shock absorbers in 2013. Germany is by far the biggest importer in the group, representing over 42 % of the imports (EUR 562 million in 2013). Combined, however, the group of 5 economies is a net exporter of shock absorbers. In 2013, around EUR 1.8 billion in shock absorbers were exported and exports were also led by Germany (56 % of all shock absorbers exported by the 5 economies combined). The exports of shock absorbers by the EU-5 grew at a 6.6 % CAGR between 2010 and 2013. Approximately 85 % of the exports are sold in Western and Eastern Europe and other developed countries (CBI Ministry of Foreign Affairs).

### 2.5.8 The automotive industry in Europe

The EU is among the world's largest producers of motor vehicles. The automotive industry is therefore central to Europe's prosperity[1]. 6.2 million vehicles are exported to almost all countries around the world (31 % to Asia and Oceania, 34 % to North America, 20 % to EFTA and Eastern Europe, 7 % to the Middle East, 6 % to Africa and 2 % to South America and the Caribbean) (3).
The European Automobile Manufacturers Association (ACEA) advises that the manufacturing of motor vehicles accounted for 843.4 EUR billion in turnover in 2012, and employs 3.1 million people in automotive manufacturing ((ACEA), European Automobile Manufacturers Association, 2014). Overall it contributes to 12.2 million people employed (5.6 % of the EU employed population). This includes activities from manufacturing, automobile use, maintenance and repair as well as activities such as transport by road and construction of roads that may not be impacted by a decision not to grant an authorisation. Nevertheless, the economic importance of this market is clearly very substantial. Moreover, the European automotive industry represents 25 % of world production of passenger cars, accounting for more than 18.4 million units in 2015, supporting a vast supply chain and generating a vast array of business services ((ACEA), European Automobile Manufacturers Association, 2016). Furthermore, the automotive industry must comply with the End of Life Vehicle Directive (EuroLex) , which regulates that new cars need to be free of hazardous substances such as Cr(VI) (except uses described in Annex II of Directive 2013/28/EU (EuroLex) amending Annex II to Directive 2000/53/EC).

In addition, the automotive industry is a key R&D investor leading in innovation worldwide, spending over 44.7 billion EUR and producing 6 000 patents per year (3).

Applications of functional chrome plating in the automotive industry are manifold, e.g. on the moving parts of an engine drive train, transmission, steering and differential components; dampers, piston rings, power train, fuel injection parts, pistons for brakes, engine valves (stems) etc.

[1] http://ec.europa.eu/growth/sectors/automotive/index_en.htm [Cited: 09 January 2016].

### 2.5.9 Supply Chain

Chromium trioxide is manufactured outside the EEA, imported, and distributed to users as a pure substance or to formulators that produce mixtures containing chromium trioxide. These mixtures are delivered to ZF facilities, which do in-house plating using chromium trioxide as part of the production process of piston rods. As described below in the Figure 22, ZF facilities in Schweinfurt and Eitorf produce the chrome plated piston rods and supply them for dampers production (internally and to other ZF facilities). Dampers are then supplied to Original Equipment Manufacturers (OEMs) from the automotive and rail sectors. In exceptional cases, the car manufacturers can be indirectly supplied with dampers via the suppliers of axles or air spring. The supply chain has been summarized in Figure 22.

[redacted]

**Figure 22: Supply chain of piston rods**

As stated, not all ZF facilities in Europe perform functional chrome plating. [redacted]

## 2.6 Overview on development process

Functional chrome plating of piston rods is fundamental for the unimpaired function of the damper system of a vehicle. The proper function of the damper system in turn is of crucial importance for the safe operation of a vehicle. The development of a new technology for the coating of piston rods in particular has therefore to be conducted with extraordinary care to meet the high quality and safety standards and in order to avoid errors and regrettable substitutions.

The development process for new technologies at ZF is separated in four overarching phases which are presented in Figure 23 with their related time-schedules. The current early state of research for the substitution of functional chrome plating of piston rods is also illustrated in the figure. The individual phases are explained in more detail below.

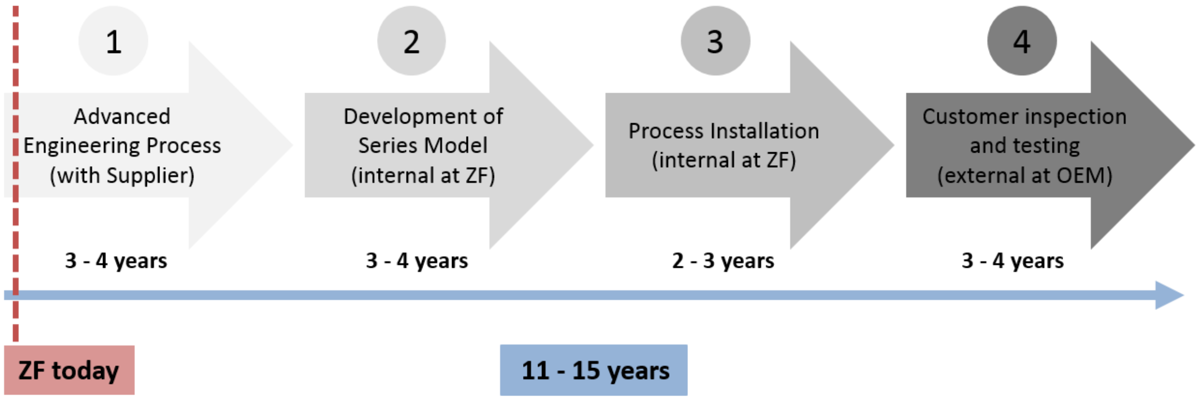


**Figure 23: Overarching phases in the four step development process of a Cr(VI)-free piston rod at ZF**

### 2.6.1 Advanced Engineering Process with Supplier (3 - 4 years)

R&D of an alternative together with a supplier is the first step in evaluating the potential of a new technology. This phase is divided into five gates (see Figure 24) which are project related checkpoints with specific technical and economic minimum requirements and have to be passed by a potential alternative coating technology.

[redacted]

**Figure 24: Procedures and gates of advanced engineering process at ZF**

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted] This is aggravated by the fact that the requirements on the piston rod coatings are very high and therefore the respective suppliers insist on internal R&D which leads to an estimated development time of **3-4 years** for this phase.

### 2.6.2 Internal Development of Series Model (3 - 4 years)

After a potential alternative has successfully passed phase 1, the internal development process of a new damper system with the respective new piston rod is conducted at ZF. During this phase, the compatibility of all damper components has to be investigated. After identification of all components which are affected by the new piston rod coating, these components have to be re-designed and also be subjected to their individual evaluation process. For example, if there is no chemical compatibility between an alternative coating and the hydraulic oil, a completely new development process arises which is in itself dependent on numerous factors that can be barely influenced by ZF. Another example is the re-design and assessment process of the damper sealing, which is mandatory for the unrestricted damper functionality.

As damper systems and respective piston rods are an important safety relevant component of different kinds of vehicles, the development and assessment process of each individual component has to be conducted very carefully. During the assessment process, also a statistical coverage of each performance criterion is required. In general, the technology under R&D must at least show a comparable performance to the hard chrome plating technology, regarding technical and economic requirements. The result of phase 2 is a fully developed pre-production damper model.

As passing phase 2 is complex and time-consuming, the internal development of a series damper model takes **3 - 4 years** if the project can be conducted without major issues.

### 2.6.3 Internal Process Installation (2 - 3 years)

Phase 3, the internal process installation is the implementation of all process relevant components. During this phase, the necessary infrastructure for the new coating technology is set up. This means that future production lines are installed at the production sites, supply chains for all kinds of resources are defined, etc. Additionally, a maintenance concept for the production lines is created and employees are trained to ensure trouble-free transition to the new process and warranty of the series production. Another important content of this phase is the execution of the environmental impact assessment.

The result of phase 3 is a ready-to-produce production process which satisfies all internal and external requirements. This includes the availability of a series production damper model as the subsequent testing at an OEM level is required to be conducted <u>only</u> with those components. The Pre-Production

Approval Process[2] is a general procedure in the automotive industry and helps to ensure the required product quality because the sampled parts are manufactured with serial tools.

Please note, that the contents of phase 3 are more of a general nature and not specifically tailored to the development of the alternative coating technology respectively piston rod respectively damper system. However, the start of phase 3 is dependent on the result of phase 2 and therefore a parallel development process is not possible or economically reasonable.

### 2.6.4 Customer Inspection and Testing (3 - 4 years)

After phase 3 is successfully completed, the newly developed damper model is presented to the different OEMs. After OEM approval, the new damper model is investigated in test vehicles according to the OEM specific testing requirements. During this phase the vehicles equipped with the new damper model are tested under extreme conditions. For example, the OEMs conduct vehicle endurance runs in cold and / or hot conditions and additionally test the performance of the damper in obstacle courses.
Please note, that the different OEMs have varying testing requirements and therefore no exact time-schedule for passing this phase can be stated.

By experience, it is estimated that the evaluation time needed at OEM level is **3 - 4 years.** If the OEM discovers any risk arising with the new technology there are two different scenarios:

1) Rejection of technology
2) Small-lot production to gain more field experience

If no risk is detected and consequently reliability is proven for the new technology, series maturity is reached. This is then finally followed by starting a systematic introduction into new vehicle projects at the OEM (start-up of the actual large-scale production).

Importantly, Cr(VI) will still be required until the last vehicle series running with Cr(VI) treated piston rods has expired, which is at least the case until End of Production (EOP) of this project. This is important, because a change of the damper technology in a running vehicle series is not possible and not accepted by the OEM as it would entail a complete re-construction of the vehicle chassis accompanied with all necessary safety assessment procedures. Usually, in the automotive sector a vehicle is produced in a series (from start of production (SOP) to EOP) for **7 years**. Furthermore, ZF produces a piston rod model in series over the whole lifetime of a vehicle, which includes aftermarket supply of spare parts for **10 - 15 years** dependent on customer requirements.

[2] (PPAP): http://www.automotiveengineeringhq.com/production-part-approval-process-ppap/

Please note that in the automotive sector, planning security for future series is mandatory. Therefore, ZF accepts and signs contracts for Cr(VI) based series production damper models at least 3 years in advance. [redacted] However, as the production volume of rail vehicle damper systems is comparatively low, this time span has not been taken into account for the derivation of the length of the review period.

ZF stated, that in a best case scenario the development of a Cr(VI) alternative takes at least 11 years. This means that the **earliest SOP of Cr(VI)-free piston rods respectively damper models is in 2028**. Due to the complexity of supply chains and required planning security (contractual arrangements are made at least 3 years in advance) in the automotive industry the **last SOP of Cr(VI)-based damper models is in 2031** leading to an **earliest EOP of Cr(VI)-based damper models in 2038** calculated with 7 years of series production.

A graphical representation of the complex development and transition process and the derivation of the review period is given in Figure 25 as a best case scenario.

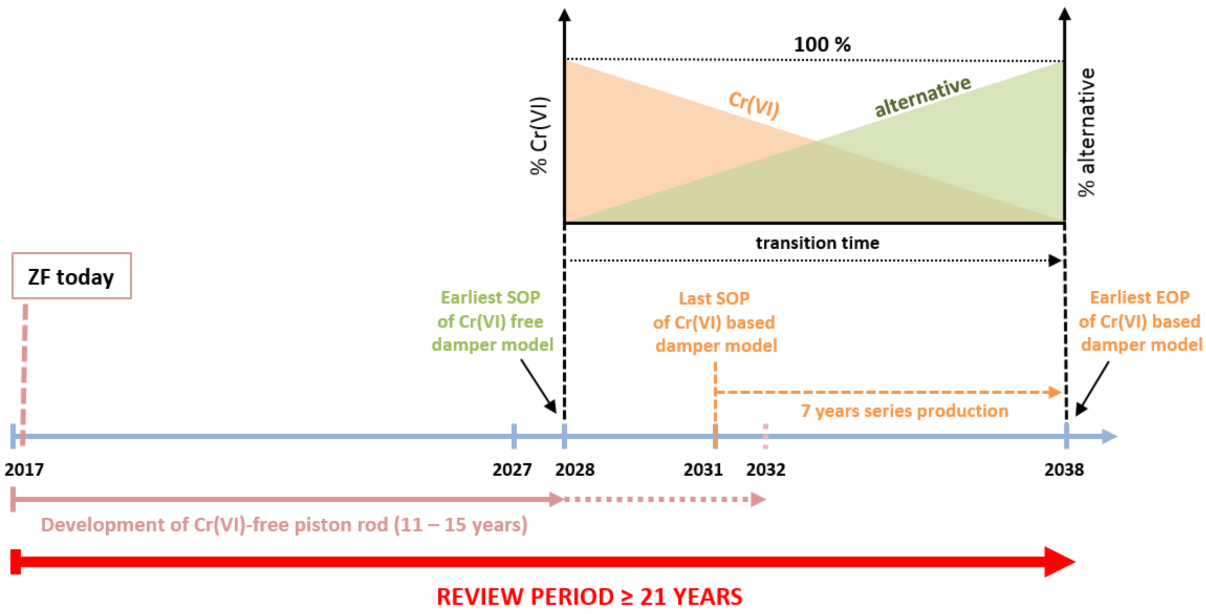


**Figure 25: Timeline for development and transition process to Cr(VI)-free piston rods**

All in all chromium trioxide based functional chrome plating of piston rods will in any case be required for further use for **at least 21 years calculated with the best estimated development time of 11 years**. [redacted]

However, it is clear that the development of damper systems in general and piston rods in particular that can be produced without Cr(VI) at all is unavoidable and priority for ZF's research and development activities.

## 2.7 Annual tonnage

The annual tonnage for the use of chromium trioxide is > 100 tonnes / year [redacted].

## 2.8 Remaining risk of the "applied for use" scenario

The assessment of human health impacts in the applied for use scenario considers workers potentially exposed at the ZF facilities in Eitorf and Schweinfurt (both in Germany) and people potentially exposed in the direct neighbourhood – man via the environment ($MVE_{local}$). In accordance with the corresponding CSR, the risk assessment for ZF workers is restricted to inhalation of airborne residues of chromium trioxide (lung cancer). For the potentially exposed local population, inhalation and oral uptake (lung and small intestine cancers) are taken into account (see **ANNEX A**).

Table 5 depicts the exposure values that were used for the monetisation of health impacts to workers (see corresponding CSR).

**Table 5: Exposure values for the monetisation of health impacts to workers**

| WCS | Activity | Actual estimated exposure (see CSR) [µg/m³] |
|---|---|---|
| 1 | Delivery and storage of raw material | 0.00E+00 |
| 2 | Encapsulated plating line, closed process | 3.80E-01 |
| 3 | Semi-closed plating process | 3.30E-01 |
| 4 | Sampling | 7.10E-03 |
| 5 | Concentration adjustment | 1.40E-01 |
| 6 | Regular maintenance | 1.00E-01 |
| 7 | Rare maintenance | 7.00E-03 |
| 8 | Waste and wastewater management | 2.30E-03 |

## 2.9 Monetised damage of human health and environmental impacts

Table 6 below shows the monetised health impacts for workers potentially exposed to chromium trioxide at the ZF facilities in Eitorf and Schweinfurt.

**Table 6: Summary of monetised health impacts for potentially exposed workers at ZF in Eitorf and Schweinfurt**

| | Health impacts for workers Lower bound [EUR] | Health impacts for workers Upper bound [EUR] |
|---|---|---|
| Total for 21 years | 119 027 | 198 804 |
| Average per year | 5 668 | 9 467 |

Details on the calculation of the values are given in **ANNEX B**.

Potential exposure to the public has been estimated based on conservative assumptions regarding inhalation and oral uptake of Cr(VI) and a substantial population at the site boundary ($MVE_{local}$) (see Table 7).

**Table 7: Exposure values for the monetisation of health impacts to the general population ($MVE_{local}$)**

| | Exposure value Schweinfurt | Exposure value Eitorf |
|---|---|---|
| $MVE_{local, inhalation}$ [µg/m³] | 4.68E-03 | 7.36E-04 |
| $MVE_{local, oral}$ [µg/kg bw/ day] | 5.69E-05 | 5.69E-05 |

As discussed in Chapter **A.1.2** of the annex, the present SEA considers the regional exposure of MVE as irrelevant.

Table 8 below sets out the monetised health impacts for members of the general population potentially exposed to chromium trioxide and potentially indirectly exposed workers. The analysis is based on a review period of 21 years.

**Table 8: Summary of monetised health impacts in the general population**

| | Lower bound [EUR] | Upper bound [EUR] |
|---|---|---|
| $MVE_{local, inhalation}$ | 0 | 2 310 905 |
| $MVE_{local, oral}$ | 0 | 425 |
| **Total for 21 years** | **0** | **2 311 330** |
| **Average per year** | **0** | **110 063** |

Note: These numbers are based on the excess risk related to workers and the general population over a time frame of 21 years (see Chapter A.1 of **ANNEX A** and **ANNEX B** for details).

Table **9** provides a summary of total health impacts for workers and the general population related to the use of chromium trioxide at ZF facilities.

**Table 9: Summary table – monetised potential health impacts**

| Type of potentially exposed population | Lower bound [EUR] | Upper bound [EUR] |
|---|---|---|
| exposed workers | 119 027 | 198 804 |
| indirectly exposed workers and direct neighbourhood ($PEC_{local, inhalation}$ and $PEC_{local, oral}$) | 0 | 2 311 330 |
| **Total for 21 years** | 119 027 | 2 509 708 |
| **Average per year** | **5 668** | **119 510** |

# 3 SELECTION OF THE "NON-USE" SCENARIO

## 3.1 Efforts made to identify alternatives

### 3.1.1 Research and development

ZF Friedrichshafen AG conducted extensive R&D since 1999. At the current stage of development, the alternatives assessed in this document are rejected as they do not fulfil the necessary combination of OEM requirements.

**ZF Friedrichshafen AG regularly conducts worldwide bench mark investigations to stay well informed about the current R&D status at competitors concerning chromium trioxide alternatives. However, no alternative to state of the art chromium trioxide is available on the market or used at any of ZF's competitors up to date for serial production.**

### 3.1.2 Data searches

ZF Friedrichshafen AG is a member of the CTAC (Chromium Trioxide Authorisation Consortium) founded in 2012, **but the information on R&D and technical assessment of alternatives data provided is based on ZF's own investigations and in-house experience.** Furthermore, searches for publically available documents were conducted to ensure that all potential alternate processes to chromium trioxide-containing applications were considered in the data analysis.

In addition to databases for scientific literature, the following programmes were intensively consulted: Toxics Use Reduction Institute, Massachusetts, US (www.turi.org/); and The Advanced Materials, Manufacturing, and Testing Information Analysis Center (AMMTIAC). Searches for SDS for chromium trioxide-containing and chromium trioxide-free applications were conducted.

### 3.1.3 Consultations

Several discussions with technical experts from ZF were carried out and detailed material was provided on the R&D activities that were conducted over the last years. From the meetings and materials, an overview on the completeness and experience with the alternatives, specific processes and the key requirements for the use of functional chrome plating of piston rods for automotive and rail applications were elaborated.

At this stage of the data analysis, some alternatives were screened out after bilateral discussions with the company, based on confirmation that technical and economic limitations clearly argue against their use as potential alternative to chromium trioxide.

To verify data and to obtain further detailed quantitative information, more focused technical questions were sent out and discussed with the experts. Moreover, site visits to Eitorf and Schweinfurt were carried out. Final data analysis led to the formation of a shortlist of alternatives.

In summary, this AoA is the outcome of extensive in-house research, and consultations with technical experts of ZF.

## 3.2 Identification of alternatives

ZF Friedrichshafen AG conducted extensive R&D for different alternative technologies for functional chrome plating using chromium trioxide. Several alternatives were examined with varying outcomes. Based on their performance, the main alternative coating technologies are classified to provide an overview on the results. Furthermore, a complete substitution of the overall surface treatment of piston rods was considered by using an alternative base material. In Table 10, all potential alternative coating technologies considered and assessed by ZF are listed. Subsequently in Table 11, the alternative pre-treatment process and the alternative base material are presented which have to be evaluated separately because the assessment criteria differ fundamentally.

**Table 10: Overview of all alternatives considered and assessed by ZF Friedrichshafen AG**

| No. | Alternative Method | Alternative Coating |
|---|---|---|
| 1 | Case Hardening Process (Nitrocarburization) | Enrichment of outer layer with nitrogen / carbon |
| 2 | Physical Vapor Deposition (PVD) Process | Titaniumcarbonitrid (TiCN) layer |
| 3 | Chemical Vapor Deposition (CVD) Process | Diamond like carbon (DLC) Layer |
| 4 | Trivalent Hard Chrome Plating Process | Chromium layer based on trivalent chromium |
| 5 | High Velocity Oxygen Fuel (HVOF) Spraying Process | Selective layering with powdered tungsten carbide cobalt spray material |
| 6 | Chemical Coating Process | [redacted] |
| 7 | Chemical Coating Process | [redacted] |
| 8 | Powder Coating Process | Polymer matrix with polytetrafluorethylene (PTFE) |
| 9 | Sol-Gel Process | Wet chemical coating |
| 10 | Lubricant Varnish Coating Process | Lubricant varnish coating |
| 11 | Galvanic Coating Process | [redacted] |
| 12 | Synthetic Material-Teflon-Coating Process | High performance polymer compound |
| 13 | Zinc - Diffusion Process with Passivation | [redacted] |

**Table 11: Further approaches of ZF Friedrichshafen AG for reduction or substitution of Cr(VI) usage**

| No. | Alternative Approach | Alternative Chemistry / Material |
|---|---|---|
| **14** | Pre-treatment | Sulfuric acid |
| **15** | Base material | Stainless steel ([redacted]) |

Due to the technical assessment, the classification of the alternatives is as follows:

1) **No. 1 - 4: Shortlisted alternatives**
2) **No. 5 - 15: Rejected alternatives**

The functional principle and full assessment of the alternatives classified as shortlisted **(No. 1 - 4)** is explained in sufficient detail in chapter 3.4. The specific technical limitations which led to the exclusion of the alternatives **No. 5 - 15** are presented in the following chapter 3.3.

**Importantly, a potential alternative coating method must fulfil <u>all</u> key functionalities (see Chapter 2.3.4.2) for piston rod applications to successfully substitute chromium trioxide in functional chrome plating. No further R&D effort is made for alternatives which fail in one of the required key functionalities. The alternative approaches No. 14 and No. 15 have to be evaluated according to other assessment criteria as they are no coating processes.**

**R&D results presented in chapters 3.3 and 3.4 are based on ZF internal laboratory testing. None of the provided information is sourced from literature references.**

## 3.3 Rejected alternatives (No. 5 - 15)

In this chapter, the technical limitations of the alternatives classified in chapter 3.2 as technically not feasible are presented in more detail.

### 3.3.1 Main treatments (No. 5 - 13)

ZF Friedrichshafen AG conducted a full technical assessment of these alternate approaches but considered them as not applicable for the substitution of chromium trioxide in functional chrome plating of piston rods at an early stage. Therefore, no future R&D efforts will be made for the development of these methods.

As these alternatives are not followed by ZF Friedrichshafen AG anymore, no description of the functional principle behind each alternative is presented in this chapter.

The technical assessment is based on the following essential key functionalities for piston rods, which are described in sufficient detail in Chapter 2.3.4.2 and presented in a non-exhaustive overview in Table 12 below.

**Table 12: Minimum requirements for piston rods used in automotive and rail applications**

| **Key functionality** | **Minimum requirements for piston rods (automotive & rail applications)** |
|---|---|
| Wear resistance | Alternative layer is tested in endurance trail of a complete damper. Testing conditions during the trails and the validation criteria are adapted to the different sectors of the piston rod applications (see chapter 2.3.4.2). |
| Corrosion resistance | Alternative layer must resist min. 240 h in salt spray test according to DIN EN ISO 9227 NSS. |
| Hardness | Alternative layer must reach a min. hardness value of > 800 HV 0.05* [redacted] |
| Coefficient of friction (surface roughness Rz) | Alternative layer must not exceed surface roughness of Rz = max. 1 µm. |
| Process conditions | Alternative treatment process must not exceed temperatures of 300 °C (plating process, tempering, drying, etc.)<br><br>Alternative process must have adequate process times.<br><br>Alternative layer must be suitable for post-treatment steps (e.g. polishing, etc.) if required. |
| Layer thickness | Alternative method must achieve an adequate layer thickness to provide with sufficient wear and corrosion resistance. Exact values are not applicable as the specific chemistry (e.g. adhesion force, oxygen permeability, etc.) behind the alternative coating(s) is the decisive factor. |

* 0.05 is the test force in kilopond (kp) applied to the piston rod during testing;

These key functionalities are of utmost importance to meet the high customer requirements such as longevity, quality and of course safety.

The assessment of the alternatives which are not applicable for automotive and rail vehicle piston rods are presented in Table 13 with their corresponding technical limitations.

**Table 13: Alternatives not applicable for automotive and rail vehicle piston rods with corresponding technical limitations**

| No. | **Alternative Method** (Alternative Coating) | **Technical Limitations**[1] (criteria described in Chapter 2.3.4.2) | |
|---|---|---|---|
| **5** | **High Velocity Oxygen Fuel (HVOF) Spraying** ([redacted]) | Process conditions | [redacted] |
| **6** | **Chemical Coating Process** ([redacted]) | Wear resistance | [redacted] |
| | | Corrosion resistance | [redacted] |
| | | Coefficient of friction | [redacted] |
| | | Process conditions | [redacted] |
| **7** | **Chemical Coating Process** ([redacted]) | Wear resistance | [redacted] |
| | | Layer thickness | [redacted] |
| | | Process conditions | [redacted] |
| **8** | **Powder Coating Process** ([redacted]) | Wear resistance | [redacted] |
| | | Hardness | [redacted] |
| | | Process conditions | [redacted] |
| **9** | **Wet Chemical Coating Process** (Sol-Gel technology) | Wear resistance | [redacted] |
| | | Hardness | [redacted] |
| | | Coefficient of friction | [redacted] |
| | | Process conditions | [redacted] |
| **10** | **Lubricant Varnish Coating Process** (Lubricant varnish coating) | Wear resistance | [redacted] |
| | | Corrosion resistance | [redacted] |
| | | Hardness | [redacted] |
| | | Coefficient of friction | [redacted] |
| | | Process conditions | [redacted] |
| **11** | **Galvanic Coating Process** ([redacted]) | Wear resistance | [redacted] |
| | | Hardness | [redacted] |
| | | Coefficient of friction | [redacted] |
| | | Layer thickness | [redacted] |
| | | Process conditions | [redacted] |
| **12** | **Synthetic Material - Teflon - Coating Process** (High performance polymer compound coating) | Wear resistance | [redacted] |
| | | Corrosion resistance | [redacted] |
| | | Coefficient of friction | [redacted] |
| | | Process conditions | [redacted] |
| **13** | **Zinc - Diffusion Process with Passivation** ([redacted]) | Wear resistance | [redacted] |
| | | Hardness | [redacted] |
| | | Coefficient of friction | [redacted] |
| | | Process conditions | [redacted] |

[1] only exclusion criteria are mentioned

### 3.3.2 Pre-treatment (No. 14)

In order to reduce the usage of Cr(VI), ZF Friedrichshafen AG tried to substitute the Cr(VI) based surface activation step by an etching process using sulfuric acid ($H_2SO_4$). However, the following significant technical limitations occurred during the R&D phase:

*Etch rate:* The etching process with sulfuric acid is purely chemical and therefore the etch rate is not exactly controllable as many different factors such as time, temperature, concentration, substrate quality, etc. play an important role. In comparison with the electrochemical Cr(VI) based etching process, which is highly adjustable, this is a major disadvantage because adequate surface activation is a pre-requisite for good adhesion of the subsequent chromium layer applied in the main process.

*Additional rinsing process:* As the Cr(VI) electrolyte in the main treatment bath contains sulfuric acid as reaction catalyst with a narrow concentration window (encapsulated plating line: 3 - 9 g/L [redacted]; semi-closed plating line: 2.5 - 3.5 g/L [redacted]) an additional rinsing process is required between pre- and main treatment. If excessive sulfuric acid is not rinsed off, the concentration in the electrolyte of the main treatment bath rises and the quality of the plating process is deteriorated due to electrochemical side reactions. However, as cross-contamination cannot be ruled out completely, the bath changing intervals for the main treatment bath are higher than with Cr(VI) based pre-treatment.

*Surface passivation:* Another important disadvantage of the sulfuric acid based etching is that the surface of the piston rod is not resistant against air oxidation occurring during the transfer between the treatment baths. Especially drastic is the oxidation of the freshly activated surface during the necessary rinsing process in water. This undesired oxidation layer deteriorates the deposition of the chromium layer in the main treatment process and surface quality decreases.

### 3.3.3 Base material (No. 15)

With the testing of stainless steel ([redacted]) as alternative piston rod base material, ZF followed another approach for the substitution of Cr(VI) based surface treatment. However, the following technical limitations led to the exclusion of stainless steel as a potential alternative:

*Assembly:* In comparison with the traditional piston rod base materials (C35, C45 and ST52-3) stainless steel is considered soft. During the R&D phase it was found that piston rods made of stainless steel showed significant failure in the assembly of the damper system. Due to the relatively soft material the torque value required for a sufficient assembly of the damper cannot be applied to the respective anchorage points or more specifically threads.

*Corrosion resistance:* Stainless steel ([redacted]) did not fulfil the minimum requirement of 240 h in salt spray test according to DIN EN ISO 9227 NSS.

**Please note that for niche uses in racing applications (short-term use under circumstances with high loads) other piston rod base materials such as titanium and carbon fibre reinforced composite are applied but none of them is technical nor economical feasible on an industrial scale for the long-term use in vehicles.**

## 3.4 Assessment of shortlisted alternatives

The four alternatives assessed in this chapter were considered the most promising, where considerable R&D efforts have been carried out within ZF Friedrichshafen AG. They either show technical limitations when it comes to the demanding requirements for automotive and rail vehicle piston rods and / or have significant economical disadvantages at the current stage.

To assess the feasibility of the alternatives, colour coded summary tables are included in the document. The colours are as follows:

| Colour | Explanation |
|---|---|
| | Not sufficient - the parameters/assessment criteria do not fulfil the requirements |
| | Cannot be determined - the parameters/assessment criteria are not comparable to Cr(VI) |
| | Sufficient - the parameters/assessment criteria do fulfil the requirements |
| | No data available |

**Importantly, a potential alternative method must fulfil all key functionalities for piston rod applications to successfully substitute chromium trioxide in functional chrome plating.**

### 3.4.1 Alternative 1: Case hardening: Nitrocarburizing

#### 3.4.1.1 Substance ID and properties

Case hardening is a process that is used to harden the outer surface of metals by creating a hard outer metal layer (case) while the deeper metallic material is not affected (see Figure 26).

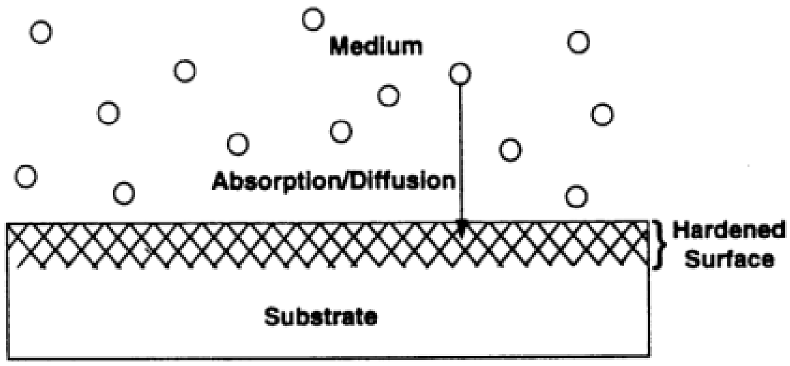


**Figure 26: Case hardening.** (NDCEE, 1995)

Nitrocarburizing of piston rods is a thermochemical process during which the dopant elements carbon and nitrogen get incorporated into the outer metal surface by diffusion. The dopant elements for the process are introduced in the form of carbon dioxide ($CO_2$), ammonia ($NH_3$) and molecular nitrogen ($N_2$). The case hardened area is highly dependent on the duration of the heat treatment and the temperature which is applied to the piston rod. In general, the longer the treatment and the higher the temperature, the deeper the dopants can diffuse into the substrate.

For piston rod base materials, temperatures between 530 °C and 630 °C with a treatment time of 1.5 h are needed to achieve case hardening with a more or less reasonable result. Longer treatment times and higher treatment temperatures have not been tested because of the degradation of the piston rod base materials

A non-exhaustive overview of general information of substances used in nitrocarburizing, as well as the overall risk to human health and the environment is provided in ANNEX D.1.

#### 3.4.1.2 Technical feasibility of Alternative 1

<u>*General assessment:*</u> Case hardening is used to increase the hardness of the metal surface of piston rods. During the hardening process, the substrates of the piston rods have to be subjected to a temperature of 590 °C in order to reach adequate case hardening. However, testing showed that this high process temperature leads to the softening of the low alloyed base materials which are only heat resistant to a maximum temperature of 300 °C without losing their initial degree of hardness.

Nitrocarburizing of piston rods results in the structural change of the surface of the substrate, leading to increased hardness of the outer layer with "soft" metal underneath. Hardness exponentially decreases with increasing depth from the substrate surface, especially when high process temperatures led to softening of the substrate.

<u>*Wear resistance:*</u> Wear resistance is a very critical issue for piston rods (automotive and rail) and evaluated in endurance trials of complete damper systems. The testing conditions during the trails and the validation criteria are adapted to the different sectors of the piston rod applications (see chapter 2.3.4.2).

Testing showed that the wear resistance of case hardened piston rods is insufficient compared to functional chrome plating using chromium trioxide (see Figure 27).

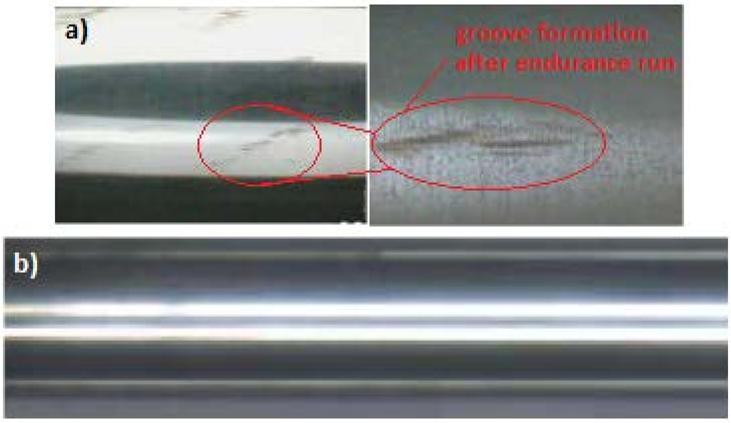


**Figure 27: Direct comparison of a) case hardened piston rod and b) Cr(VI) coated piston rod after endurance run**

<u>*Corrosion resistance:*</u> Corrosion resistance is another key functionality that must be sufficiently fulfilled by a chromium trioxide alternative. Case hardening does not fulfil the minimum requirement of 240 h in a salt spray test according to DIN EN ISO 9227 NSS. Corrosion on the respective piston rods occurred before 24 h (see Figure 28).


**Figure 28: Direct comparison of a) case hardened piston rod b) Cr(VI) coated piston rod after salt spray test (DIN EN ISO 9227 NSS)**

*Hardness:* Hardness is a key functionality. With case hardening, piston rod surfaces can reach hardness values of 420 HV which is not sufficient to the minimum requirement of > 800 HV 0.05 [redacted] achievable with functional chrome plating using chromium trioxide.

*Coefficient of friction:* A low coefficient of friction is crucial for automotive and rail vehicle piston rods as it results in less abrasion and improved sliding properties. Case hardening leads to higher surface roughness values (Rz = 2) on the functional surface of the piston rod. To satisfy the requirement of this key functionality a value of Rz = max. 1 would be needed.

*Process conditions:* Case hardening for automotive and rail vehicle piston rods requires a minimum temperature of 590 °C to reach an adequate thickness of the hardened surface area. As the base materials of piston rods are sensitive to high temperatures (softening) this method is not suitable to replace functional chrome plating using chromium trioxide. Additionally, even if a suitable alternative base material with increased heat resistance is found, the required process time in combination with the required process temperature is expected to cause the softening of the base material.

Lower process temperatures are not possible due to insufficient carbon /nitrogen enrichment of the outer layer.

**Table 14: Colour coded assessment overview for case hardened (nitrocarburizing) piston rods**

| **Criteria** | Wear resistance | Corrosion resistance | Hardness | Coefficient of friction | Process conditions |
|---|---|---|---|---|---|
| **Feasibility** | | | | | |

#### 3.4.1.3 Economic feasibility and economic impacts of Alternative 1

Because of the significant technical failure of case hardening, no quantitative analysis of economic feasibility was conducted.

ZF Friedrichshafen AG estimated the production costs per component to be approximately the same as for functional chrome plating using chromium trioxide. However, it has to be taken into account that case hardening is a completely different process compared to functional chrome plating and therefore huge investment costs for production site and process reconstruction, etc., maintenance and staff training have to be made.

#### 3.4.1.4 Availability of Alternative 1

Case hardening (nitrocarburizing) is a well-defined process which is commercially available, but it is not suitable for the treatment of piston rods for ZF's applications due to clear technical limitations. Therefore, case hardening is no possible replacement for functional chrome plating of piston rods.

#### 3.4.1.5 Hazard and risk of Alternative 1

As the alternative is technically not feasible, the hazard classification of case hardening (nitrocarburizing) is based on the available information of substances used in this alternative (see ANNEX D.1).

Carbon monoxide is classified as:

- Press. Gas
- Flam. Gas 1
- Acute Tox. 3
- Repr. 1A
- STOT RE 1

Ammonia is classified as:

- Press. Gas
- Flam. Gas 2
- Skin Corr. 1B
- Acute Tox. 3
- Aquatic Acute 1

In comparison to chromium trioxide - which is a non-threshold carcinogen - a transition to nitrocarburizing would constitute a shift to less hazardous substances.

#### 3.4.1.6 Conclusions on Alternative 1

Case hardening (nitrocarburizing) cannot be seen as a technical feasible alternative to functional chrome plating using chromium trioxide. The method shows clear technical limitations regarding the required key functionalities of piston rods. In general, the required high process temperature is not suitable for the heat sensitive piston rod base materials which was also confirmed by the respective formulator ZF was working with for the creation of the sample parts.

### 3.4.2 Alternative 2: Physical Vapour Deposition (PVD)

#### 3.4.2.1 Substance ID and properties

Physical Vapour Deposition (PVD) is the general name for a variety of vacuum coating processes. The respective coating material in a solid (or rarely liquid) form is placed in a vacuum or low pressure plasma environment and initially vaporized. The atoms of the coating material are then deposited onto the surface of the substrate, atom by atom, in order to build up a thin layer. The vaporization of the coating material is achieved by magnetron sputtering.

Magnetron sputtering is a non-thermal vaporization process where the surface atoms of the coating material are physically ejected from the solid surface (target) by the transfer of momentum from bombarding particles. Typically, the particles are gaseous ions (mostly inert gas ions) which are accelerated towards the target by an electric field. The gaseous ions are formed by a low pressure plasma or an ion gun (TURI, 2006). Magnetron sputtering uses a magnetic field, located in front of the target, to increase the collision of charged particles with the source material (target). The great benefit is that this increased particle bombardment results in more ejected source material atoms and therefore to an increased deposition rate on the respective substrate. Figure 29 illustrates the principle of magnetron sputtering.

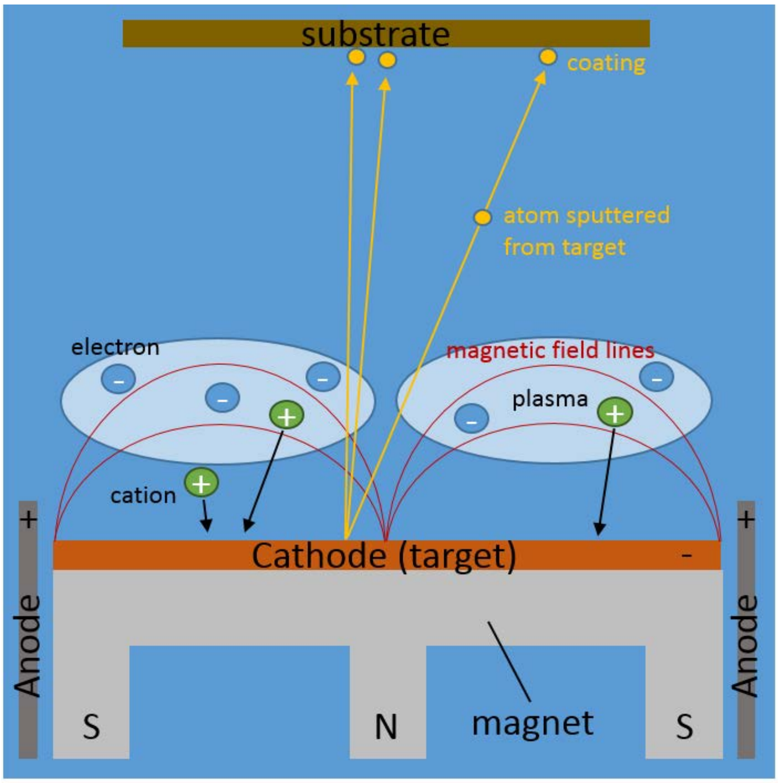


**Figure 29: Simplified setup and principle of magnetron sputtering**

For piston rods the coating material used is titanium carbonitride which is deposited on the surface at a temperature of 250 °C. The source materials for Ti(C, N) are metallic titanium, molecular nitrogen and methane:

$$2\,Ti + N_2 + CH_4 \rightarrow 2\,Ti(C,N) + 4\,H_2$$

Ti(C, N) is a mixed crystal out of titanium nitride (TiN) and titanium carbide (TiC). The deposition of the Ti(C, N) layer, in general, requires high process times. However, the time needed for sufficient deposition can be reduced by a plasma activation step prior to the actual plating process. During the plasma activation, the surface of the piston rod is bombarded with inert gas ions and therefore is limited in time because internal stress in the substrate’s structure causes material degradation.

A non-exhaustive overview of general information and the identity of relevant substances used within this alternative and the risk to human health and the environment is provided in ANNEX D.2.

#### 3.4.2.2 Technical feasibility of Alternative 2

*Wear resistance:* The wear resistance of PVD coated piston rods was evaluated in an endurance trial with specific trial conditions and according to different criteria specified to the field of application (see chapter 2.3.4.2).

Testing showed that the wear resistance of PVD coated piston rods is not comparable to functional chrome plated piston rods (see Figure 30).

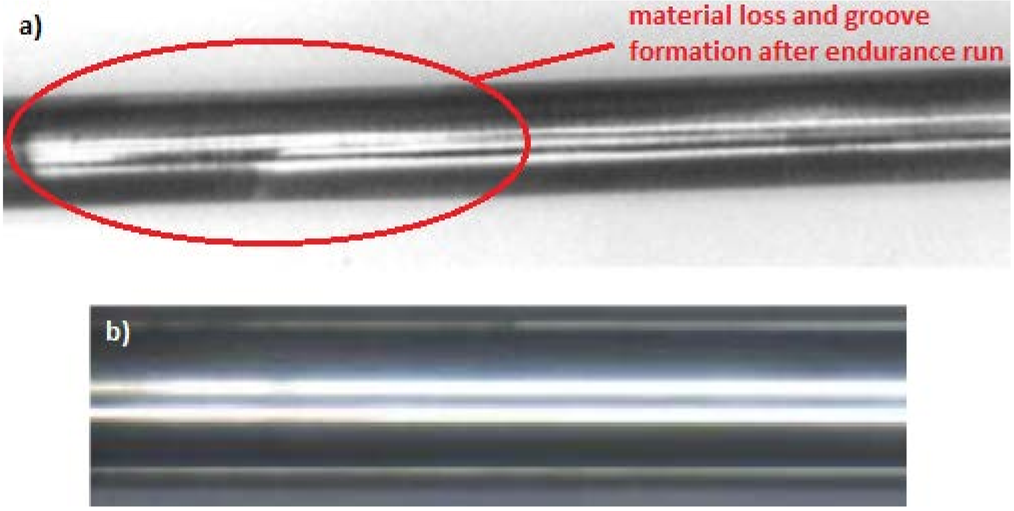


**Figure 30: Direct comparison of a) PVD coating and b) Cr(VI) coating after endurance run**

*Corrosion resistance:* PVD coatings do not satisfy the minimum requirement of **240 h** in a salt spray test according to DIN EN ISO 9227 NSS. Corrosion on the sampled piston rods occurred **before 24 h** (see Figure 31) which can be related to the necessary plasma activation step.

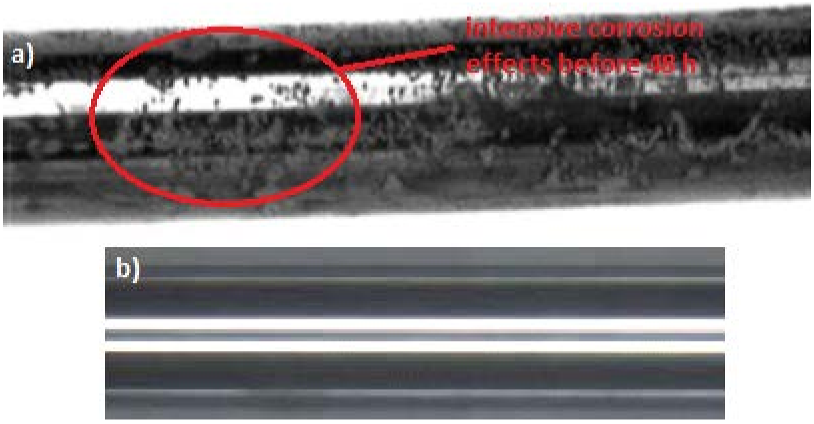


**Figure 31: Direct comparison of a) PVD coating and b) Cr(VI) coating after salt spray test (DIN 50021)**

*Hardness:* With PVD coating of piston rods hardness values of > **1000 HV** are achievable. In comparison, piston rod coatings created by functional chrome using chromium trioxide result in hardness values of > **800 HV 0.05** [redacted].

*Coefficient of friction:* PVD is capable of creating smooth surface coatings on piston rods. The surface roughness of a PVD coating (**Rz** < **1**) satisfies the requirements (**Rz = max. 1**) for a chromium trioxide alternative.

*Process conditions:* PVD coating of piston rods requires very long process times of > **6 h**. It is obvious that high a process time leads to a slow cycle time and results in smaller numbers of finished piston rods. Furthermore, the necessary plasma activation of the substrate surface minimizes the corrosion protection evaluated in a SST according to DIN EN ISO 9227 NSS.

**Table 15: Colour coded assessment overview for PVD coated piston rods**

| **Criteria** | Wear resistance | Corrosion resistance | Hardness | Coefficient of friction | Process conditions |
|---|---|---|---|---|---|
| **Feasibility** | | | | | |

### 3.4.2.3 Economic feasibility and economic impacts of Alternative 2

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

The technology for PVD processes and functional chrome plating differ fundamentally in the equipment and peripherals. The implementation of PVD requires complex machines and infrastructure equipment. The space requirement for PVD and chromium coating equipment is estimated to be approximately the same but with the **long process time (> 6 h)** for PVD coating **additional plating lines or even productions sites** are needed in the worst case to supply the market with the required amount of piston rods.

Another important aspect of the PVD alternative is energy consumption which is much higher compared to functional chrome plating using chromium trioxide. The reason behind is the energy intensive generation of the necessary high-vacuum and the vaporization of the coating material.

Due to the enormous investment and running costs, ZF Friedrichshafen AG estimated that the costs per component are **considerably** higher compared to functional chrome plating using chromium trioxide. Therefore, PVD is not considered an economically feasible alternative for piston rod applications.

#### 3.4.2.4 Availability of Alternative 2

PVD process equipment is commercially available but due to the stated technical and economic limitations not suitable to replace functional chrome plating of automotive and rail vehicle piston rods.

#### 3.4.2.5 Hazard and risk of Alternative 2

As the alternative is technically not feasible, the hazard classification of PVD is based on the available information of substances used in this alternative (see ANNEX D.2).
Metallic titanium is not classified according to the ECHA C&L inventory. However, in powdery form as used in this alternative the following hazards are stated:

- Flam. Sol. 1
- Pyr. Sol. 1
- Water-react. 1
- Skin Irrit. 2
- Eye Irrit. 2
- STOT SE 3

Methane ($CH_4$) is classified as:

- Press. Gas
- Flam. Gas 1

Molecular nitrogen ($N_2$) is classified as:

- Press. Gas (Comp.)
- Press. Gas (Ref. Liq.)

In comparison to chromium trioxide - which is a non-threshold carcinogen - a transition to PVD, using powdery metallic titanium, molecular nitrogen and methane, would constitute a shift to less hazardous substances.

#### 3.4.2.6 Conclusions on Alternative 2

Due to significant technical limitations, PVD cannot be seen as alternative for functional chrome plating using chromium trioxide.

### 3.4.3 Alternative 3: Plasma-enhanced Chemical Vapour Deposition (PE-CVD) - thin diamond like carbon (DLC) coatings

#### 3.4.3.1 Substance ID and properties

Plasma-enhanced chemical vapour deposition (PE-CVD) is a method to deposit thin layers from a gas state (vapour) to a solid state on a substrate. For this, the coating material precursor is vaporized, if required, and mixed with an inert gas. This reactant gas is then brought into the reaction chamber in which a strong electrical field, applied between substrate and a counter electrode, causes the creation of a plasma of the reactant gas. The charged particles (e.g. electrons and inert gas ions) inside the plasma initiate the dissociation of the coating material precursor which is then deposited on the surface of the substrate. A typical PE-CVD system is shown in Figure 32.

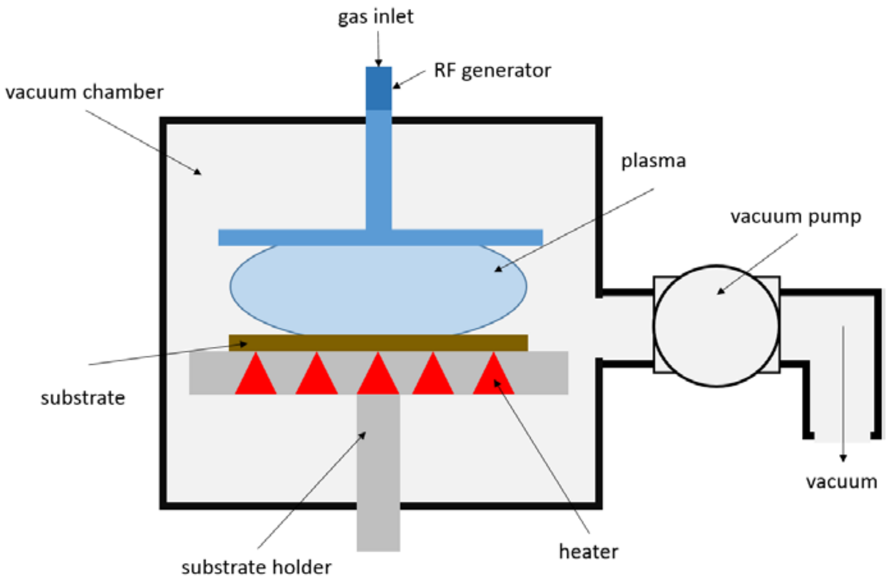


**Figure 32: Simplified setup and functional principle of PE-CVD.**

The advantage of PE-CVD is, that it is possible to only heat the surface region where the reaction occurs while the core of the component is maintained at a comparatively low temperature. Due to the lower process temperature, PE-CVD is applicable to a broader range of materials, especially heat sensitive materials as used for automotive and rail vehicle piston rods. The process temperature for the production of thin DLC coatings by PE-CVD is below 200 °C but requires a plasma activation step in which the surface of the piston rod is bombarded with inert gas ions. Plasma activation is strictly limited in time because internal stress in the substrate’s structure causes material degradation. The carbon hydrogen used as carbon source for the DLC coating is acetylene ($C_2H_2$).

A non-exhaustive overview of general substances information used for chemical vapour deposition of thin DLC and the risk to human health and the environment caused by these substances, is provided within ANNEX D.3.

#### 3.4.3.2 Technical feasibility of Alternative 3

*Wear resistance:* The wear resistance of DLC coated piston rods was evaluated in an endurance trial with specific trial conditions and according to different criteria specified to the field of application (see chapter 2.3.4.2). Testing showed that the wear resistance of thin DLC coated piston rods (coating created by PE-CVD) is comparable to functional chrome plated piston rods.

*Corrosion resistance:* Thin DLC coatings created by PE-CVD do not satisfy the minimum requirement of **240 h** in a salt spray test according to DIN EN ISO 9227 NSS. Corrosion on the sampled piston rods occurred **before 24 h** which can be related to the necessary plasma activation step.

*Hardness:* Thin DLC coatings created by PE-CVD reach hardness values of **> 2 000 HV 0.05** on the treated piston rod surfaces which is adequate to fulfil the requirements of this key functionality (**> 800 HV 0.05)** [redacted].

*Coefficient of friction:* The surface roughness of thin DLC coatings created by PE-CVD (**Rz < 1**) is sufficient to satisfy the requirements (**Rz = max. 1**) of this key functionality.

*Process conditions:* Thin DLC coating of piston rods by PE-CVD requires very long process times of **> 10 h**. It is obvious that high a process time leads to a slow cycle time and results in smaller numbers of finished piston rods. Furthermore, the necessary plasma activation of the substrate surface minimizes the corrosion protection evaluated in a SST according to DIN EN ISO 9227 NSS.

**Table 16: Colour coded assessment overview for thin DLC coating created by PE-CVD**

| **Criteria** | Wear resistance | Corrosion resistance | Hardness | Coefficient of friction | Process conditions |
|---|---|---|---|---|---|
| **Feasibility** | | | | | |

#### 3.4.3.3 Economic feasibility and economic impacts of Alternative 3

Against the background of technical failure of PE-CVD, no quantitative analysis of economic feasibility was conducted. However, the cost for PE-CVD depends on numerous different factors which are presented in a qualitative to semi-quantitative way below.

The technology for PE-CVD processes and functional chrome plating differ fundamentally in the equipment and peripherals. The implementation of PE-CVD requires complex machines and infrastructure equipment. The space requirement for PE-CVD equipment is estimated to be 20 times higher compared to functional chrome plating using chromium trioxide.

Furthermore, long process times of more than 6 h for the creation of thin DLC coatings by PE-CVD possibly demand additional plating lines or production sites in the worst case to supply the market with the required amount of piston rods.

Another important aspect of the PE-CVD alternative is energy consumption which is much higher compared to functional chrome plating using chromium trioxide. The reason behind is the energy intensive generation of the necessary high-vacuum and the vaporization of the coating material.

Due to the enormous investment and running costs, ZF Friedrichshafen AG estimated that the costs per component treated with PE-CVD are **considerably** higher (even higher as for PVD) compared to functional chrome plating using chromium trioxide. Therefore, PE-CVD is not considered an economically feasible alternative for piston rod applications.

#### 3.4.3.4 Availability of Alternative 3

PE-CVD is a commercially available process but due to the stated technical and economical limitations not suitable to replace functional chrome plating using chromium trioxide for the surface treatment of automotive and rail vehicle piston rods.

#### 3.4.3.5 Hazard and risk of Alternative 3

As the alternative is technically not feasible, the hazard classification of PE-CVD is based on the available information of the substance used in this alternative (see ANNEX D.3).

Acetylene ($C_2H_2$) is classified as:

- Press. Gas
- Flam. Gas 1

In comparison to chromium trioxide - which is a non-threshold carcinogen - a transition to PE-CVD using acetylene would clearly constitute a shift to less hazardous substances.

#### 3.4.3.6 Conclusions on Alternative 3

PE-CVD cannot be seen as alternative for functional chrome plating using chromium trioxide because of the significant technical limitations of the thin DLC coating.

### 3.4.4 Alternative 4: Trivalent Chrome Plating (including bi- and multilayer approaches)

#### 3.4.4.1 Substance ID and properties

The trivalent chrome (Cr(III)) plating alternative relates to an electrodeposition process for producing a metallic chrome coating from a trivalent chromium electrolyte. The chromium in the electrolyte derives from chromium trichloride. A typical trivalent chrome plating bath composition is shown in Table 17.

**Table 17: Cr(III) based bath chemistry**

| | |
|---|---|
| $CrCl_3.6H_2O$ | 125 g/l |
| $KCr(SO_4)_2.12H_2O$ | 25 g/l |
| $NH_4NH_2SO_3$ | 178 g/l |
| $NH_4Cl$ | 80 g/l |
| $H_3BO_3$ | 30 g/l |
| HCOOH | 30 ml/l |

The Cr(III) plating process is generally based on a similar electroplating technology as the process with chromium trioxide. However, there are important differences regarding the anodes used and additional pulse-reverse equipment, such as the rectifier, which is significantly more expensive than the equipment needed for functional chrome plating using chromium trioxide. Further differences are in the bath chemistry and some operating parameters such as pulse plating for Cr(III) instead of traditional direct current plating for chromium trioxide (TURI, 2012).

The pulse changing Cr(III) process has a maximum deposition rate of about 80 µm/h for thin layers which is potentially higher than typical functional chrome plating rate of 50 µm/h.

The temperature of a Cr(III) based electroplating bath is between 20 and 60°C whereas typical chromium trioxide functional chrome plating occurs between 67 and 73 °C. The pH value of the Cr(III) based plating bath has to be between 2.1 and 2.3 to ensure reliable process conditions compared to the wider range of pH 1 to 3 for chromium trioxide.

Electrolytes based on Cr(III) are subject to research over decades. Nowadays, Cr(III) based coatings are more and more tested as one part of a bi- or multilayer system (e.g. Cr(III) plus Ni-P).

A non-exhaustive overview of general information of substances used within trivalent chromium plating, as well as the overall risk to human health and the environment is provided in ANNEX D.4.

### 3.4.4.2 Technical feasibility of Alternative 4

Results on R&D for Cr(III) metallic chrome coatings are mainly available from laboratory scale research. Almost no results are available on industrial applications of Cr(III) based plating technologies, showing that pure Cr(III) as alternative for chromium trioxide is still under laboratory research and technically not feasible on an industrial scale. The most relevant technical limitations of pure Cr(III) are slow deposition times, electrolyte monitoring, crack formation and hydrogen embrittlement in the applied layer.

Newly developed methods include the deposition of at least one layer of electroless Ni-P and at least one chromium layer from Cr(III) and, in every form, the application of one or more heat treatment steps. Generally, the application of a multi-layer system is an interesting approach for further enhancement of the surface properties. However, the technical limitations for each of the coatings cannot be ruled out.

*Wear resistance:* Cr(III) plating requires a post heat treatment step to increase hardness. But the heat treatment step increases the number of cracks of the Cr(III) layer. Therefore it is insufficient for ZF's applications.

*Corrosion resistance:* Corrosion resistance of a single Cr(III) layer is not sufficient to fulfil ZF's requirements (see paragraph on microstructure). At laboratory scale, the corrosion resistance of a Cr(III) layer can be increased if an additional Ni layer is deposited prior to the actual Cr(III) based coating. However, further testing is needed to assess if such a multi-layer system does met ZF's corrosion requirements.

*Hardness:* On laboratory scale testing, hardness of Cr(III) layers can be increased by the post temperature treatment. However, the post temperature treatment increases the number and the dimensions of the cracks. The cracks are going to reduce the corrosion resistance.

*Process conditions:* At the current stage, heat treatment is required after the coating process, to reduce hydrogen embrittlement and consequently achieve sufficient wear resistance of the final product. It is currently tested if a heat treatment with a temperature of 300 °C is sufficient to reach the required hardness.

*Microstructure:* The metallic chromium layer deposited from Cr(III) electrolytes has a different crystal structure compared to the metallic chromium derived from Cr(VI). The crystal layer structure of Cr(VI) electrolyte shows horizontal micro-cracks. The Cr(III) electrolyte leads to vertical macro-cracks. Macro-cracks can reach the substrate and lead to increased corrosion. The macro-crack dimensions in the Cr(III) layer is further increased with heat treatment.

These structural deficiency of Cr(III) coatings are not tolerable for piston rods in ZF's applications as they result in insufficient corrosion resistance due to higher oxygen permeability and moisture penetration.

**Table 18: Colour coded assessment overview for trivalent hard chrome plating process**

| Criteria | Wear resistance | Corrosion resistance | Hardness | Coefficient of friction | Process conditions | Additional criterion: Microstructure |
|---|---|---|---|---|---|---|
| Feasibility | | | | | | |

#### 3.4.4.3 Economic feasibility and economic impacts of Alternative 4

As the trivalent hard chrome plating process is not technically feasible for piston rod applications, no quantitative analysis of economic feasibility was conducted. However, the cost for trivalent chromium plating depends on numerous different factors which are presented in a qualitative to semi-quantitative way below.

The electrodeposition of a metallic chrome coating with Cr(III) bath chemistry has not been implemented at a commercial scale yet. Based on laboratory testing, the costs for chemicals are estimated to be approximately equivalent to chromium trioxide plating.

The electricity costs are expected to be less, because the trivalent chromium process requires less current density. Accordingly, less energy is needed compared to the chromium trioxide based processes. It should be noted that besides the inevitable costs of changing process and validation activity, production costs can be higher due to the need of sophisticated measuring technology in order to stabilize the more sensitive process and the need for ion exchange and filtration systems that are necessary to maintain requisite bath purity.

Another important factor for the economical assessment of the Cr(III) plating process is space requirement. The Cr(III) process takes approximately **three times** longer than the Cr(VI) process which could demand **additional plating lines** or even **production sites** in the worst case to be able to supply the market with the required amount of piston rods. Please note that multilayer approaches (e.g. nickel coating prior to the actual Cr(III) coating) significantly **increase space requirements** as additional nickel plating lines are required.

Waste treatment and ventilation were reported to be less than those associated with chromium trioxide plating (TURI, 2006).

Taking material and process costs into account, costs for Cr(III) plating might be somewhat higher as for chromium trioxide functional chrome plating. Taking the additional space requirement, maintenance and waste water treatment into account, the Cr(III) process will be much more cost intensive than the Cr(VI) process.

#### 3.4.4.4 Availability of Alternative 4

Trivalent chrome electroplating with a pure Cr(III) electrolyte is not available at the current stage. However, R&D is ongoing with different non-chromium intermediate layers such as nickel or nickel-phosphorous but none of these alternatives is fully matured.

#### 3.4.4.5 Hazard and risk of Alternative 4

As trivalent chrome plating is not considered an alternative for functional chrome plating using chromium trioxide, the hazard classification of this method is based on the available information of the of the substances used within this method (see ANNEX D.4), trivalent chromium chloride would be the worst case with a classification as

- Skin Irrit. 2
- Eye Irrit. 2
- Acute Tox.

In general, the trivalent electroplating process is less toxic than chromium trioxide plating due to the oxidation state of the chromium ion. Cr(III) solutions do not pose serious air emission issues, but still pose the problems of disposal of stripping solutions (depending on the type of stripping solution) and exposure of staff to chrome dust during grinding.

In addition, there is a certain risk of Cr(VI) being generated during plating process. This is why appropriate security precaution and process management has to be adopted to prevent the formation of Cr(VI). The bath chemistry typically also comprises a high concentration of boric acid, which is a SVHC substance (toxic for reproduction) included on the candidate list and currently on the 6$^{th}$ recommendation round for inclusion in Annex XIV.

Despite these facts, the transition from chromium trioxide to trivalent chromium constitutes a shift to less hazardous substances.

#### 3.4.4.6 Conclusion on Alternative 4

The Cr(III) based electroplating system does not perform as technically nor economically equivalent to the chromium trioxide based plating method and is therefore not a general alternative.

As stated, different formulators are conducting intensive R&D on Cr(III) based electroplating with different under coatings such as nickel or nickel - phosphorous but to date none of these approaches has reached maturity.

## 3.5 Outlook: Current R&D Projects

The previous chapters and R&D over the last years clearly indicated that chromium trioxide cannot be easily replaced for piston rod applications. Additionally, ZF Friedrichshafen AG is aware that R&D efforts have to be spread on different approaches to maximize the chances for finding a technical and economically feasible alternative for functional chrome plating using chromium trioxide. Therefore, the company is currently investing in four potential alternatives together with different partners from industry.

Therefore, the R&D project "*Alternative surface coating without Cr(VI) material*" was started in 2015 as the most recent initiative on the development roadmap of ZF. Over the course of this project, which is carried out in close collaboration with different formulators, four candidates will be assessed on a prototype basis.

These potential alternatives can all be categorized as **galvanic** coating processes, but differ fundamentally in process conditions and source materials used for the coating itself (see Figure 33). Please note that this project also includes the development of an appropriate pre-treatment that is currently being discussed with the formulators involved. It is assumed that the formulators will propose and test different (proprietary) pre-treatments that are tailored to the respective main treatment tested. The aim of this project is to develop a coating system that is completely Cr(VI)-free. However, the focus is to find a coating system that provides the piston rod with the necessary key requirements over its lifetime.

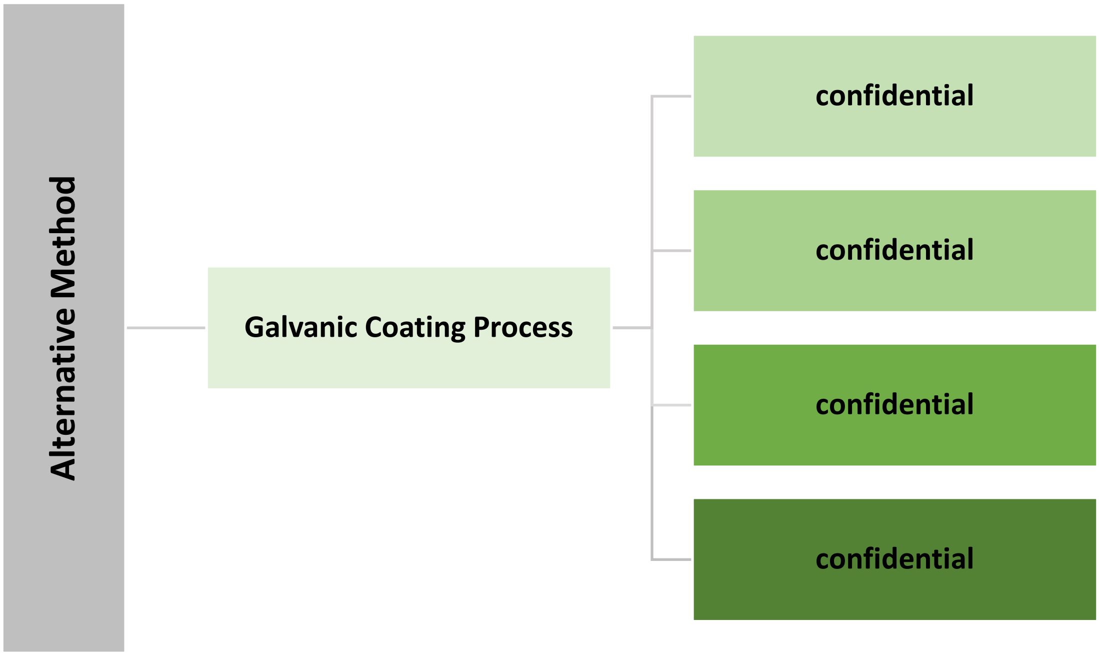


**Figure 33: Alternative technologies under R&D by ZF with corresponding alternative source materials for coating**

ZF Friedrichshafen AG initiated the project and is currently preparing for first preliminary testing in phase 1, the advanced engineering process. The following milestones are set by ZF in a best case scenario:

- Project start: 2015 (planning phase)
- Advanced engineering process (phase 1) starts by 2017
- Planned project duration: **8 - 11 years**
    - Phase 1: **3 - 4 years** for advanced engineering process
    - Phase 2: **3 - 4 years** for development of series production model
    - Phase 3: **2 - 3 years** for process installation
- Project ends after the chosen technology has reached **internal** maturity

The preliminary tests are important for ZF Friedrichshafen AG to evaluate the potential of a specific alternative coating and to prevent unnecessary R&D efforts and time loss. For alternative piston rod coatings the following tests are mandatory:

- Metallography & surface topography: quality of surface picture of the coating (e.g. crack pattern)
- Adhesion of alternative coating to the surface of the substrate
- Hardness of alternative coating
- Wear & corrosion resistance of alternative coating
- Coefficient of friction (important for wear resistance and general abrasion)
- Service life
- Bending properties of alternative coating (e.g. to exclude crack formation)

However, the current project status of all these alternatives is still at the beginning of phase 1 and therefore no realistic technical and economic assessment can be made at this point because data is not available. Although the R&D success for a potential alternative is hard to predict, ZF Friedrichshafen AG estimated a preliminary time-schedule for Cr(VI)-free piston rods presented in Figure 34.

After successfully passing this prototype phase which takes **8 - 11 years**, the subsequent step would be the customer inspection and testing at the different OEMs. Importantly, only if a technology turns out to be suitable, the developed candidate alternative(s) can be presented to OEMs which can take the technology into consideration for the use in damper systems for new series.

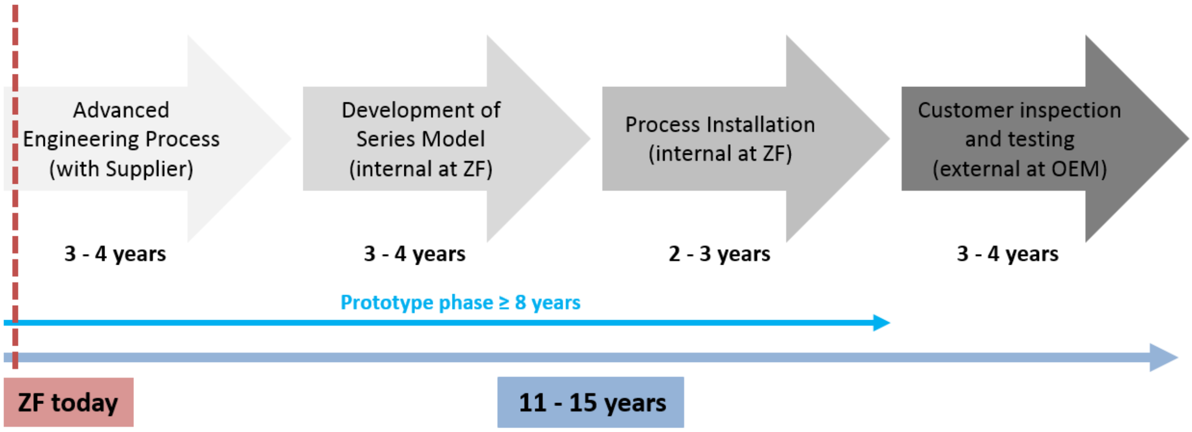


**Figure 34: Preliminary time-schedule for Cr(VI)-free piston rod**

Please note that any new technology is required to pass full qualification, certification and implementation/ industrialisation to comply with the demanding standards in the automotive sector, and the applicant's customers. OEMs will only accept new technologies if a technical and economic advantage can be presented. At a minimum, a new technology must show a comparable performance to the current technology. For development, implementation and approval of a new technology for series production at OEMs, **at least another 3-4 years** are required. Figure 35 below presents a **best estimated timeline** for start of production (SOP) with preliminary prototype phase (≥ 8 years) and OEM testing phase (≥ 3 years). The same applies to the rail vehicle industry.

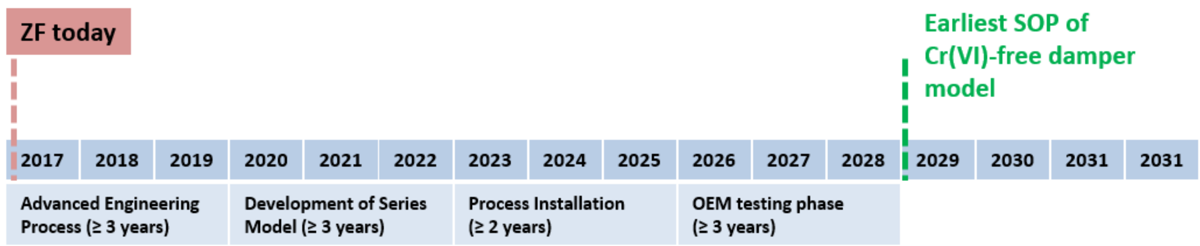


**Figure 35: Best guess timeline for SOP of Cr(VI)-Free damper model**

**From the current state of research, it will take at least 11 years until the first SOP with a newly developed Cr(VI)-free technology from ZF will take place.**

**Introducing new technologies is only feasible for damper systems in new automotive series.**

**Introducing changes to piston rods used in current series damper systems are explicitly not allowed due to contractual obligations over the life-time of the vehicle as this is a safety relevant component.**

## 3.6 The most likely non-use scenario

ZF has considered different scenarios in case authorisation for the continued use of chromium trioxide should not be granted. A detailed assessment of those scenarios resulted in one most realistic NUS.

The following scenarios have been considered by ZF:

1) Substitution of chromium trioxide by a different industrial process and/or an alternative substance
2) Relocation of the piston rod production to a non-EEA country
3) Outsourcing of the chrome plating process to a non-EEA company
4) Outsourcing of the complete piston rod production to a non-EEA country

The following chapters describe the scenarios in more detail.

### 3.6.1 Scenario 1: Substitution of chromium trioxide by a different industrial process and/or an alternative substance

This scenario considers the replacement of chromium trioxide by a different substance which could provide the same performance to the final product and/or a different process which would not require the use of chromium trioxide.

As it can be seen from the results of the AoA, no alternative substance or industrial process which could provide the final product with the same properties as in the applied for use scenario is known at the moment or expected to be developed in the next 21 years. Therefore, this scenario has been discarded.

### 3.6.2 Scenario 2: Relocation of the piston rod production to a non-EEA country

This scenario involves a stop of the piston rod production in Eitorf and Schweinfurt and the relocation of this activity to a non-EEA country. In this case, the plants would be partially shut down and one joint facility with the production capacity of Eitorf and Schweinfurt would be established on the greenfield in a non-EEA country. In this scenario, it is assumed that no production stop will occur. Foregone production during construction of the new facility will be offset by previous stock building and a stepwise ramp down process of the two facilities while the new facility is ramping up. This means that at least one facility will always be fully operational while the new one is ramped up in the non-EEA country.

Therefore, supply disruptions for downstream users of ZF Eitorf and Schweinfurt during the relocation process are highly unlikely and therefore not considered in the impact assessment.

Employees currently working in piston rod production at the 2 facilities would have to be dismissed.

Internal as well as customer re-qualifications for the products manufactured at the new location would be required.

This scenario also assumes that ZF would incur additional costs with transportation of the piston rods to the facilities in Europe and with increased inventory necessary to avoid a stop of production of dampers in case of delays with the piston rod supply.

### 3.6.3 Scenario 3: Outsourcing of the chrome plating process to a non-EEEA company

This scenario refers to outsourcing of only the chrome plating step of the production process to a firm located outside the EEA.

In this case, the mechanical manufacturing of piston rods would continue being done at ZF facilities in the EEA and only the chrome plating step would be outsourced to another firm, based outside the EEA. The plated piston rods would then be sent back to ZF for their finalisation and manufacturing of dampers.

Although theoretically possible, this scenario has been discarded due to inacceptable risks of corrosion during the transportation.

### 3.6.4 Scenario 4: Outsourcing of the complete piston rod production to a non-EEA-based company

The last assessed possibility is the outsourcing of the whole production of piston rods to a firm located in a non-EEA country. The remaining steps of the production of dampers would continue being performed at the aforementioned ZF facilities in the EEA. Due to the fact that ZF is covered under the CTAC AfA, knock-on effects for downstream users during the shift of production to the non-EEA are not expected.

This scenario would require internal as well as customer requalification of the piston rod production in the non-EEA firm. Moreover, additional transportation costs from the location where piston rods would be produced (outsourced) to the relevant ZF facilities in the EEA would be incurred. Finally, similar to scenario 2, increased inventory costs would be incurred.

### 3.6.5 Likelihood of the presented scenarios and definition of the most realistic NUS

The likelihood (or feasibility) of the scenarios described above is assessed in detail in this chapter. As stated, scenario 1 is excluded from the analysis due to the non-availability of substitutes or alternative processes. Moreover, scenario 3 is not considered further because the risk of corrosion of piston rods during transportation is considered inacceptable for the quality of the final product.
This likelihood analysis is therefore constrained to scenarios 2 and 4.

The cost elements related to the implementation of scenarios 2 and 4 are listed below.

**Table 19: Savings and costs appearing in possible NUS**

| Scenario 2<br>Relocation of the piston rod production | Scenario 4<br>Outsourcing of the piston rod production |
|---|---|
| Expenses with decommissioning of current installations | Expenses with decommissioning of current installations |
| Construction of a new facility in a non-EEA country | - |
| Requalification expenses | Requalification expenses |
| Differences in production costs (savings) | Differences in production costs (savings) |
| Transportation costs | Transportation costs |
| Increased inventory costs | Increased inventory costs |

As it can be seen from the table above, and assuming that decommissioning expenses, savings with sale of machinery, requalification expenses, differences in production costs, transportation costs and increased inventory costs would be identical in the 2 scenarios, it becomes clear that scenario 2 would be considerably more costly due to the required investments. The investments necessary for the construction of a new facility in scenario 2 have been estimated by ZF based on experience from previous construction of facilities and sum up to approx. [redacted]. Please refer to Appendix 1 for further details. [redacted]

For these reasons, scenario 4 (outsourcing of the piston rod production to a non-EEA company) is considered to be the most realistic NUS.

The assessment of impacts in the following chapters is therefore done based on scenario 4.

Note: As far as it is known to ZF, the required production capacity to absorb the production of Eitorf and Schweinfurt in the outsourcing scenario is not readily available at the moment, neither in the EEA nor in the non-EEA. Therefore, the investment in such a facility has to be made by someone in any case. However since it is unclear by whom and where such an investment would be made, i.e. where the economic impact would be realised, these costs are not considered further in the SEA.

# 4 IMPACTS OF NOT GRANTING AUTHORISATION

The following chapters describe the socio-economic impacts connected to the most realistic non-use scenario for ZF - outsourcing of the piston rod production to a non-EEA country. Please refer to Appendix 1 for further details.

## 4.1 Economic impacts

The outsourcing of the piston rod production to a firm located in a non-EEA country would require detailed planning regarding the selection and qualification of suppliers, logistics and stock management.

- **Decommissioning expenses**

The installations where piston rods are currently produced would have to be decommissioned, resulting in additional expenses in the NUS. In total, [redacted] ([redacted]).

**Decommissioning costs** are estimated at [redacted]. Therefore, total decommissioning expenses sum up to **EUR 5 000 000 - 10 000 000** [redacted]

- **(Re-)qualification expenses**

The supply chain in the automotive sector is characterised by strict qualification processes in case of changes in the production processes of the qualified suppliers. The outsourcing of the piston rod production would therefore require the non-EEA producer(s) to be qualified before supply can commence.

Requalification has to be carried out by size of the components, internally at ZF and at the customer level. In total, the non-EEA supplier needs to be qualified by [redacted] and for [redacted], see Table 20.

**Table 20: Piston rod size and production location**

| Piston rod diameter (mm) | Manufacturing location |
|---|---|
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |

ZF has estimated the requalification expenses based on the technical specifications of the design sizes. Repetitions in the requalification process of some sizes would be necessary (trials are done internally –

by ZF – and by the customer). In the worst case, the process would have to done five times (first trial plus four repetitions).

In total, expenses for the requalification of all design sizes total **> EUR 20 000 000** [redacted].

See Table 21 for an indication of the time frames needed for requalification.

**Table 21: Duration of the requalification process in the NUS**

| | **Duration** |
|---|---|
| Internal qualification (design verification process) | 3 - 6 years |
| Qualification at all customers | 4 - 8 years |
| **Total duration of the requalification process** | **7 - 14 years** |

- **Changes in logistics / inventory costs**

The outsourcing of production to a non-EEA country would have advantages regarding the costs of production. Amongst other effects, wages lower than those in Germany are expected, therefore the outsourcing of piston rods would bring cost savings. On the other side, the outsourcing of piston rod production would bring additional costs regarding the shipment of piston rods to the ZF facilities producing dampers in EEA. In addition, it is expected that larger inventories will have to be kept. This means that significant inventories are kept out of use and would result in large sums of money becoming unavailable for other activities or investments. However, the area where the piston rod production currently takes place could serve as storage space.

Overall, the savings from reduced production costs due to the outsourcing of piston rod production would be outweighed by the increased logistics/inventory costs.

## 4.2 Social impacts

In case the production of piston rods is outsourced, all workers involved with that step of the production of dampers will be made redundant and therefore dismissed. [redacted] workers from the facility in Eitorf and [redacted] from the facility in Schweinfurt would be affected in the NUS.

Following the methodology presented in a recent report commissioned by ECHA (Dubourg, 2016) the social costs related to expected job losses in the non-use scenario are valued considering the following components:

- The value of lost output/wages during the period of unemployment
- The cost of searching for a new job
- Recruitment costs
- The ´scarring costs´ (i.e. the impact of being made unemployed on future earnings and employment possibilities)

- The value of leisure time during the period of unemployment

The latter component is seen as a negative cost (i.e. a benefit) of unemployment. As such it is subtracted from the total cost resulting from the first four components.

Table 22 summarises the costs over the time frame.

**Table 22: Summary of social impacts appearing in the NUS**

| Item | [EUR] |
|---|---|
| Unemployment social cost of one job position at ZF (**2015** value) | [redacted] |
| Unemployment social cost of one job position at ZF adjusted to **2017** values (adjustment by 1.7 % a year for 2 years) | [redacted] |
| [redacted] | [redacted] |
| [redacted] | [redacted] |
| **Total social cost due to dismissal of ZF workers** | **< 60 000 000** [redacted] |

## 4.3 Wider economic impacts

The most realistic NUS would result in the importation of piston rods produced by a non-EEA firm. These imports, given their dimension and share on overall trade and provided they can be sustainably initiated before cease of the review period, cannot be said to lead to any macro-economic implications and, therefore, no wider economic impacts are foreseen.

## 4.4 Distributional impacts

Given that the most realistic NUS is the outsourcing of piston rod production to a non-EEA country, it can reasonably be assumed that non-EEA suppliers would benefit of such situation over EEA firms. However, the scope of this analysis is the EEA and therefore these impacts are irrelevant for this SEA.

Moreover, severance payments that would have to be paid to the dismissed workers in EEA are also considered to be distributional impacts in EEA. Such distributional impacts, as per their definition, have not been included in the final assessment of impacts.

## 4.5 Uncertainty analysis

The ECHA Guidance on SEA (ECHA, 2011) proposes an approach for conducting the uncertainty analysis. This approach provides three levels of assessment that should be applied if it corresponds:

- qualitative assessment of uncertainties;
- deterministic assessment of uncertainties;
- probabilistic assessment of uncertainties.

The ECHA Guidance further states: the level of detail and dedicated resources to the assessment of uncertainties should be in fair proportion to the scope of the SEA. Further assessment of uncertainties is only needed if the assessment of uncertainties is of crucial importance to the overall outcome of the SEA.

Hence, a qualitative and deterministic assessment of uncertainties has been conducted to summarise and describe potential sources of uncertainty related to the impact categories. Since a probabilistic assessment of uncertainties would not be of significant importance for the overall outcome of the SEA, this assessment has not been carried out in this SEA.

### 4.5.1 Qualitative assessment of uncertainties

Table 23 illustrates the systematic identification of uncertainties related to human health impacts.

**Table 23: Uncertainties on human health and socio-economic impacts**

| Identification of uncertainty (assumption) | Classification | Evaluation | Criteria and scaling (contribution to total uncertainty) |
|---|---|---|---|
| Shape of exposure-response function (linear versus non-linear)[3] | Model uncertainty | If non-linear, particularly at low exposure levels: **overestimation** | High |
| Working days (260 days) given by the dose-response curve | Parameter uncertainty | Not taking into account holidays, bank holidays, illness: **overestimation** | Medium |
| Use of $PEC_{local}$ (distance only 100 m from the point source) for total local exposure calculation | Parameter uncertainty | $PEC_{local}$ reduces according with the distance from the point source **overestimation** | High |

[3] The study conducted by ETeSS on behalf of ECHA clearly states that: '*[...] the lower the exposure (certainly below 1µg/m³), the more likely it is that the linear [dose-response] relationship overestimates the cancer risk.*' The study further states that '*the risk estimates for [...] exposures lower than 1 µg Cr(VI)/m³ might well greatly overestimate the real cancer risks. It is also considered that at progressively lower Cr(VI) air concentrations (from about 0.1 µg/m³ downwards), cancer risks may be negligible.*' (2)

### 4.5.2 Deterministic assessment of uncertainties

The deterministic assessment of uncertainties seeks to investigate the robustness of the results presented in Chapter 4 against changing input parameters regarding the assumptions made for the analysis of impacts.

For each of the impact parameters which are changed as part of the uncertainty analysis, two alternative scenarios are provided: a lower bound and an upper bound.

It is important to note that the lower and upper bounds of one impact parameter are not connected with the lower and upper bounds of the other impact parameters.

The variables which are considered for the deterministic analysis of uncertainties and the different combinations composing the assessed scenarios are described in the Table 24.

**Table 24: Summary of input parameters for the scenarios considered in the deterministic assessment of uncertainties**

| Scenario | Health impacts[4] | Social impacts[5] |
|---|---|---|
| US1 | Lower bound | Lower bound |
| US2 | Lower bound | Upper bound |
| US3 | Upper bound | Lower bound |
| US4 | Upper bound | Upper bound |

[4] Lower bound refers to lower bound VSL and VCM values and a value of EUR 0 for indirectly exposed workers and the local population (see Annex A.1.3 for justification). Upper bound refers to the upper bound values for VSL and VCM and considering the default value of 10 000 people for the estimation of impacts for indirectly exposed workers and the local population.

[5] Lower bound refers to the average value of social cost for one dismissal in Germany (EUR 53 877), upper bound refers to the impacts for ZF employees based on real company data (**EUR [redacted]).**

### 4.5.3 Findings of the deterministic uncertainty analysis

Table 25 summarises and combines the different scenarios analysed, showing the variations on the balance. All values are expressed as EUR.

**Table 25: Deterministic uncertainty analysis – summary**

| Uncertainty Scenario (US) | Health impacts | Requalifi-cation costs (economic impacts) | Decommis sioning expenses | Social costs | Total socio-economic impacts | Ratio health impacts : socio-economic impacts |
|---|---|---|---|---|---|---|
| US1 | 119 027 | >20 000 000 [redacted] | 5 000 000 - 10 000 000 [redacted] | 35 000 000 – 60 000 000 [redacted] | 60 000 000 - 90 000 000 [redacted] | At least 1:504 [redacted] |
| US2 | 119 027 | >20 000 000 [redacted] | 5 000 000 - 10 000 000 [redacted] | 35 000 000 – 60 000 000 [redacted] | 60 000 000 - 90 000 000 [redacted] | At least 1:504 [redacted] |
| US3 | 2 510 133 | >20 000 000 [redacted] | 5 000 000 - 10 000 000 [redacted] | 35 000 000 – 60 000 000 [redacted] | 60 000 000 - 90 000 000 [redacted] | At least 1:23 [redacted] |
| US4 | 2 510 133 | >20 000 000 [redacted] | 5 000 000 - 10 000 000 [redacted] | 35 000 000 – 60 000 000 [redacted] | 60 000 000 - 90 000 000 [redacted] | At least 1:23 [redacted] |

# 5 CONCLUSIONS

## 5.1 Comparison of the benefits and risk

Table 26 summarises the effects of a non-authorisation.

**Table 26: Comparison of impacts for the applied for use and the non-use scenario**

| Type of impact | Applied for use scenario | Non-use scenario(s) |
|---|---|---|
| Human health | • Health impacts due to the potential exposure of workers and the general population due to the use of chromium trioxide at the ZF facilities in Eitorf and Schweinfurt (DE). | • No potential exposure of workers and the general population due to the use of chromium trioxide at the ZF facilities in Eitorf and Schweinfurt (DE).<br>• Exposure of workers outside the EEA |
| Socio-economic impacts | • No additional requalification costs<br>• No dismissal of workers<br>• No decommissioning costs | • Costs to requalify [redacted] different sizes of piston rods with [redacted] large customers.<br>• Dismissal of [redacted] workers from the facility in Eitorf and [redacted] from the facility in Schweinfurt.<br>• Costs for decommissioning of existing facilities in the EEA |

Table 27 below summarises the impacts for the applied for use and the non-use scenario in terms of monetised costs and benefits which were calculated in Section 4.

**Table 27: Quantitative comparison of impacts**

| Type of impact | Uncertainty Scenario 3 [EUR] | Uncertainty Scenario 2 [EUR] |
|---|---|---|
| Potential health benefits associated with a non-authorisation of the continued use of chromium trioxide | 198 804 | 119 027 |
| Potential health benefits ‘man via the environment’ associated with a non-authorisation of the continued use | 2 311 330 | 0 |
| Negative economic impacts associated with a non-granted authorisation | [redacted] | [redacted] |
| Negative social impacts associated with a non-granted authorisation | [redacted] | [redacted] |
| **Net benefits of a granted authorisation** | [redacted] | [redacted] |

Summing up, the ratio of health benefits of a non-granted authorisation to the negative socioeconomic impacts of a non-granted authorisation is at least between 1:23 and 1:504 [redacted]

## 5.2 Information for the length of the review period

Comparing the detailed information provided in this document, against the publication made by ECHA on "*Setting the review period when RAC and SEAC give opinions on an application for authorisation*"[6], the following conclusions are drawn by the applicant on the length of the review period:

a) It is clearly shown that this AfA meets the criteria and considerations that lead to a recommendation of a long review period (12 years).

b) From a technical perspective, there are clear aspects that show that a **much longer review period of 21 years** is needed until substitution of chromium trioxide in plating of piston rods can be achieved.

- The dynamic and globally acting automotive and rail vehicle industry has a very complex and time-consuming development and implementation process in place. The applicant has been proactive in undertaking research to develop an alternative for many years. These attempts have been unsuccessful in achieving an alternative with comparable performance. Based on the current state of research, such implementation of a new technology for piston rod applications is expected to take at least 11 years until the very first SOP at one OEM (See item 1 in Figure 36). Still at that stage, chromium trioxide is far from being replaced.
- Planning reliability is crucial for the OEMs. As of 2017, contractual supply obligations for more than [redacted] projects exist for the applicants (EOP not before 2024, not taking spare parts into account). Contractual arrangements are typically signed 3 years before SOP (see item 2 in Figure 36).
- Design changes for running series are not possible, due to safety reasons. Consequently, only when the last series in production that is supplied with Cr(VI) plated piston rods reached EOP, the replacement process can be considered as successfully accomplished. Note that this does not take into account contractual obligations concerning legacy spare parts.
- With over [redacted] different parts (differences in type of connection, length, thickness, stability, etc.) at ZF currently used in production of vehicles, it is obvious that, if an alternative is found, the phase out of Cr(VI) is a long process, given the fact that it is directly dependent on the acceptance by the OEMs.
- Taking into account the typical product-lifecycle of vehicles (7 years production, 10-15 years spare part guarantee) and the staggered substitution process needed (for capacity reasons, series production do not run in parallel at OEMs but in a time-displaced manner), it can easily take 10 years until the last series reached EOP (see item 3 in Figure 36).

[6] https://echa.europa.eu/documents/10162/13580/seac_rac_review_period_authorisation_en.pdf

- The continued availability of Cr(VI) plated imports regardless the length of the review period or in case no authorisation being granted, suggests that any alternative would have to at least match the performance and price characteristics of Cr(VI) plated products. Therefore, return of investment can only be achieved if the implementation of a new technology is considered technically and economically acceptable for the OEMs under these aspects.

At this time-point, only a best case estimate on the development process can be displayed as shown in Figure 36. Realistically, R&D efforts and successful implementation at OEM level require a review period of at **least 21 years**, [redacted]

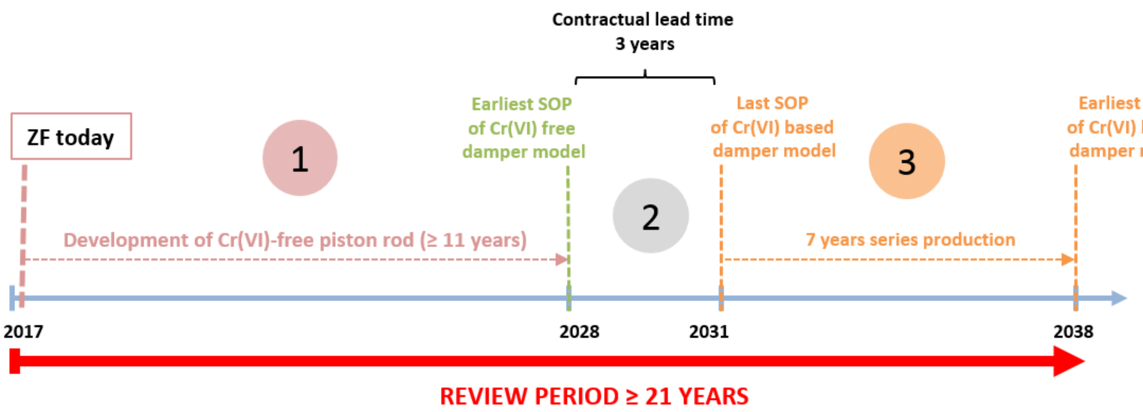


**Figure 36: Derivation of the length of the review period with a best guess development time of Cr(VI)-free piston rods of 11 years**

This is a fundamental reason why ZF requests a review period of at least 21 years. Technical hurdles related to the replacement process for piston rods are indisputable. It is very difficult for ZF to thoroughly develop Cr(VI)-free alternatives without compromising the quality of its products and putting the safety of vehicles at risk. Cr(VI)-free alternatives may be implemented step-by-step, nevertheless the use of Cr(VI)-coated piston rods will be essential in the automotive and rail industry for the next decades.

## 5.3 Substitution effort taken by the applicant if an authorisation is granted

As described in detail in Chapter 3.1, the applicant conducted extensive R&D over the last years. None of these activities was deemed to be successful, meaning that so far no alternative technology could be identified that meets the essential combination of requirements as described in Chapter 2.3.4.

In 2015, the R&D project "*Alternative surface coating without Cr(VI) material*" was started as the most recent initiative on the development roadmap of ZF after all other tested alternatives failed. Over the course of this project, which is carried out in close collaboration with different partner from industry, four candidates will be assessed on a prototype basis. After successfully passing the internal development phase, described in detail in Chapter 2.6, the technology can be presented to OEMs which can take it into consideration for new automotive series. Importantly, any potential alternative is required to pass full qualification, certification and implementation/industrialisation to comply with demanding standards in the automotive sector. OEMs will only accept new technologies if a technical and economic advantage can be presented. At least, the technology must show a comparable performance to the current technology. For replacing functional chrome plating in as many series as possible, only gradual introduction is the practicable way, constantly observing the long-term performance of the system. The timeline of this project is illustrated in Chapter 3.5 and Figure 37 below. A detailed description of the specific contents of each project phase is given in Chapter 2.6.

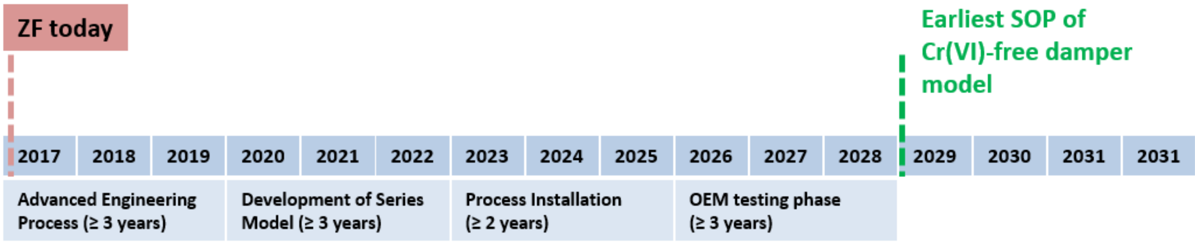


**Figure 37: Project milestones including development at OEM level**

The project timeline presented above is based on best estimates and the applicants' experience with similar projects carried out in the past. Uncertainties associated with such long-term R&D project include: technology failure at any stage, rejection of technology by OEMs followed by the necessary adaptations, or any other drawbacks. In these cases, timelines and milestones could be considerably postponed.

All in all, despite of tremendous efforts carried out in the development of new coating technologies, the R&D activities conducted by ZF throughout the last decade showed that an alternative or set of alternatives that could fully replace functional chrome plating for piston rod applications did not pass very early prototype phase. Consequently, the estimated best-case review period is **at least 21 years** until necessary functional chrome plating of piston rods could be fully replaced by an alternative technology.

## 5.4 General conclusion on suitability and availability of possible alternatives for functional chrome plating

Functional chrome plating of piston rods involves deposition a layer of metallic chromium on the surface of the metallic component consisting of non-alloy (C35 and C45) or low-alloy (ST52-3) steels. This metallic chrome coating provides the surface of the piston rod with high mechanical and wear resistance, excellent anticorrosion performance and a low coefficient of friction. Therefore, the process of functional chrome plating using chromium trioxide is essential for piston rod applications due to this unique combination of critical performance characteristics. Piston rods in ZF's damper system applications are very important safety relevant components and have to operate over the life-time of a vehicle under demanding conditions that involve high temperatures, repetitive wear and mechanical impact.

**Table 28: Overview of assessed alternatives with corresponding technical limitations**

| **Alternative** | | **Indispensable criteria which led to the exclusion of the alternative** |
|---|---|---|
| 1 | Case hardening (Nitrocarburization) | - Wear resistance<br>- Corrosion resistance<br>- Hardness<br>- Coefficient of friction<br>- Process conditions |
| 2 | Physical Vapour Deposition (PVD) | - Wear resistance<br>- Corrosion resistance<br>- Layer thickness*<br>- Process conditions |
| 3 | Plasma-enhanced Chemical Vapour Deposition (PE-CVD) | - Corrosion resistance<br>- Layer thickness*<br>- Process conditions |
| 4 | Trivalent Hard Chrome Plating | - Wear resistance<br>- Corrosion resistance<br>- Microstructure** |

* layer thickness is no assessment criterion mentioned in the technical assessments sections of the individual alternatives (chapter 3.4) but in these cases it is related to the key functionality corrosion resistance and therefore has to be stated here.
** the assessment criterion “microstructure” is only applicable for the Cr(III) plating alternative (see Chapter 3.4.4.2)

The tested coatings for piston rod applications discussed in this AoA showed promising results in some of the required key functionalities mentioned in Chapter 2.3.4.2. However, to successfully substitute chromium trioxide in functional chrome plating it is mandatory that a potential alternative satisfies **all** key requirements, which is not the case for any alternative technology assessed in this report. Table 28 provides an overview of the technical deficiencies which led to the exclusion of these alternatives. A detailed description of each exclusion criteria of each alternative can be found in the corresponding assessment chapter (see Chapter 3.4).

The exhaustive assessment of each alternative (see Chapter 3.4) clearly showed that they are not suitable for piston rod applications. The demand on a potential alternative is very high but a lot of different technical and economic aspects play a major role in the substitution of chromium trioxide in functional chrome plating.

ZF Friedrichshafen AG, together with several formulators, is conducting extensive R&D on further coating and process technologies. Details on ongoing projects are provided in Chapter 3.5. As these projects are in very early prototype phase, a thorough assessment of these coatings is not yet possible.

At this time-point, only a best case estimate on the development process can be displayed as shown in Figure 36. Realistically, R&D efforts and successful implementation at OEM level require a review period of at **least 21 years**. A detailed description of the development process is presented in Chapter 2.6.

"R&D is a time-consuming process and exact time schedules are hard to predict as scientific breakthroughs and positive results cannot be enforced but come with experience, time and patients."

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# ANNEX A – SEA METHODOLOGY

## A.1 Assessment of health impacts

In accordance with the CSR (ZF Deutschland , 2016) the risk assessment for workers exposed in this SEA is restricted to inhalation of airborne residues of chromium trioxide (lung cancer). For the general population, inhalation exposure to Cr(VI) and oral exposure to Cr(VI) via the food chain is also taken into account. Oral exposure via the food chain leads to an additional risk of small intestine cancer.
Toxicity to reproduction is not addressed in this SEA as the risk is adequately controlled (RCR < 0.01).
For details please refer to the CSR (ZF Deutschland , 2016).

### A.1.1. Quantitative health impact assessment of workers

The assessment of health risks within this SEA utilises the results of a study endorsed by ECHA identifying the reference dose-response relationship for carcinogenicity of Cr(VI) (ECHA, 2013)[7]. This paper has been agreed on at the RAC-27 meeting on 04 December 2013. These results on the carcinogenicity dose-response analysis of Cr(VI) containing substances are acknowledged to be the preferred approach of the Committee for Risk Assessment (RAC) and the Committee for Socio-Economic Analysis (SEAC) and therefore have been used as a methodology for the assessment of health risks in this SEA.
Accepting this, the following steps are necessary to complete the health impact assessment according to the ECHA methodology:

1. Evaluation of potential work exposure (CSR)
2. Estimation of additional cancer cases relative to the baseline lifetime risk of developing the disease (ELR)
3. Assessment of fatality rates (%) with reference to available empirical data
4. Monetary valuation of fatal and non-fatal cancer risks based on the new Willingness to Pay (WTP) study published by ECHA in 2016 (ECHA, 2016).

These 4 consecutive steps are explained in detail in the following.

[7] By reference to this, the applicant neither agrees nor disagrees with this dose-response relationship. However, the applicants acknowledge that the dose-response relationship is likely to be conservative and protective of human health, particularly considering the extrapolated linear relationship at low dose exposure concentrations.

**Data gathering on potential work exposure**

For the assessment of potential worker exposure, the maximum number of potentially exposed workers as well as the worst-case exposure values and combined exposure values from the CSR (ZF Deutschland , 2016) are taken into account. For further information regarding exposure values, please consider the CSR (ZF Deutschland , 2016).

**Estimation of additional cancer cases in relation to baseline**

The dose-response relationship for Cr(VI) with regard to lung cancer has been discussed in recent research published by ECHA (ECHA, 2013). These dose-response functions of an excess risk for carcinogenic effects have been used as the basis for this assessment.

For the calculation of health impacts related to lung cancer, **excess lifetime risk** (ELR) is defined as the additional or extra risk of developing cancer due to exposure to a toxic substance incurred over the lifetime of an individual. Note that developing cancer may occur during working life or after retirement.

Linear exposure-risk relationship for lung cancer as estimated by ECHA (ECHA, 2013):

$$Unit\ occupational\ excess\ lifetime\ risk = 4\text{E-}03\ per\ \mu g\ Cr(VI)/m^3$$

The dose-response relationship agreed upon by RAC refers to a working lifetime exposure with continuous working-daily exposure. As an average over different countries and economic sectors, full-time employee contracts (8 hours per day) and a working lifetime of 40 years are taken as a basis (ECHA, 2013). Note that 8 working hours per day or 40 working hours per week, as well as 40 years per working life are explicit parameters used for the full-time working equivalent (FTE) underlying the exposure-response functions (ECHA, 2013), p. 5, whereas 260 working days per year are implicitly given through the dose-response curve.

*Adaptation factors for time frame of exposure*

In order to apply this exposure-risk relationship to the case of authorisation, it has to be adapted according to the time frames used in this AfA.

Therefore, the following factors are used to adapt the exposure-risk relationship to the respective situation of this AfA:

- Factor for adaptation to the respective review period (years of authorisation granted up to the next revision envisaged)

$$\frac{envisaged\ review\ period\ [years]}{40\ years}$$

- Factor for adaptation to the actual working days per year[8]

$$\frac{working\ days\ per\ year}{260\ days}$$

Due to the fact that exposure values derived in the CSR are 8 hour time weighted average (TWA) concentrations, a correction for the actual exposure time per day is not needed. For activities performed not on a daily basis, the frequency of activities has been taken into account in the CSR and the presented exposure estimates are already corrected respectively (e.g. in case an activity is performed only once a week, the exposure estimate presented in the CSR already is an average long-term exposure corrected for frequency). This means that the factor for adaptation of the actual working days has only been applied for daily activities. Depending on working days per year at specific sites, individual correction factors have been determined for each site and used in the further assessment.

*Methodology for the estimation of additional lung cancer cases*

For an individual person, the excess lifetime lung cancer **mortality** risk derived in the ECHA paper (ECHA, 2013) indicates the differential in probability to die of lung cancer during the future life, i.e. the increase in probability compared to the baseline risk for an individual to die from this disease.

As described above and in line with ECHA, ELR of mortality associated with lung cancer = 4E-03 per µg Cr(VI) /m$^3$ x concentration [µg Cr(VI) /m$^3$] (due to an exposure over the whole working lifetime of 40 years).

Excess risk used in this equation is defined as:

$$P_{excess} = P(x) - P(0)$$

with

$$P_{excess}(x) = Excess\ risk\ at\ exposure\ x$$

$$P(x) = lifetime\ risk\ of\ persons\ exposed\ for\ dying\ from\ lung\ cancer$$

$$P(0) = Background\ risk\ (lifetime\ risk\ of\ a\ non-exposed\ comparison\ group)$$

It has to be emphasised that $P_{excess}(x)$ is an additional risk, the unit is the expected number of additional **lung cancer deaths** of a population exposed by a concentration $x$ in the sum (ECHA, 2013).

[8] 260 days per year are not explicitly stated in the RAC paper (RAC/27/2013/06 Rev.1), but are implicitly assumed by RAC. This can be shown by comparing the dose-response relationships for workers and the general population.

In the source of ECHA (ECHA, 2013), based on the research of the ETeSS consortium ((ETeSS), 2013), and in underlying studies, excess risk is used in absolute terms, not percentage points. The excess risk $P_{excess}(x)$ is linear, i.e. proportional both to individual exposure and to persons exposed. Therefore, exposures of different persons can be added.

Consequently, the aggregated excess risk is the expected value of additional lung cancer deaths due to an exposure.

The calculation of the excess risk (i.e. additional lung cancer deaths) over all employees exposed is calculated per WCS by multiplying the individual excess risk times the respective number of workers exposed. Then, the excess risk of all WCS are summed up. Thus, the estimated amount of additional lung cancer deaths is the expected value due to a continued use of Cr(VI) for the respective time frame allowed by an authorisation up to the next revision.

According to the ECHA document (ECHA, 2013), the term used is '*excess lifetime lung cancer mortality risk*'. This is also consistent with the results of ETeSS (2013) ((ETeSS), 2013) where the respective table of a preliminary report is titled '*[u]nit occupational excess lifetime risks of lung cancer death determined by different authorities or publications*'. This signifies that the dose-response function developed refers only to additional lung cancers ending fatal. In this study, only data on deaths caused by lung cancer have been taken into account for the estimation of the dose-response relationship. This will be included in Step 4 of this methodology (the monetary valuation of fatal and non-fatal cancer risks).

**Estimation of average fatality rates in %, based on empirical data from EU-27**

The individual development of cancer diseases may be fatal or non-fatal. Non-fatal cancer is defined as cancer not causing a premature death, i.e. life expectancy is not reduced due to the cancer disease, whereas fatal cancer is defined as cancer leading to premature death. This distinction is important when applying the ECHA guidance on socio-economic analysis in order to use consistent categories of monetary values.

For the determination of fatality rates for lung cancer, demographic data on age-specific cancer incidences and mortality rates have been taken into account; these are mainly:

- age profile of a population
- gender profile of a population
- relationship of risk of developing the disease and risk of dying from the disease

For lung cancer, data of the International Agency for Research on Cancer (IARC) (IARC, Lung cancer including trachea and bronchus. Estimated incidence, mortality & prevalence for both sexes, 2012, n. d.) for the EU-27, as well as data for the EU Member States, showing the age and gender profile of cancer risks in more detail have been analysed and compared to selected other EU Member States with similar data collection sets ((RKI), 2015).

Although the incidence risk and the mortality risk themselves are higher for men than for women, the relationship between incidence and mortality risk (i.e. the fatality rate) shows, apart from random fluctuations, there exist no major differences between males and females.

It has to be emphasised that any structural differences in the baseline risks (e.g. between men and women, between different EU Member States or between different age groups) do not influence the estimation of incremental cancer risks due to exposure to Cr(VI). Therefore, neither the share of male and female workers exposed at work nor the exact age of workers influence the outcome of the estimations.

The fatality rate is an important parameter for a monetary-based valuation of cancer risks. The reference dose-response relationship estimates additional fatal cancer risks only. A full health impact assessment will also consider lung cancer cases that do not result in fatality. Average **mortality rates for lung cancer in the EU-27 are 82.8 %** for both sexes. This value will be used for further analyses in this SEA.[9]

**Monetary valuation of additional cancer cases**

In order to evaluate the additional cancer cases in monetary terms, monetary values for cancer cases as suggested by the latest study published by ECHA (2016) (ECHA, 2016) are used.

In this study, the values of a statistical life (VSL) and the values for morbidity due to cancer (VCM) have been found to be the following (see Table 29)

**Table 29: Relevant values for the valuation of health impacts taken from ECHA review from 2016 (ECHA, 2016)**

| Value | Lower bound (in EUR $_{2012}$) | Upper bound (in EUR $_{2012}$) |
|---|---|---|
| Value of statistical life (VSL) | 3 500 000 | 5 000 000 |
| Value of cancer morbidity (VCM) | 410 000 | 410 000 |

Since values are based on the year 2012, they are adjusted to the respective year of the sunset date [the base year for the calculation of net present values (NPV) of costs and benefits] by using gross domestic product (GDP) deflator indexes. This will be explained in the following.

[9] In these figures of EU-27, Croatia is not yet included. Respective IARC data for Croatia (with a relatively low population) show an even higher mortality rate of 91.3 % for both sexes in the year 2012, but due to the use of relative rates for calculation they cannot directly be aggregated to EU-28.Therefore, the EU-27 parameter is used.

*Implementation of a price adjuster*

In this SEA, costs and benefits are made comparable by basing them to the year of the sunset date (the sunset date is used as the reference year for all cost estimations of the SEA). Therefore, health risks as well as additional costs relating to the continued use of chromium trioxide in case of the authorisation are based to the year of the sunset date.

To adjust the values to the base year, these values are multiplied by a price adjuster, which is the appropriate price index of the reference year divided by the appropriate price index of the year 2010. When using as appropriate price index the GDP deflator of the EU-28 issued by the statistical office of the European Union (EUROSTAT), complete data could be gathered up to the year 2015. The quarterly deflator is calculated from seasonally adjusted GDP values and rescaled so that 2010 equals 100. For 2015, which is the last year with complete data sets, the deflators of the 4 quarters range from 108.0 (first quarter) to 109.4 (fourth quarter), with an arithmetic mean of 108.9 for the 4 quarters.[10] A price index development from 100.0 (in 2010 as the starting point where the index is based on) up to 108.9 in 2015 is equivalent to an **average annual growth factor of 1.017** (geometric mean over 5 years from 2010 to 2015). We assume that in the average the calculated rate of price increase will continue in future from 2015 up to the reference year; therefore, the factor of **1.017 per year** is applied to extrapolate the price index development into the future, i.e. between 2015 and the reference year.

[10] Source: http://ec.europa.eu/eurostat/tgm/table.do?tab=table&plugin=1&language=en&pcode=teina110 [Cited: 24 August 2015]. Note that earlier versions of this EUROSTAT source still used an index based on the year 2000 = 100, which was the basis for the calculations in previous SEA documents.

**Table 30: Monetary values for VSL and VCM, based on ECHA review from 2016 (ECHA, 2016)**

| | **Lower bound** | **Upper bound** |
|---|---|---|
| Value of statistical life (VSL) for cancer (2012) | EUR 3 500 000 | EUR 5 000 000 |
| Value of cancer morbidity (VCM) | EUR 410 000 | EUR 410 000 |
| Adjusting the 2012 values to the year of the sunset date (2017) | $1.017^{\text{sunset year – 2012}}$ | $1.017^{\text{sunset year – 2012}}$ |
| Value of statistical life (VSL) for cancer (2017) | EUR 3 807 788 | EUR 5 439 698 |
| Value of cancer morbidity (VCM) (2017) | EUR 446 055 | EUR 446 055 |

*Calculation of an additional cancer case based on adjusted VSL and VCM values*

The value for one additional lung cancer case (fatal and non-fatal) is calculated by the following equation:

**Value of a lung cancer case =** $(\mathbf{1}+\boldsymbol{i})^{-\boldsymbol{l}} \times \left(\boldsymbol{VSL} + \left(\left(\mathbf{1}+\frac{(\mathbf{1}-\boldsymbol{f})}{\boldsymbol{f}}\right) \times \boldsymbol{VCM}\right)\right)$

with

$\boldsymbol{i}$ being the discount rate (considered to be **4% a year** as recommended by ECHA in the SEA guidance (ECHA, 2011))

$\boldsymbol{l}$ being the latency period (assumed to be **10 years for lung cancer** as done in the ECHA review from 2016 (ECHA, 2016))

$\boldsymbol{f}$ being the fatality rate of the cancer type (assumed to be **82.8 % for lung cancer** in EU-27 (Nadler & Zurbenko, 2014))

Taking into account the VSL (lower and upper bounds) and VCM values as adjusted for 2017 and following the formula and assumptions described above, the values of one additional lung cancer case[11] (lower and upper bounds) amount to **EUR 2 936 341 and EUR 4 038 801.**

*Individual ELR per WCS*

[11] This value includes, in addition to the fatal case, the share of non-fatal lung cancer cases occurring per one fatal lung cancer case.

In order to monetise the excess risk (i.e. additional fatal lung cancers) relating to the authorisation of the continued use of chromium trioxide, first the excess risk is calculated according to the following equation:

$$ELR = \frac{review\ period\ [years]}{40\ years} \times \frac{working\ days\ per\ year}{260\ days} \times \text{ 4E-03 per } \frac{\mu\text{g Cr(VI)}}{\text{m}^3} \times \text{ concentration } \left[\frac{\mu\text{g Cr(VI)}}{\text{m}^3}\right]$$

where

$$\text{concentration } \left[\frac{\mu\text{g Cr(VI)}}{\text{m}^3}\right]$$

represents the Cr(VI) concentration taken from the ES in the CSR.

As already mentioned before, the correction factor for working days is only applied where necessary.

*Total ELR over all WCSs and workers*

The calculation of the excess risk (i.e. additional fatal lung cancers) over all employees potentially exposed is calculated per WCS by multiplying the individual excess risk with the respective number of workers potentially exposed. Then, the excess risk of all WCS are summed up. Thus, the estimated amount of additional fatal lung cancers is the expected value due to a continued use of Cr(VI) for the respective time frame allowed by an authorisation up to the next revision.

$$\sum_{i=1}^{n} (\boldsymbol{ELR_i} \times \boldsymbol{number\ of\ workers_i})$$

i = WCS

*Monetisation of the total ELR*

In the next step, the monetisation of the total ELR is done by multiplying the total ELR value by the value of <u>one additional lung cancer case (fatal and non-fatal)</u>.

Following this methodology, the actual assessment of health impacts related to the authorisation of the continued use of chromium trioxide is conducted in **ANNEX B**.

**<u>Note:</u>** The monetisation approach suggested in the ECHA review from 2016 (ECHA, 2016) was not fully adopted in the present assessment because it does not match with the available dose-response relationship for inhalation exposure to hexavalent chromium (ECHA, 2013). The dose-response relationship for lung cancer made available by ECHA refers to an excess lifetime lung cancer **mortality**

**risk** while the monetisation approach suggested in the review from 2016 (ECHA, 2016) deals with a dose-response relationship referring to **cancer (incidence) risk.** In the case where the dose-response relationship refers to a mortality risk, the monetisation approach must additionally account for the cancer cases which did not end up in death of the patient, as it is done in the present assessment.

### A.1.2. Quantitative health impact assessment of the general population

According to ECHA Guidance on information requirements and chemical safety assessment Chapter R.16: Environmental exposure estimation, version 2.1, October 2012 (ECHA Guidance R.16) (ECHA, n. d.), potential exposure via the environment should be assessed on 2 spatial scales: locally in the vicinity of point sources of release to the environment, and regionally for a larger area which includes the point source or all point sources in that area. Releases at the continental scale are not used as endpoints for exposure. The end results of the exposure estimation are predicted environmental concentrations (PECs) in the environmental compartments for both local and regional scale which have been calculated in the ES.

As noted in the EU risk assessment report (RAR) for Cr(VI) substances (European Chemicals Bureau, 2005), "releases of Cr(VI) from any sources are expected to be reduced to Cr (III) in most situations in the environment (…)" and "the impact of Cr(VI) as such is therefore likely to be limited to the area around the source." (p. 26). For this reason, the aforementioned EU RAR for Cr(VI) substances set the focus of its assessment on the local impacts of the emissions.

Such understanding about the impacts of Cr(VI) being limited to the area around the source has been shared by RAC in previous opinions such as in the opinion on the AFA-O-0000006480-78-01/D (ECHA, 2016), where it is stated: "Cr(VI) is effectively reduced to Cr(III) in the environment, which is why EU RAR concluded that the regional exposure may not be relevant. RAC agrees with EU RAR that regional exposure is likely not to be very relevant." (p. 35).

Given this background, the present SEA considers the regional exposure of MVE as not relevant and focuses its assessment on the local exposure of MVE.

The local Predicted Environmental Concentration (= MVE local), based on modelled data, is used to calculate potential risks for on-site workers not directly exposed as well as the direct neighbourhood. The respective value for MVE oral provided in the CSR has been taken as a basis for calculation of impacts resulting from oral uptake via the food chain.

*MVE local*

The local exposure assessment considers workers that do not work with Cr(VI), but work in the vicinity (potentially indirectly exposed workers) as well as people living in the direct neighbourhood of the sites. As a default number recommended as the basis of the local exposure assessment in the ECHA

Guidance R.16 (ECHA, n. d.), the total number of people potentially exposed on a local scale is estimated in 10 000 per site using Cr(VI).

As a worst-case scenario, the exposure concentration used for the risk assessment of the whole group of people is the $PEC_{local}$ independent from the distance from the emitting source.

Since there is no basis for a reliable distinction between the number of potentially indirectly exposed workers and people living in the neighbourhood, the dose-response curve for the general population is taken as a basis following the worst-case approach, i.e. workers would be exposed for less time, e.g. 8 hours per day for 260 days, than the general population (24 hours per day for 365 days of exposure).

Table 31 summarises the most important input parameters.

**Table 31: Overview of the most important input parameters for calculation of health impacts for MVE**

| **Exposure concentration** | **Group of potentially exposed people** | **Number of potentially exposed people** | **Dose-response curve for** |
|---|---|---|---|
| $PEC_{local}$ | Potentially indirectly exposed workers and direct neighbourhood per site | 10 000 | General population |

**Estimation of additional cancer cases in relation to baseline**

In addition to inhalation exposure to Cr(VI) via the environment, for the general population oral exposure to Cr(VI) via the food chain is also taken into respect, which leads to an additional risk of small intestine cancer. Dose-response relationships, but also fatality rates and latency times and therefore monetary valuation of cancer cases are different for small intestine cancer than for lung cancer. The dose-response relationship for Cr(VI) with regard to lung and small intestine cancer for the general population has been discussed in recent research published by ECHA (ECHA, 2013).

Linear exposure-risk relationship for lung cancer as estimated by ECHA (ECHA, 2013):

$$Unit\ excess\ lifetime\ risk = 2.9\text{E-}02\ per\ \mu g\ Cr(VI)/m^3$$

Linear exposure-risk relationship for small intestine cancer as estimated by ECHA (ECHA, 2013):

$$Unit\ excess\ lifetime\ risk = 8\text{E-}04\ per\ \mu g\ Cr(VI)/kg\ bw/day$$

It has to be emphasised that for small intestine cancer the dose-response relationship refers to the incidence and not to fatality of cancer, unlike for lung cancer. According to the ECHA document

(ECHA, 2013), the term used is '*excess lifetime intestinal cancer risk*'. This signifies that the dose-response function developed refers to additional intestinal cancers ending either fatal or non-fatal. In this study, data on cancer incidence, not cancer mortality have been taken into account for the estimation of the dose-response relationship. This will be included in step 4 of this methodology (the monetary valuation of fatal and non-fatal cancer risks).

*Adaption factor*

The dose-response curve for the general population considers 365 days of exposure and 70 years of life-time. Accordingly, it is necessary to adjust the exposure duration to the foreseen review period of 21 years by the factor 21/70.

**Estimation of average fatality rates in %, based on empirical data from EU-27**

As explained in Chapter A.1.1 of ANNEX A, the individual development of cancer diseases may be fatal or non-fatal. The fatality rate is an important parameter for a monetary-based valuation of cancer risks.

As stated above the reference dose-response relationship for lung cancer estimates the fatal cancer risks, whereas the reference dose-response relationship for small intestine cancer estimates both fatal and non-fatal cancer risks.

According to IARC the average mortality rates for lung and intestinal cancer in the EU-27 are 82.8 % and 39.7 %, respectively, for both sexes (IARC, Lung cancer including trachea and bronchus. Estimated incidence, mortality & prevalence for both sexes, 2012, n. d.) and (IARC, Cancer of the large bowel. Estimated incidence, mortality & prevalence for both sexes, 2012, n. d.), i.e. intestinal cancer has a more favourable survival prognosis than lung cancer. This value will be used for further analyses in this SEA.[12]

**Monetary valuation of additional cancer cases**

Analogous to the approach in Chapter A.1.1 of ANNEX A, the additional cancer cases are evaluated in monetary terms. As stated before, the average mortality rate for lung cancer and intestinal in the European Union (EU) are 82.8 % and 39.7 %, respectively.

[12] In these figures of EU-27, Croatia is not yet included. Due to the use of relative rates for calculation they cannot directly be aggregated to EU-28.Therefore, the EU-27 parameter is used.

*MVE local*

*Individual ELR lung cancer (local):*

$$ELR = \frac{review\ period\ [years]}{70\ years} \times 2.9\text{E-}02 \text{ per } \frac{\mu\text{g Cr(VI)}}{\text{m}^3} \times \text{ MVE local inhalation}$$

*Individual ELR intestinal cancer (local):*

$$ELR = \frac{review\ period\ [years]}{70\ years} \times 8.0\text{E-}04 \text{ per } \frac{\mu\text{g Cr(VI)}}{\text{kg bw/day}} \times \text{ MVE local oral}$$

where MVE local represents the predicted local environmental Cr(VI) concentration taken from the ES in the CSR.

*Total ELR*

For the calculation of the total ELR related to MVE local, the total number of potentially indirectly exposed people is assessed taking into account the foreseen population potentially exposed around each site as described above.

The calculation of the total excess risk follows the methodology described in Chapter A.1 of ANNEX A according to the following equations:

*ELR lung cancer (local):*

$$ELR = \frac{review\ period\ [years]}{70\ years} \times 2.9\text{E-}02 \text{ per } \frac{\mu\text{g Cr(VI)}}{\text{m}^3} \times \text{ MVE local inhalation} \\ \times \text{number of people potentially exposed}$$

*ELR intestinal cancer (local):*

$$ELR = \frac{review\ period\ [years]}{70\ years} \times 8.0\text{E-}04 \text{ per } \frac{\mu\text{g Cr(VI)}}{\text{kg bw/day}} \times \text{ MVE local oral} \\ \times \text{number of people potentially exposed}$$

*Monetisation of an additional cancer case based on adjusted VSL and VCM values*

Due to differences in the dose-response relationships of lung cancer and small intestine cancer (the first relationship measures mortality risk while the second calculates cancer risk), the monetisation of total ELR for each of the cancer types is done using different equations.

The monetised value for one additional lung cancer case (fatal and non-fatal) is calculated in the same way as described above for worker exposure and therefore ranges between **EUR 2 936 341 and EUR 4 038 801**[13]**.**

In regards to small intestine cancer, the monetised value for one additional small intestine cancer case (ending fatal or non-fatal) is calculated following the same approach described in the ECHA review from 2016 (ECHA, 2016):

**Value of cancer case = Discount factor x (fatality probability x VSL x VCM)**

or

$$(\mathbf{1}+\boldsymbol{i})^{-\boldsymbol{l}} \times (\boldsymbol{f} \times \boldsymbol{VSL} + \boldsymbol{VCM})$$

with

$i$ being the discount rate (considered to be **4% a year** as recommended by ECHA in the SEA guidance

$l$ being the latency period (assumed to be **26 years for small intestine cancer** (Nadler & Zurbenko, 2014))

$f$ being the fatality rate of the cancer type (assumed to be **39.7 % for intestinal cancer** in EU-27 (IARC, Cancer of the large bowel. Estimated incidence, mortality & prevalence for both sexes, 2012, n. d.))

Considering the VSL (lower and upper bounds) and VCM values as adjusted for 2017, the values of one additional small intestine cancer case (lower and upper bounds) amount to **EUR 706 138 and EUR 939 817**.

*Monetisation of total ELR*

In the next step, the monetisation of the ELR regarding general population exposure is done by multiplying the ELR value by the value of one additional cancer case (lung or small intestine cancer separately, according to the ELR calculated).

Following this methodology, the actual assessment of health impacts related to the authorisation of the continued use of chromium trioxide is conducted in **ANNEX B**.

[13] This value includes, in addition to the fatal case, the share of non-fatal lung cancer cases occurring per one fatal lung cancer case.

### A.1.3. Overestimation of the quantitative assessment

The overall calculation approach entails an overestimation of health impacts for the following reasons:

- The exposure estimates presented in the CSR are already worst case assumptions regarding frequency of activities (see CSR for more details).
- Applicants have been asked to provide worst case estimations for number of exposed workers. This means that for example workers not involved in relevant activities have nevertheless been counted in case there is a theoretical possibility that these workers enter respective areas.
- Taking into account that the MVE local air represents the concentration 100 m from the point source (considered to represent the average distance between the release source and the border of the industrial site), it is clear that in reality it is impossible that 10 000 people are exposed to concentrations calculated for MVE local air at the boundary of each site at which Cr(VI) is used. It can reasonably be inferred that the majority of the population is located much more than 100 m from the point source. Therefore, the majority of the local population is exposed to concentrations much lower than the estimated concentration 100m from the point source. This is because the concentration of Cr(VI) is decreasing with increasing distance from the emission source. However, for the calculations in the SEA all of these people have been assumed to be exposed at exposure rates as predicted 100m from the stack (MVE local). Differently spoken, all the potentially exposed local population have been assumed to be located only 100m from the emission source, which results in a clear overestimation of impacts.
- Calculating the excess of risk evolving cancer for the general population on basis of the dose-response curve published by ECHA (ECHA, 2013) assumes a linear relationship between dose and response, even at low doses (below 0.1 µg/m$^3$). The ETeSS study ((ETeSS), 2013) which was the basis for the dose-response curve published by ECHA (ECHA, 2013) itself recognises that a linear dose response relationship for carcinogenicity of Cr(VI) is not established below 1ug/m$^3$. The study conducted by ETeSS on behalf of ECHA clearly states that: '[…] the lower the exposure (certainly below 1µg/m3), the more likely it is that the linear [dose-response] relationship overestimates the cancer risk.' The study further states that 'the risk estimates for […] exposures lower than 1 µg Cr(VI)/m$^3$ might well greatly overestimate the real cancer risks. It is also considered that at progressively lower Cr(VI) air concentrations (from about 0.1 µg/m$^3$ downwards), cancer risks may be negligible.' The $MVE_{local}$ 100m from the point source considered in the CSR/SEA is 7.36E-04 µg/m$^3$ and 4.68E-03 µg/m$^3$ , respectively and therefore approximately 136/21 times lower than the concentration from where the ETeSS study states that cancer risks may be negligible.

- For the calculation of health impacts for the local population, the respective dose response relationship provided by RAC has been used. This dose response curve is based on the estimation that exposure occurs 365 days a year and 24 h a day. In reality, the local population is not present in the relevant area every day a year for full 24 h. For example, people leave the area for 8 h a day in case their work places are located somewhere else or go on holidays for several days a year. The dose response function has not been corrected and therefore over-estimates risk based on inflated assumptions about exposure frequency and duration.

- On-site workers usually live in the direct neighbourhood or in the surrounding area. Therefore, a double counting appears when calculating health impacts for on-site workers and the local population.

In general, an assessment of man via the environment is a requirement of application for authorisation. The assessment was based on clearly worst case assumptions in order to avoid criticism that the health impacts are under-estimated. These assumptions were made only for the purpose of this SEA and the outcome of the assessment should not be taken out of context.

# ANNEX B - HEALTH IMPACT ASSESSMENT

## B.1 Number of potentially exposed people

Table 32 provides the relevant number of potentially exposed workers at ZF, potentially indirectly exposed workers and the potentially exposed general population which is considered for the exposure route Man via the Environment (MVE).

**Table 32: Number of people potentially exposed**

| | |
|---|---|
| Industrial workers at the relevant ZF sites | <98 [redacted][14] |
| Potentially indirectly exposed workers and direct neighbourhood ($PEC_{local}$) | 20 000 |

The human health impact assessment in the following chapter is based on the methodology suggested by ECHA and described in Chapter A.1 of ANNEX A.

## B.2 Calculation of health impacts

Following the methodology described in Chapter A.1 of ANNEX A, the monetised health impacts for the continued use of surface treatment with chromium trioxide at ZF's production sites are given in Table 33.

[14] Worst case assuming the unrealistic situation that every WCS is conducted by different workers

**Table 33: Activities (WCSs) and resulting ELRs Schweinfurt**

| WCS | Exposure estimate (CSR) [µg Cr(VI)/m³] | ELR | Factor to adjust to review period | ELR adjusted to review period | Max. number of potentially exposed workers | Max. ELR for potentially exposed workers (adjusted to frequency and review period) | Value [EUR] upper bound |
|---|---|---|---|---|---|---|---|
| 1 | 0.00E+00 | 0.0E+00 | 0.525 | 0.0E+00 | [redacted] | [redacted] | [redacted] |
| 2 | 3.80E-01 | 4.4E-03 | 0.525 | 2.3E-03 | [redacted] | [redacted] | [redacted] |
| 3 | 3.30E-01 | 3.8E-03 | 0.525 | 2.0E-03 | [redacted] | [redacted] | [redacted] |
| 4 | 7.10E-03 | 2.7E-05 | 0.525 | 1.4E-05 | [redacted] | [redacted] | [redacted] |
| 5 | 1.40E-01 | 1.1E-04 | 0.525 | 5.9E-05 | [redacted] | [redacted] | [redacted] |
| 6 | 1.00E-01 | 3.8E-04 | 0.525 | 2.0E-04 | [redacted] | [redacted] | [redacted] |
| 7 | 7.00E-03 | 1.3E-06 | 0.525 | 6.8E-07 | [redacted] | [redacted] | [redacted] |
| 8 | 2.30E-03 | 8.8E-06 | 0.525 | 4.6E-06 | [redacted] | [redacted] | [redacted] |
| | | | | | | | [redacted] |

**Table 34: Activities (WCSs) and resulting ELRs Eitorf**

| WCS | Exposure estimate (CSR) [µg Cr(VI)/m³] | ELR | Factor to adjust to review period | ELR adjusted to review period | Max. number of potentially exposed workers | Max. ELR for potentially exposed workers (adjusted to frequency and review period) | Value [EUR] upper bound |
|---|---|---|---|---|---|---|---|
| 1 | 0.00E+00 | 0.0E+00 | 0.525 | 0.0E+00 | [redacted] | [redacted] | [redacted] |
| 2 | 3.80E-01 | 4.4E-03 | 0.525 | 2.3E-03 | [redacted] | [redacted] | [redacted] |
| 3 | n/a | n/a | n/a | n/a | [redacted] | [redacted] | [redacted] |
| 4 | 7.10E-03 | 5.7E-06 | 0.525 | 3.0E-06 | [redacted] | [redacted] | [redacted] |
| 5 | 1.40E-01 | 1.1E-04 | 0.525 | 5.9E-05 | [redacted] | [redacted] | [redacted] |
| 6 | 1.00E-01 | 3.8E-04 | 0.525 | 2.0E-04 | [redacted] | [redacted] | [redacted] |
| 7 | 7.00E-03 | 1.3E-06 | 0.525 | 6.8E-07 | [redacted] | [redacted] | [redacted] |
| 8 | 2.30E-03 | 8.8E-06 | 0.525 | 4.6E-06 | [redacted] | [redacted] | [redacted] |
| | | | | | | | [redacted] |

See Table 35 for description of the activities carried out in the respective WCS.

**Table 35: Activities (WCSs) relevant for potential worker exposure**

| WCS | Activity |
|---|---|
| 1 | Delivery and storage of raw material |
| 2 | Encapsulated plating line, closed process |
| 3 | semi-closed plating process |
| 4 | sampling |
| 5 | concentration adjustment |
| 6 | regular maintenance |
| 7 | rare maintenance |
| 8 | waste and wastewater management |

Based on the value for the total ELR which is calculated according to the following equation and a review period of 21 years (see Table 33),

$$ELR = \frac{21\ years}{40\ years} \times 4\text{E-03}\ per\ \frac{\mu g\ Cr(VI)}{\text{m}^3} \times concentration \left[\frac{\mu g\ Cr(VI)}{\text{m}^3}\right]$$

the equation for the calculation of the monetised health impacts for workers at ZF is as follows

$$monetary\ value\ for\ fatal\ and\ non-fatal\ cancers = ELR \times value\ of\ one\ additional\ lung\ cancer\ case$$

As described in Chapter A.1 of ANNEX A, the value of one additional lung cancer case is calculated to range between EUR 2 936 341 and EUR 4 038 801.

Table 36 summarises the monetised impacts derived from the equations above for workers potentially exposed to chromium trioxide at ZF when continuing the use of the substance for chrome plating of piston rods. The analysis is based on a review period of 21 years. Following the worst-case approach by applying upper bound number of potentially exposed people at the ZF sites.

**Table 36: Monetised health impacts for potentially exposed workers at 2 company sites**

| Group of potentially exposed people | Monetised value [lower bound EUR] | Monetised value [upper bound EUR] |
|---|---|---|
| Workers | 119 027 | 198 804 |

**Potentially exposed population 'man via environment'**

The applied methodology and main underlying assumptions are given in Chapter A.1.2 of ANNEX A. The calculations are provided for $MVE_{local}$ and follow generally the calculations presented for the health impact assessment of potentially exposed workers. It should be noted that the following calculations are based on worst-case assumptions and therefore have to be regarded as overestimated (see Chapter A.1.3 of ANNEX A). Additionally, there is uncertainty about the dose-response curve at very low exposure values. The linear dose-response curve recommended by RAC might be too conservative for this exposure level (see Chapter A.1 of ANNEX A for further information).

**MVE $_{local}$**

With the exposure values for $PEC_{local}$ provided by the CSR a the further calculation follows the methodology described in Chapter A.1.2 of ANNEX A:

The excess risk is calculated according to the following equations:

$$ELR\ lung\ cancer = \frac{review\ period\ [years]}{70\ years} \times 2.9\text{E-02 per } \frac{\mu\text{g Cr(VI)}}{\text{m}^3} \times \text{PEC}_{\text{local,inhalation}} \times \text{number of people potentially exposed}$$

$$ELR\ intestinal\ cancer = \frac{review\ period\ [years]}{70\ years} \times 8\text{E-04 per } \frac{\mu\text{g Cr(VI)}}{\text{m}^3} \times \text{PEC}_{\text{local,inhalation}} \times \text{number of people potentially exposed}$$

In a second step, the monetised value for additional cancer cases are again calculated by multiplication of the ELR with the WTP value adjusted to the year of the sunset date:

$$monetary\ value\ for\ fatal\ and\ non-fatal\ \ cancers = ELR\ \times value\ of\ one\ additional\ cancer\ case$$

For one additional small intestine cancer case, the value varies from EUR 706 138 (lower bound) and EUR 939 817 (upper bound).

Table 37 shows the monetary value for health impacts for $MVE_{local}$.

**Table 37: Monetised potential health impacts for MVElocal**

| General population - local | Lower bound [EUR] | Upper bound [EUR] |
|---|---|---|
| $PEC_{local, inhalation}$ | 0 | 2 310 905 |
| $PEC_{local, oral}$ | 0 | 425 |
| **Total** | **0** | **2 311 330** |

## B.3 Summary

Table 38 provides a summary of total health impacts for workers and the general population related to the use of chromium trioxide at ZF facilities.

**Table 38: Summary table – monetised potential health impacts**

| Type of potentially exposed population | Lower bound [EUR] | Upper bound [EUR] |
|---|---|---|
| Potentially exposed workers | 119 027 | 198 804 |
| Potentially indirectly exposed workers and direct neighbourhood ($PEC_{local, inhalation}$ and $PEC_{local, oral}$) | 0 | 2 311 330 |
| **Total** | **119 027** | **2 510 133** |

# ANNEX C – OTHER ZF SUSPENSION TECHNOLOGY FACILITIES

## C.1 Other ZF suspension technology facilities in the EEA

- **Ahrweiler (Germany)**

The facility in Ahrweiler employs [redacted] workers (including temporaries) and in 2015 had sales amounting to around EUR [redacted]. Twintube shock absorbers and suspension struts (approximately [redacted]) are the products manufactured in Ahrweiler, see Figure 38.

**Figure 38: Suspension struts produced at the facility in Ahrweiler**

- **Candiolo (Italy)**

The facility in Candiolo generated approximately EUR [redacted] in sales in 2015 while employing [redacted] people (including temporaries). Around [redacted] parts a day in shock absorbers and suspension forks, both for motorcycles, are produced at the site (see Figure 39).

**Figure 39: Shock absorber and suspension forks for motorcycles produced at the facility in Candiolo**

- **Levice (Slovakia)**

[redacted]

- **Lezama (Spain)**

[redacted]

**Figure 40: Monotube shock absorbers/systems produced at the facility in Lezama**

## C.2 Suspension technology business locations outside the EEA

Besides the locations in EEA, the ZF business unit of suspension technologies is also present in Turkey, China, South Korea and Mexico. The facility in Argentina, despite being part of the business unit CV damper technology (T-division), also produces twintube shock absorbers and suspension struts. A brief description of those facilities is available in the table below.

**Table 39: Suspension technology business locations outside the EEA**

| Location | General description | Products |
|---|---|---|
| [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] |
| [redacted] | [redacted] | [redacted] |

*Including temporary workers

# ANNEX D – Information on substances used in alternatives

## D.1 ALTERNATIVE 1: Case hardening (nitrocarburizing)

**Table 40: Substance IDs and physicochemical properties of Alternative 1**

| **Parameter** | **Value** | **Physicochemical properties** | **Value** |
|---|---|---|---|
| Chemical name and composition | Carbon monoxide (mono constituent substance) | Physical state at 20°C and 101.3 kPa | Gaseous (odourless) |
| EC number | 211-128-3 | Melting point | -199°C |
| CAS number | 630-08-0 | Density | 1.18 g/cm³ |
| IUPAC name | Carbon monoxide | Vapour pressure | 20,664,910 hPa (at 25°C) |
| Molecular formula | CO | Water solubility | 21.4 ml/L (at 25°C) |
| Molecular weight | 28.01 g/mol | Flammability<br><br>Flash Point: | ≥ 10.9 % lower flammability limit in air<br>≥ 77.6% upper explosion limit<br>- |
| **Parameter** | **Value** | **Physicochemical properties** | **Value** |
| Chemical name and composition | Ammonia (mono constituent substance) | Physical state at 20°C and 101.3 kPa | Gaseous (colourless, irritating) |
| EC number | 231-635-3 | Melting point | -77.7°C |
| CAS number | 7664-41-7 | Density | - |
| IUPAC name | ammonia | Vapour pressure | 8,611 hPa (at 20°C) |
| Molecular formula | $NH_3$ | Water solubility | 482 g/L (at 25°C) |
| Molecular weight | 17.03 g/mol | Flammability<br><br>Flash Point: | ≥ 16% Lower explosion limit<br>≥ 25% upper explosion limit<br>- |
| **Parameter** | **Value** | **Physicochemical properties** | **Value** |
| Chemical name and composition | Nitrogen | Physical state at 20°C and 101.3 kPa | Colourless gas |
| EC number | 231-783-9 | Melting point | -210.0 °C |
| CAS number | 7727-37-9 | Density | 1.145 g/L |
| IUPAC name | nitrogen | Vapour pressure | - |
| Molecular formula | $N_2$ | Water solubility | Slightly soluble |
| Molecular weight | 28.013 g/mol | Flammability<br>Flash Point: | Non flammable<br>- |

**Table 41: Hazard classification and labelling of Alternative 1**

| Substance Name | Hazard Class and Category Code(s) | Hazard Statement Code(s) (labelling) | Number of Notifiers | Additional classification and labelling comments | Regulatory and CLP status |
|---|---|---|---|---|---|
| Carbon monoxide (CAS 630-08-0) (EC 211-128-3) | Flam. Gas 1 | H220 (extremely flammable gas) | 462 | | Harmonised Classification- Annex VI of Regulation (EC) No 1272/2008 (CLP Regulation). Index Number: 006-001-00-2 |
| | Press. Gas (Comp.) | H280 (may explode if heated) | 289 | | |
| | Acute Tox. 3 | H331 (toxic if inhaled) | 458 | | |
| | Repr. 1A | H360 (may damage fertility or the unborn child) | 462 | | |
| | STOT RE 1 | H372 (causes damage to organs) | 462 | | |
| Ammonia (CAS 7664-41-7) (EC 231-635-3) | Flam. Gas 2 | H221 (flammable gas) | 2454 | | Harmonised Classification- Annex VI of Regulation (EC) No 1272/2008 (CLP Regulation). Index Number: 007-001-00-5 |
| | Flam. Liq. 3 | H226 (flammable liquid and vapour) | 20 | | |
| | Press. Gas (Comp.) | H280 (may explode if heated) | 1170 | | |
| | Acute Tox. 3 | H301 (toxic if swallowed) | 355 | | |
| | Acute Tox. 4 | H302 (harmful if swallowed) | 15 | | |
| | Asp. Tox. 1 | H304 (may be fatal if swallowed and enters airways) | 1 | | |
| | Skin Corr. 1B | H314 (causes severe skin burns and eye damage) | 2463 | | |
| | Eye. Dam. 1 | H318 (causes serious eye damage) | 518 | | |
| | Acute Tox. 2 | H330 (fatal if inhaled) | 377 | | |
| | Acute Tox. 3 | H331 (toxic if inhaled) | 2084 | | |
| | STOT SE 3 | H335 (may cause respiratory irritation) | 375 | | |
| | STOT SE 3 | H336 (may cause drowsiness or dizziness) | 5 | | |
| | Aquatic Acute 1 | H400 (very toxic to aquatic life) | 2462 | | |

| Substance Name | Hazard Class and Category Code(s) | Hazard Statement Code(s) (labelling) | Number of Notifiers | Additional classification and labelling comments | Regulatory and CLP status |
|---|---|---|---|---|---|
| | Aquatic Chronic 1 | H410 (very toxic to aquatic life with long-lasting effects) | 157 | | |
| | Aquatic Chronic 2 | H411 (toxic to aquatic life with long-lasting effects) | 235 | | |
| Nitrogen (CAS 7727-37-9; EC: 231-783-9) | Press. Gas. | H280 (may explode if heated) | 409 | Additional notifications are available | Substance is not REACH registered. Not included in the CLP Regulation, Annex VI; Included in C&L inventory |
| | Press. Gas. | H281 (may cause cryogenic burns or injury) | 191 | | |
| | Skin Irrit. 2 | H315 (causes skin irritation) | 1 | | |
| | Eye Irrit. 2 | H319 (causes serious eye irritation) | 1 | | |
| | Acute Tox. 4 | H332 (harmful if inhaled) | 1 | | |
| | STOT SE 3 | H335 (may cause respiratory irritation) | 1 | | |
| | Muta. 1B | H340 (may cause genetic defects) | 1 | | |
| | Carc. 1A | H350 (may cause cancer) | 1 | | |

## D.2 ALTERNATIVE 2: Physical Vapour Deposition (PVD)

**Table 42: Substance ID and physicochemical properties of Alternative 2**

| **Parameter** | **Value** | **Physicochemical properties** | **Value** |
|---|---|---|---|
| Chemical name and composition | Titanium nitride | Physical state at 20°C and 101.3 kPa | Solid (brown) |
| EC number | 247-117-5 | Melting point | 2,930 °C |
| CAS number | 25583-20-4 | Density | 5.90 g/cm³ |
| IUPAC name | Titanium nitride | Vapour pressure | - |
| Molecular formula | TiN | Water solubility | Insoluble |
| Molecular weight | 61.87 g/mol | Flammability<br>Flash Point | Non flammable<br>- |
| **Parameter** | **Value** | **Physicochemical properties** | **Value** |
| Chemical name and composition | Titanium carbide | Physical state at 20°C and 101.3 kPa | Solid, crystalline (dark grey) |
| EC number | 235-120-4 | Melting point | 3067 °C |
| CAS number | 12070-08-5 | Density | 4.93 g/cm³ |
| IUPAC name | - | Vapour pressure | - |
| Molecular formula | TiC | Water solubility | Insoluble |
| Molecular weight | 59.89 g/mol | Flammability<br>Flash Point | Non flammable<br>- |
| **Parameter** | **Value** | **Physicochemical properties** | **Value** |
| Chemical name and composition | Nitrogen | Physical state at 20°C and 101.3 kPa | Colourless gas |
| EC number | 231-783-9 | Melting point | -210.0 °C |
| CAS number | 7727-37-9 | Density | 1.145 g/L |
| IUPAC name | nitrogen | Vapour pressure | - |
| Molecular formula | $N_2$ | Water solubility | 0.018 mg/L (20 °C) |
| Molecular weight | 28.013 g/mol | Flammability<br>Flash Point: | Non flammable<br>- |
| **Parameter** | **Value** | **Physicochemical properties** | **Value** |
| Chemical name and composition | Methane | Physical state at 20°C and 101.3 kPa | gaseous |
| EC number | 200-812-7 | Melting point | -182.47 °C |
| CAS number | 74-82-8 | Density | 0.423 g/cm³ |
| IUPAC name | methane | Vapour pressure | - |
| Molecular formula | $CH_4$ | Water solubility | 24.4 mg/L |

| Parameter | Value | Physicochemical properties | Value |
|---|---|---|---|
| Molecular weight | 16.04 g/mol | Flammability<br>Flash Point: | Extremely flammable<br>-161.5 °C |

**Table 43: Hazard classification and labelling of Alternative 2**

| Substance Name | Hazard Class and Category Code(s) | Hazard Statement Code(s) (labelling) | Number of Notifiers | Additional classification and labelling comments | Regulatory and CLP status |
|---|---|---|---|---|---|
| Titanium nitride<br>(CAS 25583-20-4)<br>(EC 247-117-5) | Not classified | | 12 | | Pre registered substance;<br>Notified Classification and labelling according to CLP criteria. |
| | Flam. Sol. 2 | H228 (flammable solid) | 53 | | |
| | Skin Irrit. 2 | H315 (causes skin irritation) | 10 | | |
| | Eye Irrit. 2 | H319 (causes serious eye irritation) | 10 | | |
| Titanium carbide (CAS<br>12070-08-5) | In REACH registrations no hazards have been classified | | | | Substance is not REACH registered. |
| Nitrogen<br>(CAS 7727-37-9;<br>EC: 231-783-9) | Press. Gas. | H280 (may explode if heated) | 335 | Additional notifications are available | Substance is not REACH registered.<br>Not included in the CLP Regulation, Annex VI;<br>Included in C&L inventory |
| | Ref. Liq. Gas. | H281 | 182 | | |
| | Liq. Gas | H280 (may explode if heated) | 41 | | |
| Methane (CAS 74-82-8; EC 200-812-7) | Flam. Gas 1 | H220 | 440 | | Notified Classification and labelling according to CLP criteria. |
| | Press. Gas (Liq. & Comp.) | H280 (may explode if heated) | 228 | | |
| | Press Gas (Ref. Liq.) | H281 | 76 | | |
| | STOT SE 3 | H336 | 27 | | |

## D.3 ALTERNATIVE 3: Plasma-enhanced Chemical Vapour Deposition (PE-CVD) - thin diamond like carbon (DLC) coatings

**Table 44: Substance ID and physicochemical properties of Alternative 3**

| Parameter | Value | Physicochemical properties | Value |
|---|---|---|---|
| Chemical name and composition | Acetylene | Physical state at 20°C and 101.3 kPa | Gaseous, organic, colourless |
| EC number | 200-816-9 | Melting point | -80.7 °C |
| CAS number | 74-86-2 | Density | 0.73 g/cm³ (-84 °C) |
| IUPAC name | acetylene | Vapour pressure | 4535 kPa (22 °C) |
| Molecular formula | $C_2H_2$ | Water solubility | 1200 mg/L (20 °C) |
| Molecular weight | 26.03728 g/mol | Flammability<br>Flash Point | Flammable<br>-18.15 ° C |

**Table 45: Hazard classification and labelling of Alternative 3**

| Substance Name | Hazard Class and Category Code(s) | Hazard Statement Code(s)<br>(labelling) | Number of Notifiers | Additional classification and labelling comments | Regulatory and CLP status |
|---|---|---|---|---|---|
| Acetylene (EC: 200-816-9; CAS: 74-86-2) | Press. Gas<br>Flam. Gas 1 | H220 | | | Harmonised Classification- Annex VI of Regulation (EC) No 1272/2008 (CLP Regulation).<br>Index Number: 601-015-00-0 |

## D.4 ALTERNATIVE 4: Trivalent Chrome Plating (including bi- and multilayer approaches)

**Table 46: Substance ID and physicochemical properties of Alternative 4**

| **Parameter** | **Value** | **Physicochemical properties** | **Value** |
|---|---|---|---|
| Chemical name and composition | Chromium trichloride hexahydrate | Physical state at 20°C and 101.3 kPa | Solid (green) |
| EC number | - | Melting point | 80-83°C |
| CAS number | 10060-12-5 | Density | - |
| IUPAC name | Chromium(III) chloride hexahydrate | Vapour pressure | - |
| Molecular formula | $CrCl_3 \cdot 6H_2O$ | Water solubility | 590 g/L (at 20°C) |
| Molecular weight | 266.45 g/mol | Flammability<br>Flash point | Non flammable<br>- |
| **Parameter** | **Value** | **Physicochemical properties** | **Value** |
| Chemical name and composition | Boric acid (mono constituent substance) | Physical state at 20°C and 101.3 kPa | Solid (crystalline, odourless) |
| EC number | 233-139-2 | Melting point | No melting point detected below 1,000°C |
| CAS number | 10043-35-3 | Density | 1.49 g/cm$^3$ |
| IUPAC name | Boric acid | Vapour pressure | 9.90 $^x$ 10$^{-8}$ kPa (25 °C) |
| Molecular formula | $B(OH)_3$ | Water solubility | 48.40 g/L (20°C, pH = 3.6) |
| Molecular weight | 61.83 g/mol | Flammability<br>Flash point | Non flammable<br>- |
| **Parameter** | **Value** | **Physicochemical properties** | **Value** |
| Chemical name and composition | Chromium potassium bi(sulphate) | Physical state at 20°C and 101.3 kPa | Solid (purple red) |
| EC number | - | Melting point | 89.0°C |
| CAS number | 7788-99-0 | Density | 1.83 g/cm$^3$ |
| IUPAC name | Chromium(3+) potassium sulfate hydrate (1:1:2:12) | Vapour pressure | - |
| Molecular formula | $CrKS_2O_8 \cdot 12\ H_2O$ | Water solubility | 250 g/L |
| Molecular weight | 499.4 g/mol | Flammability<br>Flash Point | Non flammable<br>- |
| **Parameter** | **Value** | **Physicochemical properties** | **Value** |
| Chemical name and composition | Formic acid (mono constituent substance) | Physical state at 20°C and 101.3 kPa | Liquid |
| EC number | 200-579-1 | Melting point | 4.0°C |
| CAS number | 64-18-6 | Density | 1.22 g/cm$^3$ (at 20°C) |

| Parameter | Value | Physicochemical properties | Value |
|---|---|---|---|
| IUPAC name | Formic acid | Vapour pressure | 42.71 hPa (20°C) |
| Molecular formula | $CH_2O_2$ | Water solubility | Miscible in any ratio |
| Molecular weight | 46.0 g/mol | Flammability<br>Flash Point | Flammable<br>49.5°C (at 1,013 hPa) |
| **Parameter** | **Value** | **Physicochemical properties** | **Value** |
| Chemical name and composition | Ammonium sulfamidate | Physical state at 20°C and 101.3 kPa | Solid (colourless) |
| EC number | 231-871-7 | Melting point | 131-135°C |
| CAS number | 7773-06-0 | Density | 1.00 g/cm$^3$ |
| IUPAC name | Ammonium sulphamate | Vapour pressure | - |
| Molecular formula | $H_6N_2O_3S$ | Water solubility | 1,666 g/L |
| Molecular weight | 114.12 g/mol | Flammability<br>Flash Point | Non flammable<br>- |
| **Parameter** | **Value** | **Physicochemical properties** | **Value** |
| Chemical name and composition | Ammonium chloride | Physical state at 20°C and 101.3 kPa | Solid (crystalline) |
| EC number | 235-186-4 | Melting point | 340°C (sublimation) |
| CAS number | 12125-02-9 | Density | 1.53 g/cm$^3$ (at 20°C) |
| IUPAC name | Ammonium chloride | Vapour pressure | - |
| Molecular formula | $NH_4Cl$ | Water solubility | 283 g/L (25°C) |
| Molecular weight | 53.5 g/mol | Flammability<br>Flash Point | Non flammable<br>- |

**Table 47: Hazard classification and labelling of Alternative 4**

| Substance Name | Hazard Class and Category Code(s) | Hazard Statement Code(s) (labelling) | Number of Notifiers | Additional classification and labelling comments | Regulatory and CLP status |
|---|---|---|---|---|---|
| Chromium trichloride hexahydrate (CAS 10060-12-5) | Acute Tox. 4 | H302 (harmful if swallowed) | 29 | | Substance is not REACH registered.<br>Not included in the CLP Regulation, Annex VI;<br>Included in C&L inventory |
| | Acute Tox. 4 | H312 | 1 | | |
| | | H314 | 2 | | |
| | Skin Irrit. 2 | H315 (causes skin irritation) | 32 | | |
| | | H317 | 2 | | |
| | Eye Irrit. 2 | H319 (causes serious eye irritation) | 32 | | |

| **Substance Name** | **Hazard Class and Category Code(s)** | **Hazard Statement Code(s) (labelling)** | **Number of Notifiers** | **Additional classification and labelling comments** | **Regulatory and CLP status** |
|---|---|---|---|---|---|
| | Acute Tox. 4 | H332 (harmful if inhaled) | 1 | | |
| | | H334 (may cause allergy or asthma symptoms or breathing difficulties if inhaled) | 2 | | |
| | STOT SE 3 | H335 (may cause respiratory irritation) | 32 | | |
| Boric acid<br>(CAS 10043-35-3;<br>EC 233-139-2) | Repr. 1B | H360FD | 155 | | Harmonised classification- Annex VI of Regulation (EC) No 1272/2008<br>Included in CLP Regulation, Annex VI (index number 005-007-00-2) |
| Chromium potassium bi(sulphate) dodecahydrate<br>(CAS 7788-99-0) | Skin Irrit. 2 | H315 (causes skin irritation) | 6 | | Pre-registered substance<br>Not included in the CLP Regulation, Annex VI;<br>Included in C&L inventory |
| | Eye Irrit. 2 | H319 (causes serious eye irritation) | 6 | | |
| Formic acid<br>(CAS 64-18-6<br>(EC 200-579-1) | Skin Corr 1A | H314 (causes severe skin burns and eye damage) | | Skin Corr. 1A; H314: C ≥ 90%<br>Skin Corr. 1B; H314: 10% ≤ C < 90%<br>Skin Irrit. 2; H315: 2% ≤ C < 10%<br>Eye Irrit. 2; H319: 2% ≤ C < 10% | Harmonised classification- Annex VI of Regulation (EC) No 1272/2008<br>Included in CLP Regulation, Annex VI (index number 607-001-00-0); |
| Ammonium sulphamidate<br>(CAS 7773-06-0)<br>(EC 231-871-7) | Acute Tox. 4 | H302 (harmful if swallowed) | 49 | | Pre-registered Substance<br>Not included in the CLP Regulation, Annex VI;<br>Included in C&L inventory |
| | Not classified | - | 46 | | |
| | Acute Tox. 4<br>Aquatic Acute 1 | H302 (harmful if swallowed)<br>H400 (very toxic to aquatic life) | 23 | | |
| Ammonium chloride<br>(CAS 12125-02-9)<br>(EC 235-186-4) | Acute Tox. 4 | H302 (harmful if swallowed) | | | Harmonised classification- Annex VI of Regulation (EC) No 1272/2008; Included in CLP Regulation, Annex VI (index number 017-014-00-8); |

# Appendix 1

[redacted]