ANALYSIS OF ALTERNATIVES

and

SOCIO-ECONOMIC ANALYSIS

Legal name of applicant(s):	APPH Ltd.
Submitted by:	APPH Ltd.
Date:	05.04.2023
Substance:	Chromium trioxide [CAS 1333-82-0; EC 215-607-8]
Use title:	Use of chromium trioxide for functional chrome plating of aircraft components for civil & military sectors that meet the airworthiness certification requirements and hydraulic components for military vehicles
Use number:	Use 1

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LIST OF ABBREVIATIONS

AoA	Analysis of Alternatives
ASTM	American Society for Testing and Materials
B	Billion
BAuA	German Federal Institute for Occupational Safety and Health
CAA	Civil Aviation Authority
CAGR	Compound annual growth rate
CAS	Chemical Abstracts Service
CLP	Regulation (Ec) No 1272/2008
Co	Cobalt
Cr	Chromium
Cr0	Zero valent chromium (metallic chromium)
CrIII	Trivalent chromium
CMM	Component Maintenance Manual
CrO_3	Chromium trioxide
CrVI	Hexavalent chromium
CSR	Chemical Safety Report
CVD	Chemical Vapour Deposition
DC	Direct current
DoD	The United States Department of Defense
DT&E	Developmental test and evaluation
DU	Downstream user
EASA	European Aerospace Safety Agency
ECHA	European Chemicals Agency
ECIS	European Cancer Information System
EEA	European Economic Area
EHLA	Extreme High-speed Laser Application
EU	European Union
EUSES	European Union System for the Evaluation of Substances
ESTCP	Environmental Security Technology Certification Program
FAIR	First Article Inspection Report
GB	Great Britain
GBP	British pound

HCAT	Hard Chrome Alternative Team
HICP	Harmonised Index of Consumer Prices
HD	Héroux-Devtek
HV	Vickers Hardness
#B [redacted]	[redacted]
HVOF	High Velocity Oxygen Fuel
ISO	International Organisation for Standards
JTP	Joint Test Protocol
k	Thousand
LRU	Line-replaceable unit
M	Million
MLG	Main Landing Gear
MOC	Means of Compliance
MoD	Ministry of Defense
MRL	Manufacturing Readiness Level
MRO	Maintenance, repair and overhaul
NADCAP	National Aerospace and Defense Contractors Accreditation Program
NASA	National Aeronautics and Space Administration
nCoP	Nanocrystalline cobalt-phosphorus
Ni	Nickel
NiII	Divalent nickel
NiP	Nickel-phosphorus
NLG	Nose Landing Gear
NSS	Neutral Salt Spray
NUS	Non-Use Scenario
O/D	Outside diameter
OE	Original equipment
OEM	Original equipment manufacturer
O&R	Overhaul and repair
OT&E	Operational test and evaluation
PEC	Predicted Environmental Concentration
PN	Part number
PVD	Physical Vapour Deposition
QPL	Qualified Products List

RAC	Committee for Risk Assessment
R&D	Research and Development
RC	Rockwell hardness scale
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RPE	Respiratory protective equipment
SAE	Society of Automotive Engineers
SAGA	Suitable alternative available in general
SEA	Socio-Economic Analysis
SEAC	Committee for Socio-Economic Analysis
SERDP	Strategic Environmental Research and Development Program
STP	Supplemental Type Certificate
SVHC	Substance of Very High Concern
TAT	Turnaround time
TBO	Time Between Overhauls
TRL	Technical Readiness Level
UK	United Kingdom
USD	United States dollar
VCM	Value of Cancer Morbidity
VSL	Value of Statistical Life
WCS	Worker contributing scenario
W	Tungsten
WC	Tungsten carbide

DECLARATION

The Applicant, APPH Ltd, is aware of the fact that further evidence might be requested by the UK HSE to support the information provided in this document.

Also, we request that the information blanked out in the “public version” of the Analysis of Alternatives and Socio-economic Analysis is not disclosed. We hereby declare that, to the best of our knowledge as of today (05/04/2023), 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.

Digitally signed by Mario Herrera
DN: C=UK, OU=HD UK,
O=Operations, CN=Mario Herrera,
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Reason: I am the author of this document
Location: Runcorn, UK
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Signature: Mario Herrera Hortal Date, Place: Runcorn, 05/04/2023

1. SUMMARY

The applicant APPH Ltd. (also known as Héroux-Devtek UK and referred to as HD UK from here on) is applying for authorisation for the continued use of chromium trioxide in functional chrome plating in the production and maintenance, repair and overhaul (MRO) of aircraft components for military and civilian sectors at its production site in Runcorn, England. The chrome plated components include structural parts of landing gear systems as well as items such as hydraulic units (e.g. actuators, valves, accumulators) and flight controls. In addition, HD UK chrome plates hydraulic components for military vehicles.

Functional chrome plating is an electrolytic process in which a layer of metallic chrome (Cr0) is deposited on the substrate from a hexavalent chromium (CrVI) plating solution based on chromium trioxide. The function of the chrome plating is to protect the aircraft components against wear and corrosion, thus increasing the component durability and service life. The unique properties of the chrome coating including high hardness, resistance against wear and corrosion, low coefficient of friction and strong adhesion are key for ensuring the successful operation of the aircraft and military vehicle components in very harsh, challenging and safety critical environments. Thanks to these properties and the inherent crack pattern which provides lubricant retention, functional chrome plating is particularly suited for coating of gas/oil sealing surfaces.

Identification and assessment of alternatives

Based on extensive R&D efforts to identify functional chrome plating replacements within the aerospace industry, consultations and data searches, in total 9 possible alternatives were identified. These alternatives are further categorised into shortlisted (Alternative 1), potential alternatives not yet assessed (Alternatives 2 and 3) and rejected alternatives (Alternatives 4-9).

The shortlisted Alternative 1 covers the thermal spraying technologies High Velocity Oxygen Fuel (HVOF) #B [redacted]. The HVOF tungsten carbide coating WC/CoCr is currently being deployed at HD UK for new development programmes #B [redacted]. The technical feasibility of the HVOF WC/CoCr coating is summarised in Table 1. For a complete assessment, please refer to Chapter 3.3.

Table 1. Overview of the technical feasibility of shortlisted Alternative 1

Process temperature	Compatibility with component geometry	Component rebuilding	Wear resistance	Hardness	Coefficient of friction	Corrosion resistance	Surface finish	Adhesion	Layer thickness
● (green)	● (red)	● (yellow)	● (green)	● (green)	● (green)	● (green)	● (green)	● (green)	● (green)

Red: technical requirement not fulfilled; yellow: criteria fulfilment partial/unclear; green: technical requirement fulfilled.

The main disadvantages of the HVOF coatings are the inability to coat components with complex geometries and/or non-exposed surfaces (internal surfaces/bores), the more demanding surface finish requirement and the risk of coating spallation under high loads. HVOF coatings are more easily applied to new equipment being developed as the equipment design can be tailored around this technology taking into account its specific design parameters rather than those of chrome plating.

Continued use scenario

If HD UK is granted an authorisation, the implementation of HVOF will continue for new development programmes and the results and learnings of this will be utilised in the replacement of functional chrome plating with HVOF coating for 'old programmes', covering equipment for existing aircrafts in service and some still in production. However, HVOF WC/CoCr is not a "drop-in" replacement for hard chrome and the replacement involves many challenges. In most cases, the hard chrome coating cannot be replaced with a HVOF coating without additional re-design of the component and other parts of the assembly, which is time-consuming. The replacement is in all cases also only possible after successful re-qualification and customer approval. The configuration control of 'hard chrome and HVOF variants' of original equipment (OE) and legacy equipment is also challenging. Similar re-qualification and certification requirements exist for the military vehicle components.

HD UK is requesting a review period of 12 years, based simply on the time-consuming activities by the engineering function required for replacing the chrome coating with HVOF. For further information, please refer to the Substitution plan presented in Chapter 4.1.3.

As explained earlier, for HD UK to fully phase-out the use of chromium trioxide in functional chrome plating, at least one additional alternative would have to be implemented. This alternative has not yet been identified.

Non-use scenario and assessment of impacts

In the most likely non-use scenario (NUS), HD UK would shutdown the production completely and relocate the production to other facilities outside the GB, resulting in the following economic impacts:

- Producer surplus loss due to ceasing the use applied for in the GB: #C [2-10] M GBP per year
- Decommissioning cost: 0.30 M GBP per year
- Social cost of unemployment of 320 people in the GB: #C [1.5-2.5] M GBP per year

In conclusion, the benefits of the continued use (#C [3.8-12.8] M GBP per year) outweigh the risks (0.037 M GBP per year) by ca. #C [100-350] times. The analysis presented in this combined AoA-SEA report outlines that a **review period of 12 years** is needed for the applicant to continue its use of chromium trioxide functional chrome plating and ensure the availability of chrome plated components for the production of aircrafts and military vehicles as well as MRO activities until an alternative has been successfully qualified, certified and industrialised.

2. AIMS AND SCOPE

2.1. Aims of the analysis

Chromium trioxide is covered by entry 16 of UK REACH Authorisation List (Annex XIV) and solely authorised uses are permitted after the sunset date given in the entry (21.09.2017) unless otherwise exempted. As chromium trioxide is a non-threshold carcinogen, adequate control of risks cannot be demonstrated and therefore applications for authorisation must follow the socio-economic route.

HD UK has prepared this application for authorisation to continue its use of chromium trioxide for functional chrome plating in the manufacturing and maintenance, repair and overhaul (MRO) of aircraft components for civil & military sectors that meet the airworthiness certification requirements and hydraulic components for military vehicles. The chrome plated aircraft components include structural parts of landing gear systems as well as items such as hydraulic units (actuators, valves, accumulators) and flight controls.

The use of chromium trioxide occurs at one site in Runcorn, England. Reliable estimates of the current workplace exposure levels at HD UK are provided in the Chemical Safety Reports (CSR) included with this authorisation application.

The combined Analysis of Alternatives (AoA) and Socio-Economic Analysis (SEA) report will demonstrate that there is no technically and economically feasible alternative to chromium trioxide available for HD UK’s use by the time of the expiry of the Elementis authorisation (UK REACH authorisation number 37UKREACH/20/18/12) in September 2024 or in the near future. The report will demonstrate that the socio-economic benefits associated with the continued use outweigh the remaining risks to human health.

2.2. Applicant

Héroux-Devtek Inc. is an international company specializing in the design, development, manufacture, repair and overhaul of aircraft landing gears, hydraulic and electromechanical flight control actuators, custom ball screws and fracture-critical components for both the commercial and defence sectors of the Aerospace market. The corporation was founded in 1942. Beginning as a machine shop for aircraft components, Héroux added landing gear design to its product offering in the 60s and manufactured the legs of the Apollo lunar lander. In 2014 HD acquired APPH (the UK sites), an integrated provider of landing gear and hydraulic systems and assemblies for original equipment manufacturers and aftermarket applications. The highlights of the company’s history are summarised in Figure 1.

Figure 1. HD's history

Today the company is the third largest landing gear company worldwide, supplying both the commercial and defence sectors of the aerospace market with new landing gear systems and components, as well as aftermarket products and services. The corporation also manufactures hydraulic systems, fluid filtration systems and electronic enclosures.

In addition to its ability to design and manufacture complete landing gear and actuation systems to specification, Héroux-Devtek has built a strong reputation for its ability to support and service landing gear and actuation systems for a wide range of defence and civil aircraft, including several out-of-production aircraft. Service offerings include complete maintenance, repair and overhaul, spares provisioning and supply, warranty administration and support, technical publications, as well as on-site technical support and training. The corporation's emphasis on Research & Development, its systems integration accomplishments, and its engineering prowess are increasingly making Héroux-Devtek a preferred partner for the design, qualification and manufacture of complete landing gear systems.

Headquartered in Québec, Canada, Héroux-Devtek now employs almost 2,000 dedicated people at its 18 sites located in Canada, the United States, the United Kingdom and Spain. In 2022 the corporation recorded a sales revenue of 332 M GBP.

The two UK sites are located in Runcorn, Cheshire and Nottingham, Nottinghamshire. HD UK is a "One Stop Shop" for design, development, test, manufacture, certify, in service support and MRO support – for all their products on fixed and rotary wing aircraft within the commercial and military marketplace. In addition, HD UK manufactures hydraulic components for military vehicles. Approximately one third of the UK sites production is placed on the internal markets. The Runcorn site is applying for authorisation for the continued use of CrO_3 for the functional chrome plating of aircraft and military vehicle components. Nottingham site is a unit of Héroux-Devtek's landing gear operations, this plant (48,000 sq. ft.) manufactures small to medium landing gear components. Runcorn site is a unit of Héroux-Devtek's landing gear operations, this plant (90,000 sq. ft) is a fully-integrated facility offering manufacturing and repair and overhaul services to the major players in the landing gear industry. This facility is the UK center of excellence for surface treatment and assembly of medium to large size landing gear systems. The Nottingham plant is focused on machining activities of details parts from the raw material. Once machining operations are completed, those parts are delivered to Runcorn to perform the surface finishing and assembly activities giving as a result the final product that is delivered to the customers. HD UK has long-term relations with most of its customers, some of them for more than 60 years. They provide parts for customers around the globe through the different platforms and expect that some of those platforms will still be serviceable for the next 30 years.

Business indicators, such as sales revenue, profit and number of employees, used in the socio-economic assessment for the application are presented in Table 2. The table outlines the indicators for the entire corporation and for the UK sites.

Table 2. Business indicators used in the assessment (#C for all redactions in the table)

Indicator	Entire HD	GB
Number of employees	1,960	320
Average annual gross salary GBP	-	[redacted] [30,000-50,000]
Annual Revenue M GBP[1]	320.8	[redacted] [10-100]
Annual Profit M GBP[1]	49.4	[redacted] [5-20]
Annual growth %	-	[redacted] [between 4-30 %]

In addition, Figure 2 outlines how the entire HD corporation's business is formed. 72 % is defence related business and 28 % civil related. The most important part of the defence segment is Transport with approx. 30 % share of total business. Large jets with approx. 14 % share of total business contributes the most to the civil segment. 52 % of HD's business is proprietary business, marketed under HD's brand name. 48 % of business is so called build-to-print business, where HD produces according to the customer's exact specifications. The vast majority of HD's sales is to the OEM market – approx. 73 % compared to its counterpart Aftermarket – approx. 27 %. Most of HD's end customers are located in the US with approx. 58 % share. Approx. 7 % of HD's end customers are located in the UK.

[1] Average between 2018-2022

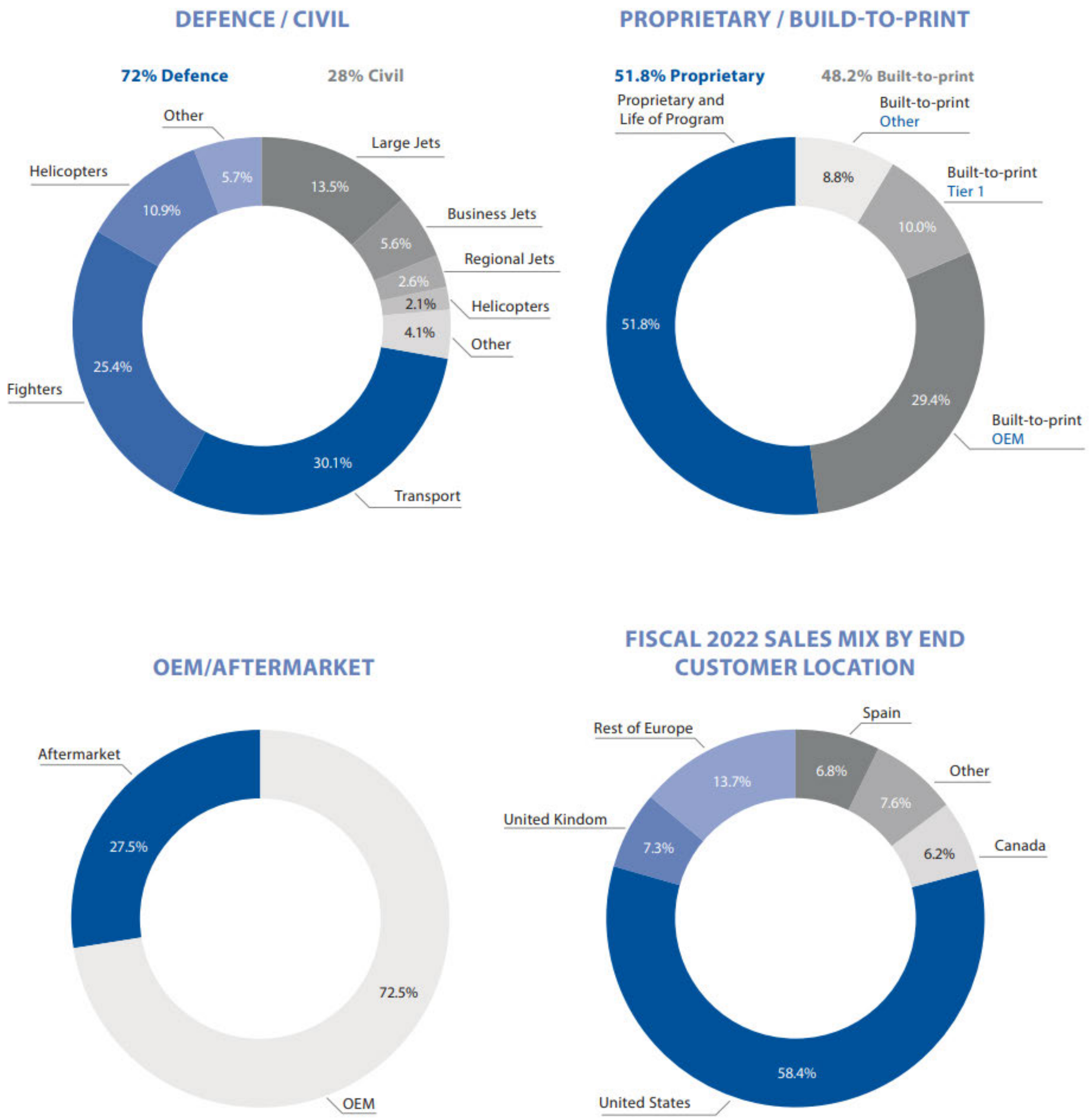

Figure 2. HD's business

2.3. Supply chain

The aviation industry is very complex and includes thousands of specialised companies producing millions of parts and components which are used in aircrafts. The industry relies on numerous different supply chains that provide the raw materials and components for the manufacture and servicing of aircrafts. Generally, aviation supply chains involve several tiers. The tier-based aerospace supply chains can be simplified as follows: The original equipment manufacturers (OEMs) that produce aircraft for airline operators and MoDs source structures and systems from tier 1 suppliers, who source components from tier 2 suppliers, who source parts from tier 3 suppliers, who source raw materials from tier 4 suppliers. In addition to manufacturing aircraft, OEMs are engaged in the provision of maintenance, repair and overhaul (MRO) services to airline operators, who usually outsource these functions.[2]

In the aviation industry, the major OEM companies are aerospace/military contractors such as Airbus, Boeing, BAE Systems and Saab. These companies make aircraft, aircraft components, missiles and space vehicles. These OEMs supply aircraft to end-users, MoDs and commercial airline companies.[3]

As mentioned, the aviation tier-based supply chain comprises of four levels. Tier 1 companies are typically manufacturers of major components or systems who receive parts or subassemblies from the tier 2 supply chain. The equipment that tier 1 manufactures are final systems that are supplied to the OEM. These companies who directly supply the aviation sector are the most important and viable in the chain. They manufacture a wide array of critical finished products such as engines, control systems, landing gear, braking systems, flight deck, avionics, aerostructures, electronic warfare systems and interior cabin products. Tier 1 companies are the drivers of the supply chain and are responsible for ensuring that the entire operation is being managed in an effective and efficient manner, following all required government guidelines. They serve as the pull through of the entire supply network. In its main role as a landing gear system manufacturer, HD is part of tier 1.[3]

Tier 2 companies are responsible for the manufacture of parts or subsystem assemblies used by tier 1 companies. Aviation tier 2 plays a highly critical role in support of the industry. These companies are responsible for keeping the supply chain moving from tier 3, through their operations and ultimately to the tier 1 manufacturers. Tier 2 companies provide critical components ranging from actuators, airfoils and tires to missile nose cones and airframe structures to transmissions and flight controls. These suppliers carry a significant responsibility at the middle of the supply funnel. They are vital for ensuring the rate of flow of materials and production. They are also the companies that are held most accountable to the specifications, standards and compliances of parts and components. HD manufacturers actuators and other components for its landing gear systems and are thus part of tier 2 as well.[3]

Tier 3 companies are mostly component manufacturers that ship their products directly to tier 2 companies for the manufacturing of critical parts and subsystems. Tier 3 companies can be big players in the supply chain and may also be providing critical parts that must be certified. Some examples of products tier 3 component manufacturers' supply include hydraulic fittings and hose, instrumentation fittings and tubing, high strength fasteners and pins. Some tier 3 companies can be smaller machine shops that produce thousands of parts which ultimately serve a critical purpose. There are also many tier 3 suppliers that produce mission-critical components and software that are more than just nuts and bolts.[3]

Tier 4 companies are raw materials suppliers such as chromium trioxide importers and suppliers. The raw material supply can also be very critical. For example, if HD can't source chromium trioxide, they can't ultimately manufacture landing gears and are not able to offer MRO services to their customers' fleet which would consequently be grounded.

[2] https://www.itfglobal.org/sites/default/files/resources-files/scalop_aeronautical_supply_chains_english.pdf

[3] https://blog.brennaninc.com/what-are-the-three-tiers-in-the-aerospace-supply-chain

The tier-based aviation supply chain and HD's roles in it are simplified in Figure 3 below. As indicated with light orange boxes in the figure, HD operates on tier 1 as a system assembler and on tier 2 as a principal component manufacturer, and also as an MRO operator offering maintenance, repair and overhaul services to its customers. HD utilises chrome plating when it is manufacturing components which are used in landing gear systems supplied to aircraft manufacturers, and when providing MRO services to end-users. HD purchases chromium trioxide from an UK based importer who imports the substance into the country. The flow of chromium trioxide is shown with orange arrows in the figure.

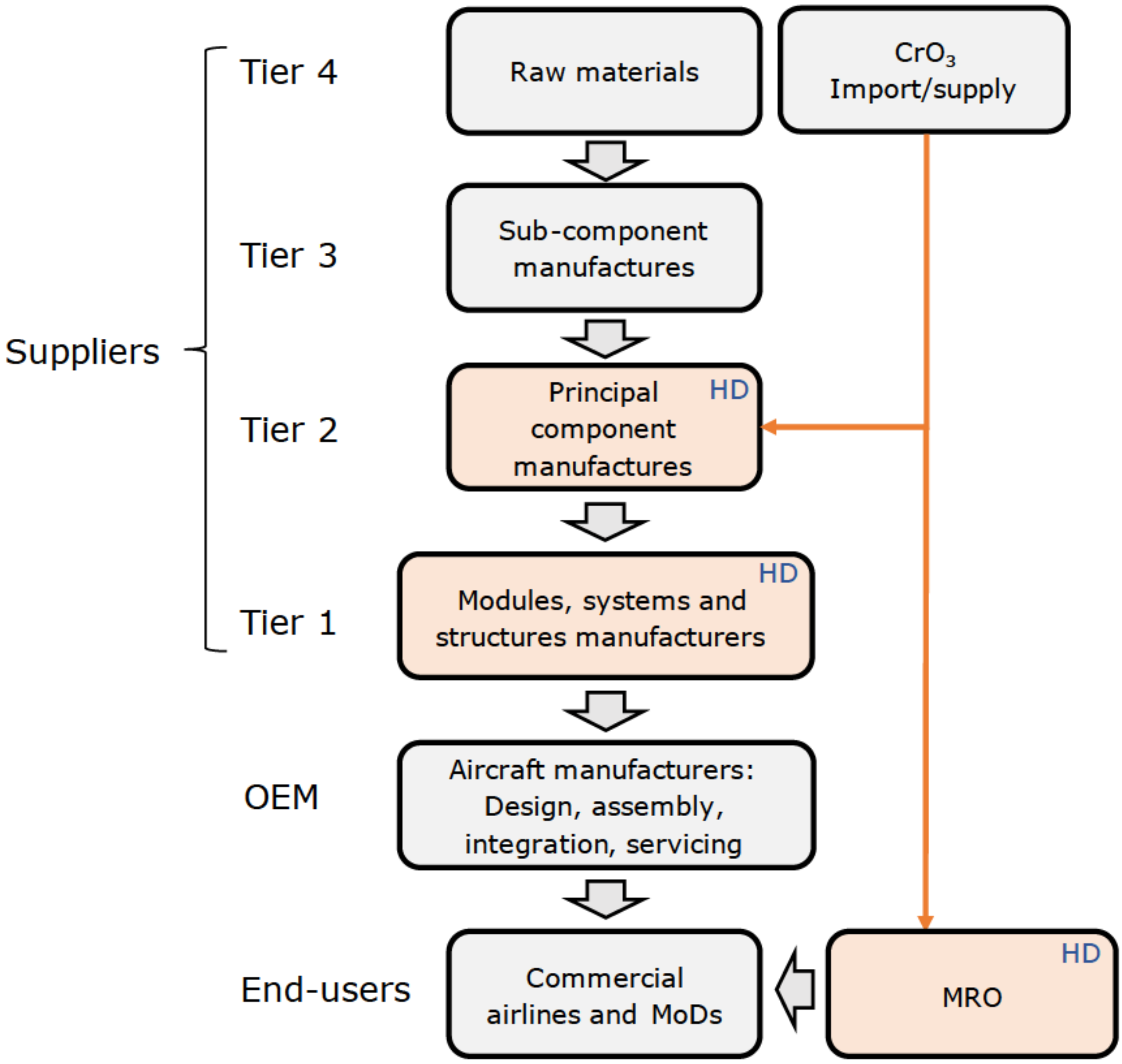

Figure 3. Aerospace supply chain with HD's positions

2.4. Scope of the analysis

2.4.1. Geographical scope

The sites of HD UK are located in Midlands and the north England. One site in Runcorn, Cheshire in the North West England. The other site is located in Nottingham, Nottinghamshire in the East Midlands. Economic and social impacts of the non-use scenario would be relevant for both of these areas. Human health impacts of the non-use scenario be relevant only in Runcorn because the chrome plating takes place there. Both areas have been selected as the geographical scope of the socio-economic analysis for this application. The Runcorn site is located in an industrial area with a limited number of people living in the proximity. Therefore, the population density of Cheshire is used for the human health impact estimation as it gives more realistic results than the EUSES default or the Runcorn populations. Area, population and population density of Cheshire are outlined in Table 3. A map showing the locations is given in Figure 4.

Table 3. Geographical scope

Geographical Scope	Population	Surface area (km²)	Population density (population per km²)
Cheshire	1,059,271	2343	452

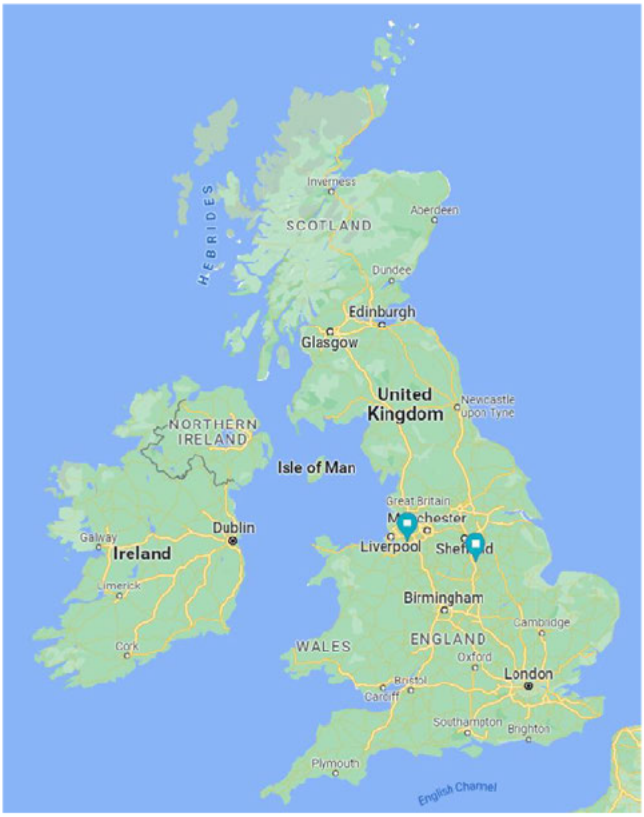

Figure 4. HD sites on the map

2.4.2. Temporal scope

Heroux Devtek's current use is covered by the CTACSub authorisation decision for "Use 2" (Functional chrome plating) granted under EU REACH and grandfathered into UK REACH (UK Authorisation number 37UKREACH/20/18/12)[4]. The authorisation is valid until the end of the review period (September 21st, 2024). Heroux Devtek will need to continue its use after this date and needs to apply for its own authorisation as the upstream authorisation holder has decided not to submit a review report for UK REACH. As the application will not be covered by "transitional arrangements", Heroux Devtek will need to have their authorisation decision before the expiry of the CTACSub review period to avoid a gap in authorisation coverage.

The impact calculations assume a 12-year review period starting from 2024 and ending in 2035. The assumption is solely for the calculations prepared in the socio-economic assessment and HD is requesting 12 years starting from September 22nd, 2024.

More information about the length of the review period can be found in Chapter 4.7.

[4] The authorisation decision is available on the UK HSE website at https://www.hse.gov.uk/reach/applications-for-authorisation.htm (Grandfathered applications tab of the Excel spreadsheet)

3. ANALYSIS OF ALTERNATIVES

3.1. SVHC use applied for

Functional chrome plating, also known as hard chrome plating, has been used for more than 80 years in metal finishing to improve the functional surface properties of the plated components. The use of chromium trioxide in functional chrome plating is well established in numerous industries since the resulting coating confers many beneficial properties which makes it the best solution in a variety of end-uses involving demanding use conditions. This is also the case for aviation industry, where normal operating conditions include exposure to both extremely low (sub-zero temperatures at cruise altitude) and high temperatures (ground temperatures exceeding 60 °C), humidity, pressure, altitude, flight loads and the possibility of being struck by lightning.

Over many years, functional chrome plating has become the industry standard within aerospace industry and the use is widespread. The chrome coating is applied to both aero structures, landing gears, engine mounts as well as air frames. The resulting chrome coating is extremely **hard** as well as highly **wear and corrosion resistant**. The coating has a **low coefficient of friction**, and in many cases, it is applied to lower the friction of components with metal-to-metal contact between moving parts. A lower friction means that less heat and wear is generated between the contacting surfaces. The **microcracked** structure of the chrome coating also enables **lubricant retention**. Thanks to this unique combination of properties, the chrome coating provides increased durability, operational reliability and service life for the plated components.

HD is the third largest designer and manufacturer of landing gear systems in the world. At HD UK, the chrome coating is applied to aircraft components during production as well as repair of worn or damaged components removed from aircraft during overhaul and production of spare parts. The chrome plated components include structural parts of landing gear systems as well as items such as hydraulic units (actuators, valves, accumulators) and flight controls. The aircraft components are supplied to all types of aircraft including military helicopters, advanced fighter jets, civil airliners and business jets. In addition, HD UK chrome plates hydraulic components for military vehicles. The chrome plated components must perform under sever loading conditions and in many different environments and have therefore very stringent requirements for performance.

In the following section, the functional chrome plating process as it is carried out at HD UK is described.

3.1.1. Functional chrome plating process

The functional chrome plating process at HD UK consists of three phases: i) pre-treatment, ii) main plating process and iii) post-treatment. A schematic overview of the process is presented in Figure 5.

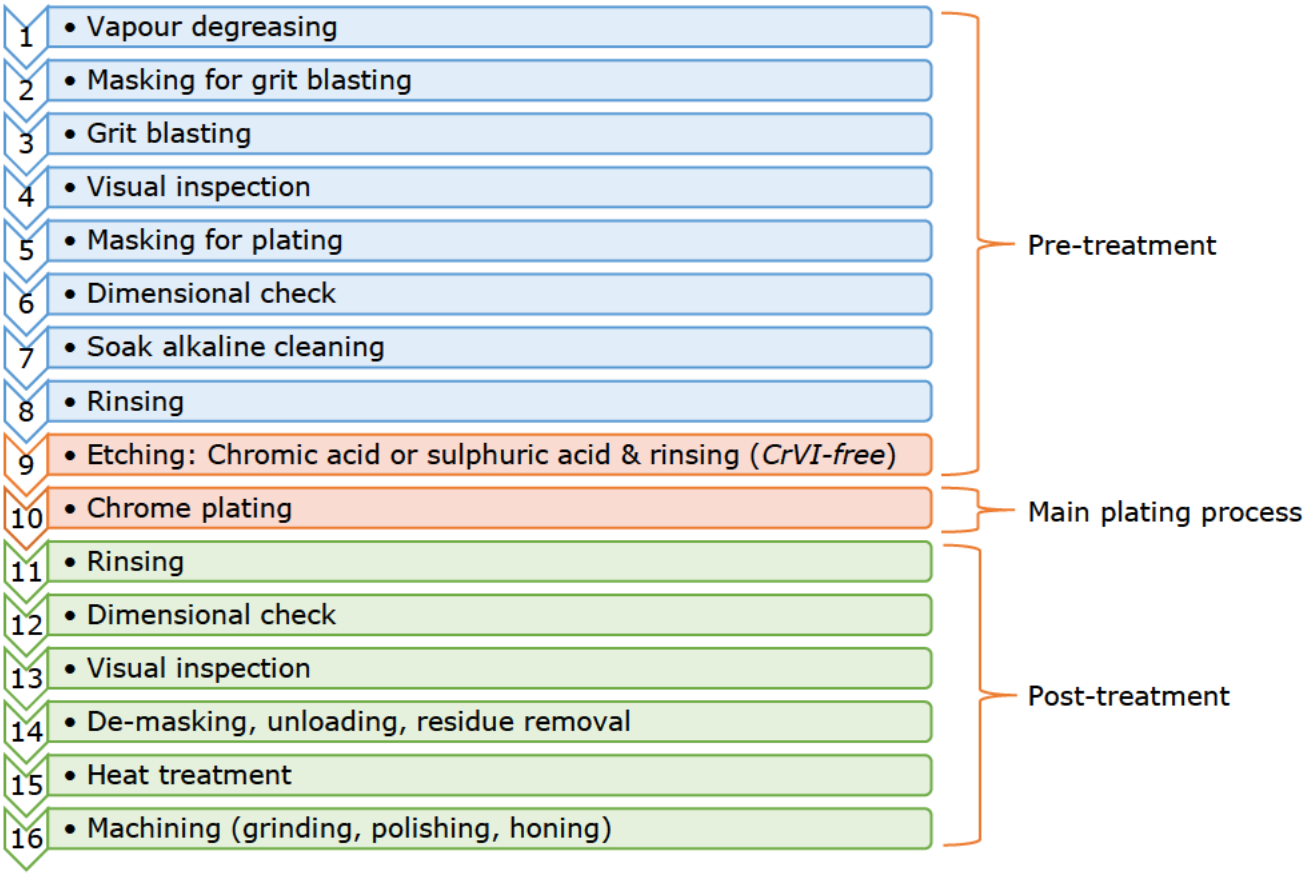

Figure 5. Functional chrome plating process. Steps where CrVI is used are indicated in red

Pre-treatment:

Before the main plating process, the components undergo a set of pre-treatments. The purpose of the pre-treatments is to condition the surface of the components to ensure strong adhesion of the coating. It is critical that the component surface is completely free of impurities, corrosion products (metal oxides) and contaminants to ensure the effective bonding of the metallic chrome coating to the substrate surface.

The process starts with vapour degreasing to remove oil and grease from component surface, followed by masking for grit blasting. Grit blasting is a process in which abrasive particles are accelerated and forcefully directed against the component surface to remove contaminants and increase the surface are by roughening. The components are visually inspected to ensure all abrasive media is removed and to check the condition of the component. Masking is added on areas where chrome plating is not required. The size of each component is checked and recorded. The components are then attached to jigs and moved to the chrome plating area.

The components undergo soak alkaline cleaning followed by rinsing in cold water. Prior to chrome plating an activation step known as etching is performed, which makes the surface of the component more receptive to chrome plating, improving adhesion of the coating. The etching treatment is performed either in a sulphuric acid bath followed by rinsing (*CrVI-free*) or with chromic acid either in a separate chromic acid bath (CrO_3 concentration [redacted] [200-300] g/l) or directly in the plating bath using reverse current.

Main plating process:

Functional chrome plating is an electroplating process in which a layer of metallic chromium (Cr0) is deposited on a metal substrate, here the aircraft components. The principle of the process is known in chemistry as electrolysis and involves four elements: an anode, a cathode, an electrolyte and a direct current source (Figure 6). Together they form an electrolytic cell.

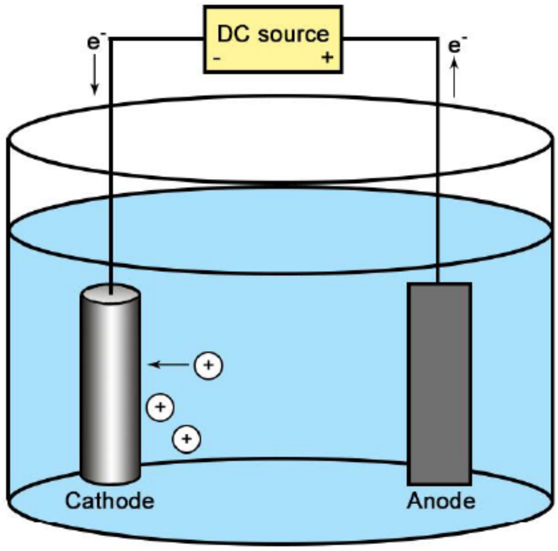

Figure 6. Principle of electroplating

In the present case, the electrolyte is the chrome plating solution, the component to be chrome plated acts as the cathode and an inert electrode is the anode. The DC source provides the electric potential (current) needed for the electroreduction of CrVI to metallic chromium at the cathode, resulting in the deposition of a chrome coating.

In the main plating process, the pre-treated components are immersed into the chrome plating solution which contains chromic acid (aqueous solution of chromium trioxide) as the source of dissolved hexavalent chromium CrVI cations, sulphuric acid as the catalyst and demineralised water. Current density and the immersion time is adjusted according to the part to be plated and the required layer thickness of the chrome coating. Information on the plating bath composition and operating parameters are given in Table 4.

Table 4. Plating bath composition and operating parameters (#B for all redactions in the table)

Parameter	Value
CrO_3 concentration	[redacted] [200-300] g/l
Sulphuric acid concentration	[redacted]
Current density	Flash chrome plate: [redacted] Chrome plate: [redacted]
Operating temperature	[redacted] [30-70] °C

Functional chrome plating baths have a tendency of building thicker deposits in high current density areas (e.g. edges) compared to low current density areas (e.g. recessed areas, holes) on substrates. Auxiliary anodes are used for plating of components with complex surface geometries or internal diameters to distribute the current evenly along the surface of the substrate and thereby achieve a coating with uniform thickness and full coverage. The auxiliary anodes are designed to match the surface geometry of the substrate to obtain even anode-cathode distance.

Post-treatment:

After chrome plating, the components are rinsed with cold and hot #B [redacted] water to remove excess plating solution. The size of each component is checked against drawing and recorded. The components are visually inspected to ensure that the surface is free of defects. The masking is removed, and the components are unloaded from the jigs. If wax was used for masking this is boiled off in the hot water rinse bath. The parts and jigs are then moved to the degreaser off the plating line for final cleaning process.

The chrome plated parts are de-embrittled by a heat treatment #B [redacted] for time periods specific to the type of steel the substrate is made of. Following this, the components are typically ground, polished and/or honed to achieve the final size and surface finish requirements.

Quality control and assurance is of the utmost importance in aircraft manufacturing. Manufacturers are required to document, track, and inspect, and reinspect all items and phases to ensure that everything is completed to very strict standards. All OE (original equipment) components are manufactured in accordance with issue controlled drawings and operation sheets. All MRO components are repaired in accordance with approved repair schemes. The inspection performed on 100 % of components involves:

- Visual inspection
- Dimensional measurements
- Surface finish
- Adhesion testing
- Non-destructive testing – in accordance with ASTM E 1444

In addition, monthly quality assurance testing is performed as listed below:

- Solution analysis
- Hardness
- Adhesion (Bend & chisel tests)
- Porosity (program specific)
- Embrittlement (program specific)

All processing areas are subject to NADCAP (National Aerospace and Defense Contractors Accreditation Program) requirements. HD UK is certified according to the international quality management standard ISO 9001 and aerospace industry specific quality system standards (BSI registration BSEN-ISO9001, AS9100 & AS9110). All items are released in line with relevant requirements of the customer, EASA (PART 145 / PART 21G) or CAA.

For a more detailed description of the plating process at HD UK, please refer to the CSR submitted with this application. A description of the operating conditions and risk management measures in place at the applicant's site is also provided in the document.

3.1.2. Description of the functions(s) of CrO_3 and performance requirements of the aircraft components

As explained in the previous chapter, chromium trioxide is the source of hexavalent chromium CrVI, which will form the metallic chrome Cr0 layer on plated parts through electrodeposition. HD UK uses chromium trioxide to hard chrome plate aircraft components and hydraulic components for military vehicles during manufacturing operations and MRO activities. The aircraft components include structural parts of landing gear systems as well as items such as hydraulic units (actuators, valves, accumulators) and flight controls (please see Chapter 3.1.3.1 for more information). The customer specifications mandate which chrome plating specification should be used in production, and these are typically AMS2460, DEF STAN 03-14, QQ-C-320 and AMS 03-14 which cover the requirements for electrodeposited chromium plating. Coating hardness, adhesion & thickness are all controlled criteria in the specifications.

Landing gear components must endure severe loading conditions (e.g. impact force during landing and support weight of aircraft on the ground) and exposure to harsh environmental conditions. The function of the chrome coating is to protect the components from premature wear and corrosion, thus ensuring successful operation and safety of landing gear systems under very harsh and demanding environmental conditions over an increased lifespan. The key performance functionalities of the chrome coating and the related technical requirements are described in Chapter 3.1.2.2.

Importantly, the features of the CrVI based functional plating process itself are also critical for the applicability of the coating process to the components covered by this application. These process related functionalities are described in the following chapter.

In addition, the airworthiness regulations (e.g. EU Regulation No 2018/1139, retained in UK domestic law) require that all components, equipment, materials and processes incorporated in an aircraft must be qualified, certified and industrialised before production can start. Similar processes are followed in the military sector. An overview of the airworthiness requirements is provided in Chapter 3.1.2.3.

3.1.2.1. Key process functionalities

As explained in the previous chapter, HD UK uses chromium trioxide in both the etching and the plating steps. The etching treatment is necessary to activate the component surface to ensure proper adhesion of the chrome coating. It should be noted that the use of chromium trioxide in the etching treatment is not a standalone use but part of the multi-step functional chrome plating process.

CrVI based etching has several advantages: adjustable etch-rate, adhesion promotion between substrate and coating, chemical compatibility with the subsequent plating process (no cross-contamination and no additional rinsing steps required as is needed for the sulphuric acid based etching) and straightforward bath maintenance. The alternatives identified for functional chrome plating do not require a CrVI based etching and thus, result in full substitution of chromium trioxide. Therefore, the functions provided by chromium trioxide in the etching treatment and related requirements are not relevant criteria for the analysis of alternatives.

The key process related functionalities of chromium trioxide based functional chrome plating are summarised in Table 5.

Table 5. Key process functionalities for the chrome plating process

Process key functionality	Requirement
Process temperature	The process temperature must be compatible and cause no distortion or dimensional changes of the base material.
Compatibility with substrate geometry	The process must result in efficient and uniform coverage of components with complex geometries, non-exposed surfaces (e.g. internal diameters) and/or large in size.
Component rebuilding / repair	The surface treatment process allows for rebuilding / repair of worn or damaged components.

A description of each process-related functionality is provided below.

Process temperature

The low process temperature #B [redacted] makes it compatible for components made of different base materials as it causes no distortion or dimensional changes of the base material. The components are often heat treated to attaint he required mechanical properties. Exposure to high temperatures during the plating process could potentially temper the component and thus adversely affect the mechanical properties of the base material and thereby its strength and structural capability.

Compatibility with substrate geometry

The functional chrome plating process is suitable for coating of components with complex geometries, non-exposed surfaces (e.g. internal diameters) and/or very large in size (using equally sized plating baths). Auxiliary anodes are used to distribute the electroplating current evenly along the surface of the substrate and thereby achieve a coating with uniform thickness and full coverage.

Component rebuilding / repair

As already mentioned, at HD UK functional chrome plating is also needed during MRO of worn components. Many aircraft components require regular overhauls as defined in the maintenance program of the aircraft. For commercial aircrafts, landing gear overhauls are performed on average every 10 years. Functional chrome plating is also used to recover worn components that would have otherwise been scrapped.

The worn chrome coating is removed in a process called stripping. This process does not cause damage to the underlying base material or dimensional alterations. The component is then replated with a fresh layer of hard chrome. The chrome coating is typically deposited in excess thickness followed by machining to restore the original dimensions of the component according to its drawing. This process can be repeated several times over the lifetime of the aircraft components.

3.1.2.2. Key performance functionalities

As mentioned, the function of the chrome coating is to protect the components from premature wear and corrosion, thus ensuring successful operation and safety of landing gear systems under very harsh and demanding environmental conditions over an increased lifespan. The key performance related functionalities provided by the chrome coating are listed in Table 6 together with the technical requirements and relevant testing required for demonstrating fulfilment of these requirements to ensure the performance and reliability of the aircraft and military vehicle components.

Table 6. Key performance functionalities of the chrome coating and related technical requirements

Key performance functionalities	Technical requirement (quantitative and/or qualitative)
Wear resistance	The wear resistance is specified as the number of operational cycles per flying hour and is typically in the region of 8,000-100,000 cycles. The requirement is demonstrated by a dedicated endurance testing of the equipment to meet the specific customer requirements.
Hardness	Typical surface hardness: 60-65 Rc The surface hardness is a controlled parameter on the component drawing.
Corrosion resistance	Corrosion resistance testing according to RTCA/DO-160 (Environmental Conditions and Test Procedure for Airborne Equipment).
Coefficient of friction	The friction is assessed as part of the overall unit/system. The aim is to minimise any friction losses. This is often demonstrated by a dedicated performance test.
Surface finish	The surface finish is a controlled parameter on the component drawing. A good surface finish is required to minimise wear and friction. In hydraulic units where the chrome interfaces with elastomer seals, a specific surface finish is required (typically [redacted]) to ensure successful operation of the seal.

Key performance functionalities	Technical requirement (quantitative and/or qualitative)
Adhesion	Adhesion to base material is a controlled element of the manufacturing process. It is crucial that the chrome coating is compatible with and adheres successfully to the substrate material. The adhesion must be strong to withstand mechanical, chemical and thermal stresses throughout the component's service life. Delamination, flaking or blistering of the coating is not acceptable.
Layer thickness	The layer thickness of the chrome coating is a controlled parameter on the drawing. The required thickness is dependent on the functional requirements and is typically [redacted] for dynamic applications and [redacted] for non-dynamic applications.

A description of each key performance functionality provided by the chrome coating and its relevancy for the aircraft components is provided next. The assessment of these functionalities against the technical requirements is also explained.

Wear resistance

One of the most important functionalities of the functional chrome plating is its high wear resistance. The chrome coating provides protection from wear and scratches caused by mechanical stress and abrasive materials. This is key for increasing the durability of the chrome plated components and ensuring a longer service life. The degree of wear resistance needed varies with the amount, frequency and type of stress the components are subject to. Depending on the use area, chrome plated landing gear components experience different types of wear. Landing gear utility actuators and inner cylinders are exposed to long-stroke sliding wear, while pins and hydraulic cylinders are subjected to short stroke, oscillating wear (withering, fretting) during ground operations.

The wear resistance is specified as the number of operational cycles per flying hour and is typically in the region of 8,000-100,000 cycles. Fulfilment of the requirement is demonstrated by dedicated endurance testing of the equipment to meet the specific customer requirements. The endurance test is part of the qualification process of aircraft components. Similarly, assemblies for military vehicles also have to be qualified against a discrete set of requirements. However, in this case the number of cycles will be lower.

HD UK's customers demand landing gear systems that function as intended in operation for as long as possible without the need for MRO. The increased service is vital for minimising the overall life cycle cost. The cost of landing gear overhaul is significant and can be similar to the price of a new landing gear set when over & above's[5] are taken into account. The industry standard for MRO turnaround time (TAT) is 60 days.

[5] Any discrepancies found during the inspection that require additional parts and labour are quoted over and above.

Hardness

The hardness of a material measures how well it can resist deformation when a force is applied. The chrome coating is harder than most other metallic coatings which makes it resistant towards wear and abrasion. Abrasive wear occurs when two surfaces rub against each other and the harder surface grinds away and causes wear on the softer surface. However, it should be noted that hardness and wear resistance are not interchangeable properties and a material much harder than chrome could in fact be much less resistant to wear as this performance is dependent on the ductility of the coating and the tribological properties (e.g. friction) of the mating surfaces.

The coating hardness is a controlled parameter on the drawing. The requirement for the hardness is based on experience and typically the surface hardness should be 60-65 RC[6].

Corrosion resistance

Corrosion resistance is defined as the ability of a material to resist damage from oxidation caused by chemical reactions with its surrounding environment. The chrome coating resulting from functional chrome plating is highly resistant towards atmospheric corrosion caused by moisture and oxygen.

Corrosion resistance is assessed in salt fog test according to RTCA/DO-160 (Environmental Conditions and Test Procedure for Airborne Equipment). The sample is placed in a chamber where it is exposed to an artificial atmosphere consisting of saltwater fog. The formation of corrosion products on the sample surface is evaluated after a specified period.

The salt fog test does not predict corrosion behaviour of a coating under the actual conditions of use and the ability to maintain a level of corrosion resistance over a longer time period in operation. As an inexpensive, fast, standardised and repeatable test it is mainly used for comparative testing of corrosion resistance properties between different coating materials and to ensure that the chrome coating resulting from the electroplating process conforms to its expected corrosion resistance. As an accelerated test it is extremely useful for screening out coatings with clearly deficient corrosion resistance properties.

Coefficient of friction

The chrome coating has a low coefficient of friction, which means that there is less force resisting the relative motion of one surface over another. This property is important for components subject to sliding contact with mating surfaces in relative motion as it reduces wear and allows components to operate at a lower temperature (lower temperature build-up due to friction) and with increased efficiency (higher sliding properties).

Chrome plated parts are often used in dynamic joints and the friction is assessed as part of the overall unit/system. The aim is to minimise any friction losses. This

[6] Rockwell hardness scale

is often demonstrated by a dedicated performance test. For example, the friction of the shock absorber main sliding piston (which is one of the largest components chrome plated at HD UK) can only be assessed and measured when part of the whole assembly. This is because friction is a contact parameter and is affected by several factors, such as the seal squeeze, the internal pressure of the shock absorber, the amount of lubricity provided by the inherent 'crack' pattern in the chrome, the surface finish and wear rate of the coating etc. The same rationale applies to the chrome plated pistons used within the hydraulic actuators. These tests involve the 'stroking' of the assemblies through a number of agreed cycles.

Surface finish

The surface smoothness/roughness describes the deviations in the direction of the normal vector of a real surface from its ideal form. The most commonly used roughness parameter Ra is the arithmetic average of the absolute values of these deviations (the peaks and valleys) measured across a surface (expressed in µm). Another common roughness parameter is the Ten-point mean roughness Rz, which is the average value of the summed absolute values of the 5 tallest peaks and 5 deepest valleys over the sampled length.

The surface finish is a controlled parameter on the drawing, typically specified as Ra but also Rz on some specific parts. The required surface finish depends on the component and its intended use (e.g. the material and properties of mating surfaces, and the desired tribological properties between the interacting surfaces). For sealing surfaces the required surface finish is typically #B [redacted]. A good surface finish is required to minimise wear and friction. In hydraulic components, a specific surface finish is required on the chrome plated surface which runs against elastomeric seals to ensure successful operation of the seal. Leaking seals result in lowered performance due to the pressure drop in hydraulic cylinders, and eventually component malfunction or failure. A smooth chrome coating also minimises the wear on sealing, thus enabling a longer seal life. Post-plating, components can undergo machining treatments to achieve the correct surface finish. For some components, machining is not possible or would be very difficult due to the geometry of the component and the correct surface finish must be obtained as plated. For some components HD UK applies only a thin chrome coating, referred to as flash chrome plating, which follows the surface finish of the pre-machined substrate and is not subject to machining post-plating.

During the electrodeposition process, microcracks are formed in the chrome coating. The size and density of the microcracks depends on the electroplating process parameters (e.g. bath temperature, current density) as well as the thickness of the coating as the cracks tend to increase for thicker coatings. The microcracked structure is advantageous as it provides lubricant retention (lubricant is retained in the microcracks) and improves the dry running properties of components in the absence of lubrication. Lubrication is needed to reduce friction and wear between mating surfaces during operation and it also provides protection against corrosive agents (e.g. water, de-icing fluid). Too smooth surfaces cannot retain lubrication, leading to overheating and wear between mating surfaces.

A macrocracked coating on the other hand is undesirable as this reduces the corrosion protection provided by the coating. The base material gets exposed to corrosive agents via the macrocracks while the smaller microcracks still act as a barrier. For sealing surfaces, leakage can occur via the macrocracks. Macrocracks also causes more abrasive wear on mating surfaces.

Adhesion

Adhesion refers to the interfacial bonding between the coating and the base material. The adhesion between the chrome coating and the component onto which the coating is electrodeposited is achieved by a molecular bond. It is crucial that the chrome coating is compatible with the substrate material and that it successful adheres to the component surface. This is a controlled element of HD UK's manufacturing process. The adhesion is assessed in bend & chisel tests. Careful conditioning of the substrate surface during the pre-treatment phase is required to achieve optimal adhesion.

Poor adhesion causes delamination, flaking or blistering of the coating, which is not acceptable as in the worst case this could cause critical failure of the landing gear systems. After plating, all components are visually inspected to ensure that the surface is free of such defects. The adhesion must remain strong and resist exposure to mechanical, chemical and thermal stresses throughout the service life of the component to ensure the reliability and safety of the aircraft and military vehicle components.

Layer thickness

The layer thickness of the chrome coating is a controlled parameter on the component drawing. The coating thickness must conform to the drawing within specified tolerance limits to ensure that the component fits and functions as intended in the related aircraft unit/system. The required coating thickness depends on the functional requirements and is typically [redacted] for dynamic applications and [redacted] for non-dynamic applications. Coating thickness of [redacted] is normally before machining and is reduced to [redacted] after machining. For component rebuilds and repairs during MRO activities, the chrome coating is typically deposited in excess thickness followed by machining to wanted thickness to restore the dimensions of the component.

It should be noted that an alternative must meet or exceed the performance of functional chrome plating in all areas regarded as critical. A coating that is merely harder is not sufficient – it must also resist wear, corrosion, impact damage and fretting, and the coating process must not cause hydrogen embrittlement or an excessive fatigue debit. Fulfilment of these performance requirements must be demonstrated in qualification tests.

3.1.2.3. Airworthiness requirements

Airworthiness is essential to ensure the safety of personnel and passengers in the air and on the ground. The airworthiness requirements and the approval process in the aviation industry as well as the implications of these on substitution of substances are described in detail in the report "An elaboration of key aspects of the authorisation process in the context of aviation industry" published by ECHA and the European Aerospace Safety Agency (EASA) in 2014.[7]

"An aircraft must be able to perform safely, with a high level of utilization (around 16 hours per day), in a severe operational environment, such as:

- sub-zero temperatures at cruise altitude to ground temperatures exceeding 60 °C
- humidity
- pressure
- altitude
- flight loads (including turbulent conditions)
- the possibility of being struck by lightning.

Airworthiness requirements are set as the measure of an aircraft's suitability for safe flight under these conditions."

Airworthiness regulations (e.g. EU Regulation No 2018/1139, retained in UK domestic law) require that all components, equipment, materials and processes incorporated in an aircraft must be qualified, certified and industrialised before production can start (see Figure 7). This extensive process must also be followed if a substance used in a material, process component, or equipment is changed in order to comply with the airworthiness requirements. This means that an alternative can only be considered suitable and available once these steps are completed.

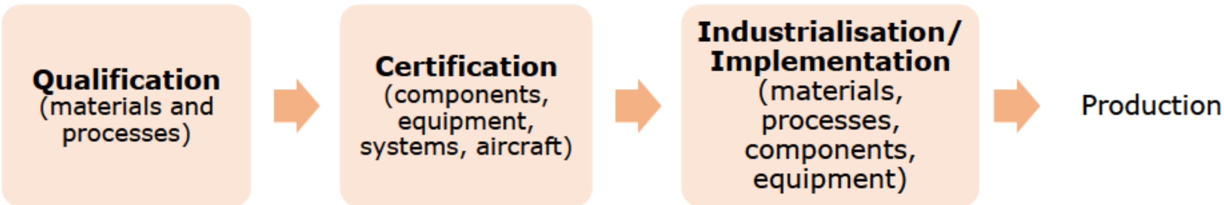

Figure 7. Schematic illustration of qualification, certification and industrialisation processes[7]

The development of a new aircraft can take up to 15 years. The production of a specific aircraft model can continue for more than 50 years, and the lifespan of an aircraft is typically 20-30 years. Differences exist in the suitability of an alternative for new aircraft designs (not yet in production) and existing aircraft designs in production and legacy aircrafts (in operation but no longer in production). Even when an alternative is successfully qualified, certified and industrialised for new component and aircraft designs, functional chrome plating will still be needed for the production of equivalent components of existing aircrafts as well as maintenance, repair and overhaul (MRO) activities for continuing airworthiness of aircrafts in operation. Substituting chrome plated components for existing aircrafts requires that an alternative is successfully re-qualified and re-certified for use in the aircraft type.

The replacement of functional chrome plating with an alternative coating may impact the complete (dimensional) design of the component, which means that retrofitting an

[7] https://www.easa.europa.eu/en/downloads/17236/en

alternative to existing aircrafts is challenging. The new component design may not be compatible with the dimensions and materials of counterparts present in the same component assembly (e.g. sealing technology), triggering the need for design changes of further components. Especially for legacy aircrafts, functional chrome plating may be needed to ensure the availability of compatible spare parts, considering the lengthy, challenging and very expensive re-design, re-qualification and re-certification processes.

In addition, a single component can be installed into several different aircraft units / systems, each with its own design requirements. Successful substitution of functional chrome plating with a qualified alternative for one component in a specific subsystem or system does not imply that it is suitable for use in another (sub)system.

Although the airworthiness requirements (and related Certification Specifications) do not specify the substances or materials to be used in production and maintenance of aircrafts, they set the performance requirements which must be fulfilled, and thereby drive the choice of substances / materials. A description of the qualification, certification and industrialisation processes in the aviation industry is provided next based on the report from ECHA-EASA. Similar processes are followed in the defence industry.

Qualification

Qualification is the process under which a company determines that a material, process, component or equipment meets or exceeds specific performance requirements defined in technical standards or specifications issued by government-accredited bodies, industry or military organisations, or upon company-developed proprietary specifications. These specifications include explicit performance requirements, testing methods, acceptance testing and other characteristics that are based upon R&D results and prior product experience. The "Qualified Products List" (QPL) or "Materials Control" section identifies products that have met the performance requirements.

Once potential alternatives have been developed by formulators / technology providers, the OEM performs screening tests (laboratory testing) on the alternatives. The testing performed under a limited set of conditions in a controlled laboratory environment cannot fully simulate the performance in the actual use environment where there are many more variables. Confidence in an alternative's performance is critical, as some aviation hardware is in locations that cannot be readily inspected, sometimes for the life of the aircraft. Extreme caution must be exercised, and risks understood before replacing a material which has proven field experience.

If the alternative fails the screening tests, further reformulation or technology development by the alternative provider is needed before resuming screening tests with typically multiple iterations. For those materials that pass screening, production scale-up, development of process control documents, manufacturing site qualifications, and extensive qualification testing is required to demonstrate equivalent or better performance to that which is being replaced.

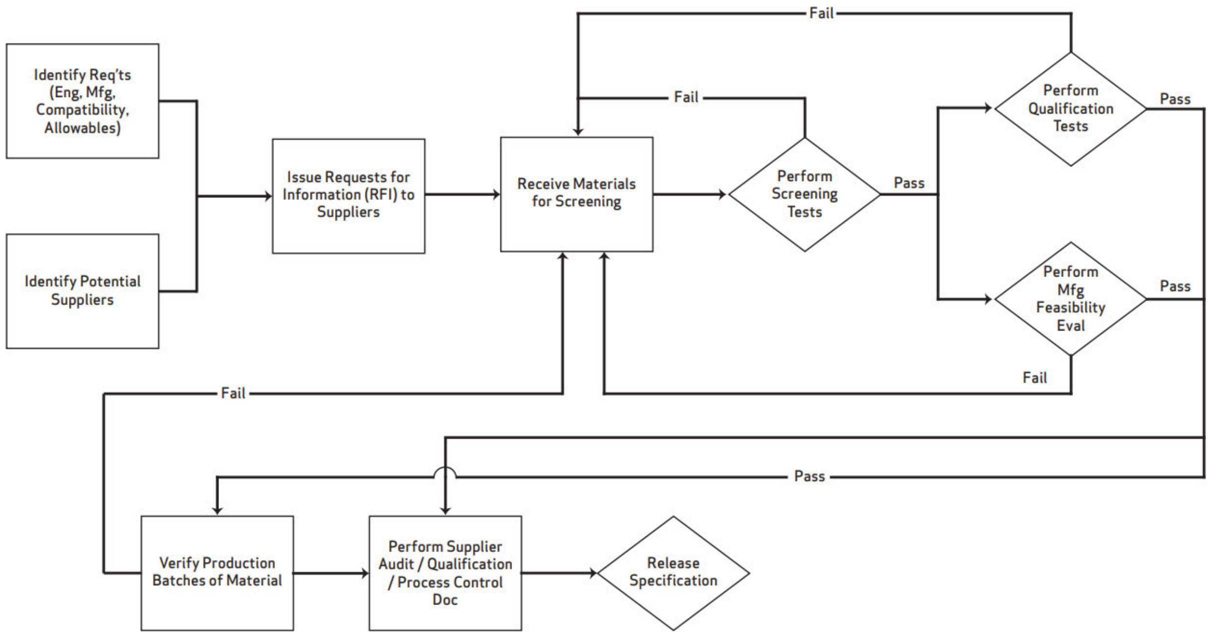

Figure 8. Qualification process[7]

As explained in the report from ECHA-EASA, "this process is an extensive internal approval process with many different steps from basic technology research up to technology demonstration in a lab environment. Depending upon the difficulty of the technical requirements, these initial steps can easily take 3-5 years. After initial laboratory testing, each specific application must be reviewed, which means additional testing for specific applications / parts. Airworthiness Certification begins at this same time, this certification can take from 6 months to years. Additional time is needed for production scale-up and development of a supply chain."[7]

The development and qualification processes at OEMs in the aviation sector follow the Technology Readiness Levels (TRL), originally developed by National Aeronautics and Space Administration (NASA) as a tool to measure the technical maturity of a technology (see below table), with company specific adaptations. TRLs are based on a scale from 1 to 9, where 9 is the most mature technology. Before the qualification of an alternative can start, extensive research (TRL 1-3) and development (TRL 4-6) work must have already been successfully completed and the alternative technology's readiness demonstrated at TRL 6.

Table 7. Technology Readiness Levels[8]

TRL	Definition	Description
1	Basic principles observed and reported	Basic scientific research that can be turned into and application or a concept under a research and development program is considered.
2	Technology concept or application formulated	And idea is proposed for the practical application of current research, but there are no experimental proofs or studies to support the idea.
3	Concept or application proven through analysis and experimentation	Active research and development begins, including analytical laboratory-based studies to validate the initial idea, providing and initial "proof of concept".
4	Basic prototype validated in laboratory environment	Basic examples of the proposed technology are built and put together for testing to offer an initial vote of confidence for continued development.
5	Basic prototype validated in relevant environment	More realistic versions of the proposed technology are tested in real-world or near real-world conditions, which includes integration at some level with other operational systems.
6	System or subsystem model or prototype demonstration in a relevant environment	A near final version of the technology in which additional design changes are likely is tested in real-life conditions.
7	System prototype demonstrated in a relevant environment	The final prototype of the technology that is as close to the operational version as possible at this stage is tested in real-life conditions.
8	Actual system completed and qualified for flight through test and demonstration	The technology is thoroughly tested and no further major development of the technology is required. Its operation as intended is demonstrated without significant design problems.
9	Actual system proven through successful mission operations	The final operational version of the technology is thoroughly demonstrated through normal operations, with only minor problems needing to be fixed. Any further improvements to the technology at this point, whether planned or not, will be treated as a TRL 1.

The TRLs provide a common understanding of the technology status and help engineers and management in making decisions concerning the development and transitioning of technology. Criteria and required deliverables are defined to determine when a technology can advance from one TRL level to the next one including formal validation processes. A similar set of Manufacturing Readiness Levels (MRLs) are used for assessing the maturity level of a manufacturing process.

[8] https://www.nasa.gov/sites/default/files/thumbnails/image/technology-readiness-level.gif National Academies of Sciences, Engineering, and Medicine, 2014

Certification

"Certification is the process under which it is determined that an aircraft, engine, propeller or any other aircraft part or equipment comply with the safety, performance environmental (noise & emissions) and any other requirements contained in the applicable airworthiness regulations, like flammability, corrosion resistance etc."[7]

The primary certification of the aircraft (or engine and propeller) is granted to the manufacturer by the Competent Aviation Authority of the "State of Design" which is typically the authority of the state where the manufacturer of the aircraft (or engine or propeller) is officially located, e.g. Civil Aviation Authority (CAA) in the UK and EASA in the EU in case of aircraft for the civilian sector. Aircrafts exported to other countries must also be certified (validated) by the respective authority of the "State of Registry".

A detailed description of the certification process is provided in the ECHA-EASA report[7]:

"Manufacturers work with the certification authorities to develop a comprehensive plan to demonstrate that the aircraft meets the airworthiness requirements. This activity begins during the initial design phase and addresses the aircraft structure and all systems in normal and specific failure conditions (e.g. tire failure, failure of structural components, hydraulics, electrical or engines). The tests needed to demonstrate compliance, range from thousands of coupon tests of materials, parts and components of the airplane, up to tests that include the complete aircraft or represents the complete aircraft (system). The performance and durability of the various materials have to be confirmed while the behaviour of the parts, components and the complete airplane will have to be tested in the applicable environmental and flight conditions including various potential damage or failure conditions. For a new Type Certificate this overall compliance demonstration covers several thousands of individual test plans of which some will require several years to complete. Often, after the initial issuance of the Type Certificate, the tests that have the objective to demonstrate durability of the aircraft during its service life, will continue.

All the different aspects covered by the Type Certificate together define the "approved type design" which includes, among other aspects, all the materials and processes used during manufacturing and maintenance activities. Each individual aircraft has to be produced and maintained in conformity with this approved type design.

Changes to the approved type design may be driven by product improvements, improved manufacturing processes, new regulations (including those such as new authorisation requirements under REACH), customer options or the need to perform certain repairs. When new materials or design changes are introduced, the original compliance demonstration will have to be reviewed for applicability and validity, in addition to a review of potential new aspects of the new material or design change that could affect the airworthiness of the aircraft. Depending on the change, this review could be restricted to coupon or component tests, but for other changes this could involve rather extensive testing. E.g. changes in protective coatings could affect not only the corrosion resistance but could also affect the friction characteristics of moving components in actuators in the different environmental conditions, changing the dynamic behaviour of the system, which in the end affects the dynamic response of the airplane.

Before the new material or design change can be introduced on the aircraft, all test and compliance demonstrations have to be successfully completed and approved by the Competent Authority. This approval results in the issuance of a Supplemental Type Certificate (STC), change approval or repair approval.

It is important to note that, according to the EU Regulation No 216/2008[9], EASA is the design competent authority for civil aircraft only. Any other aircraft (e.g. military, fire-fighting, state and police aircraft) will have to follow similar rules of the corresponding State of Registry.

To be able to maintain and operate an aircraft the responsible organisations must be approved by the competent authority and compliance is verified on a regular basis. Maintenance of an aircraft requires that the organization complies with specific procedures and materials described in the maintenance manuals which are issued by and the responsibility of the OEMs."

As indicated in the ECHA-EASA document, the duration of the certification process is from 6 months up to several years.

Industrialisation

The industrialisation of an alternative is described in the ECHA-EASA report:

"Industrialisation is an extensive step-by-step methodology followed in order to implement a qualified material or process throughout the manufacturing, supply chain and maintenance operations, leading to the final certification of the aerospace product. This includes re-negotiation with suppliers, investment in process implementation and final audit in order to qualify the processor to the qualified process.

Taking into account that an aircraft is assembled from several million parts provided by several thousand suppliers, this provides an indication of the complexity for the industrialisation stage of replacement materials/processes, and the supply chain which provides these parts.

Special challenges are:

- Low volumes limit influence on changes to suppliers' materials / processes
- Procurement & insertion of new equipment
- Scale-up & certification of new process
- Incompatibility of coatings could be a risk.
- Re-negotiation of long term agreements with suppliers.

The operating environment, longevity of the aircraft, supply chain complexity, performance and above all airworthiness requirements are some of the considerations which can constrain the ability of the industry to make changes and adopt substitutes in the short, medium or long term."

[9] Repealed by EU Regulation No 2018/1139

3.1.3. Market analysis of products manufactured with the Annex XIV substance

3.1.3.1. Description of the products

The applicant HD UK is part of Héroux-Devtek, the leading provider of landing gear systems and components to a diverse array of aircraft manufacturers. Over the years, the Corporation has developed landing gear systems that are recognized for their excellence and innovation. Numerous design improvements to existing landing gear systems developed by Héroux-Devtek have become industry standards on different programs. Such improvements not only ensure superior reliability and maintainability, but also increase the lifecycle of the landing gear.

At HD UK, the chrome coating is applied to aircraft components during production as well as repair of worn or damaged components removed from aircraft during overhaul. The chrome plated components include structural parts of landing gear systems as well as items such as hydraulic units (actuators, valves, accumulators) and flight controls. The aircraft components are supplied to all types of aircraft including military helicopters, advanced fighter jets, civil airliners and business jets. There are approximately [redacted] OEM/MRO aircraft platforms [redacted] for which HD UK provides chrome plated components. In addition, HD UK manufactures chrome plated components for [redacted] Many of the aircrafts have remaining lifetime of up to 25 years for MRO. All legacy programs have in excess of 12 years life left on them. In addition, HD UK chrome plates hydraulic components for military vehicles in use by [redacted]

Landing gear systems are one of the most critical systems of an aircraft. The landing gear of an aircraft is the structure that supports an aircraft on the ground and allows it to taxi, take-off and land. Landing gear is designed to repeatedly absorb and dissipate the kinetic energy of landing impact without causing damage to the aircraft or disturbance to passengers. The wheel braking system of the landing gear facilitates braking of the aircraft and the wheel steering system provides directional control of the aircraft on the ground.

At HD UK, chrome plating is applied to many components of the landing gear including all the major ferrous parts of the equipment: sliding pistons, attachment pins, axles, hydraulic cylinders etc. In total, HD UK applies chrome plating to [redacted] unique part numbers across the entire legacy product range as well as some of the new landing gear developments. Examples of these components are shown in the pictures below. The red arrows indicate the chrome plated surfaces.

#B

[redacted]

Figure 9. Examples of chrome plated components

#B

[redacted]

Figure 10. Examples of chrome plated components

3.1.3.2. Market analysis

The post-COVID boost in the air traffic has increased the number of airline services, which is spurring the market growth. The recovery of the global aerospace market is well underway. Global air passenger traffic has returned to 85 % of pre-pandemic levels and the growth prediction for this market is positive – with global backlog of Aircraft (between Airbus & Boeing) at over 11,800 a/c. In addition to the conventional a/c, there is a new market for landing gears emerging in the eVTOL (electric vertical takeoff & landing a/c) market. Aircraft manufacturers are focusing on weight reduction of the aircraft as it improves fuel efficiency and increase profit margins for the airlines. Thus, increasing demand for light weight landing gear is driving the market growth. In addition, increasing R&D investments and ongoing technological advancement in the aircraft models is expected to create significant opportunities for the market players in the future. Aircraft landing gear market size was valued at 9.21 B USD in 2020 and is projected to reach 34.62 B USD by 2028, growing at a CAGR of approx. 18 % from 2021 to 2028 according to Verified Market Research[10]. Other web-based outlets project more conservative growth figures but all conclude that the market is growing rapidly due to the post-COVID boost. The primary factors driving the market growth are increasing the adoption of modern aircraft due to their improved properties and fuel efficiency. In addition, with the growing demand for fleet expansion and the development of low-cost and ultra-low-cost airlines, the market is witnessing a surge in orders for commercial aircraft, which is expected to drive this market. In addition, increased government spending on military aircraft to strengthen defence capabilities could also contribute to market growth. Also, the adoption of unmanned aerial vehicles for military operations increases the market growth. Increased passenger air traffic and aircraft flight times are expected to increase the need for maintenance or equipment replacement and increase opportunities for aftermarket or maintenance, repair, and overhaul (MRO) operators. The MRO segment derives a significant portion of its revenue from these large exchange shipments. In addition, increasing the defence budget to modernize the fleet of aircraft by replacing traditional landing gear systems with technologically advanced technologies is the factor driving the growth of the market. In summary, the landing gear market looks healthy with high confidence in growth and new emerging markets opening up going forward.[10] [11]

In addition to the above, the applicant has access to more detailed market analysis of landing gears[12]. This analysis reports years 2019 and 2020. The entire market was severely hit by the pandemic; market size in terms of sales revenue plummeted almost 40 % in 2020. Because of this uncharacteristic crash in 2020 the following analysis reports the situation in 2019 as it is more representative with the current post pandemic situation where the market has almost entirely recovered.[12]

According to [redacted] [market research company], the market is quite hierarchical and consolidated. At the top of the tree are those companies which can supply an integrated landing gear system. This typically includes the wheels and brakes and sometimes the aircraft tyres as well. Although there are some integrated landing gear system contracts awarded by the aircraft OEMs, most landing gear is not procured in this

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[10] https://www.verifiedmarketresearch.com/product/aircraft-landing-gear-market/

[11] https://growthmarketreports.com/report/commercial-aircraft-landing-gear-market-global-industry-analysis

[12] [redacted]: Aircraft Landing Gear Market 2021

way and the system integration is performed to a lesser or greater extent by the aircraft OEM. Often the landing gear structure, the aircraft wheels and brakes, and tyres are awarded separately. On larger aircraft there is often a choice of supplier on wheels and brakes, and tyres, so the customer can choose from, for example, price and fleet commonality.[12]

The landing gear market can be segmented either by aircraft category (Table 8) or by component structure (Table 9). The estimated landing gear market size was 10.9 B USD in 2019. By aircraft category, the market is dominated by large commercial aircraft with approx. 65 % share as outlined in Table 8 below. By component category, the market is more balanced. However, gear structures contribute approx. 40 % to the entire market size.[12]

Table 8 and Table 9 also divides the entire market into three submarkets: original equipment market, spares market and repairs market. One of the most prominent features which distinguishes the landing gear market from many other industries is the share of spares and repairs markets; approx. 59 % of the market is spares and repairs. On a large commercial aircraft, landing gear is estimated to represent 20 % of total aircraft maintenance costs, the second largest proportion, after engines. Given the cost of landing gear MRO, there has been considerable effort put into minimising this with improved repair techniques and efforts to increase overhaul intervals.[12]

Table 8. Landing gear market size by aircraft category

Landing gear market size, M USD (constant 2020 USD)	**OE**	**Spares**	**Repairs**	**Total**
Large Commercial Aircraft	3,077	2,290	1,746	7,112
Business Jet	461	382	243	1,086
Regional	198	269	228	695
Freighter	207	251	192	650
Military Transport / Special Mission	252	201	130	583
Fighters and Jet Trainers	120	114	73	307
Turbine GA	83	73	44	200
Helicopter	83	78	36	198
UAV	29	6	4	39
Turboprop Trainers / Light Attack	11	15	10	35
Grand total	**4,521**	**3,677**	**2,707**	**10,904**

Table 9. Landing gear market size by component structure

Landing gear market size, M USD (constant 2020 USD)	OE	Spares	Repairs	Total
Gear structure	2,458	1,522	417	4,398
Tyres	39	628	1,639	2,306
Braking system	697	329	335	1,361
Actuation	782	467	89	1,338
Wheels	194	604	210	1,007
Sensors	128	56	6	189
Landing gear harnesses	122	40	7	169
Landing gear control computer	67	20	2	89
Hydraulic dressing	34	11	2	47
Grand total	**4,521**	**3,677**	**2,707**	**10,904**

In the report, [redacted] [market research company] proposes three scenarios for the next 10 years which show the impact of the Covid-19 pandemic on the industry. [redacted] [market research company] predicts a gradual recovery in the market with total production reaching 2019 levels in 2025 in its most likely scenario. See Figure 11 below related to market growth by aircraft category and Figure 12 by component structure.[12]

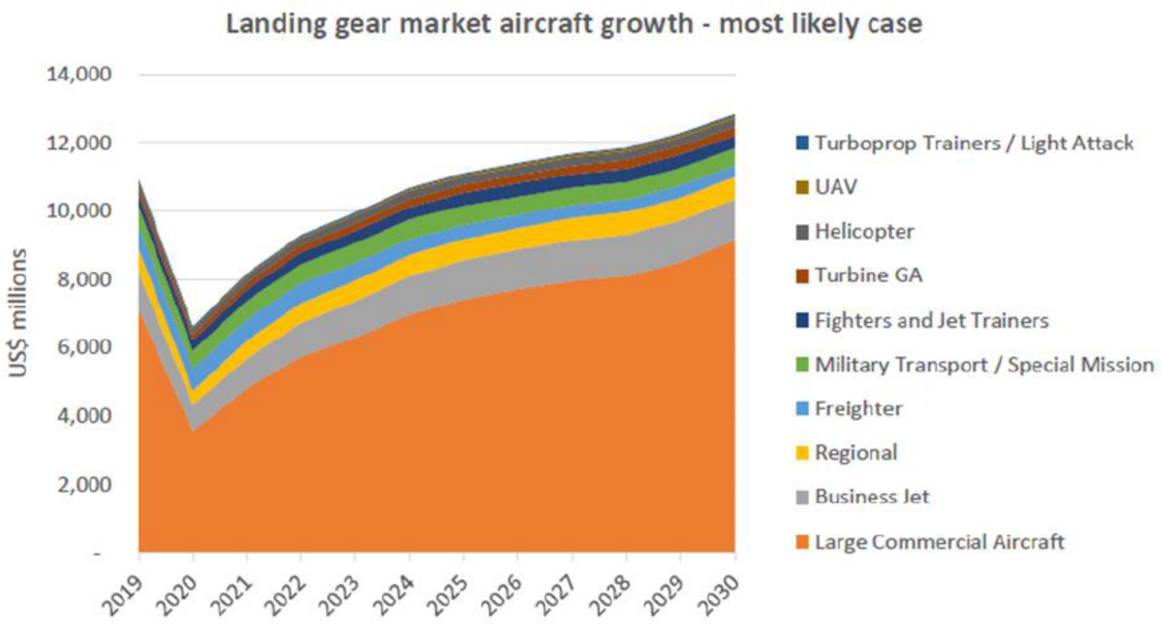

Figure 11. Landing gear market growth by aircraft category

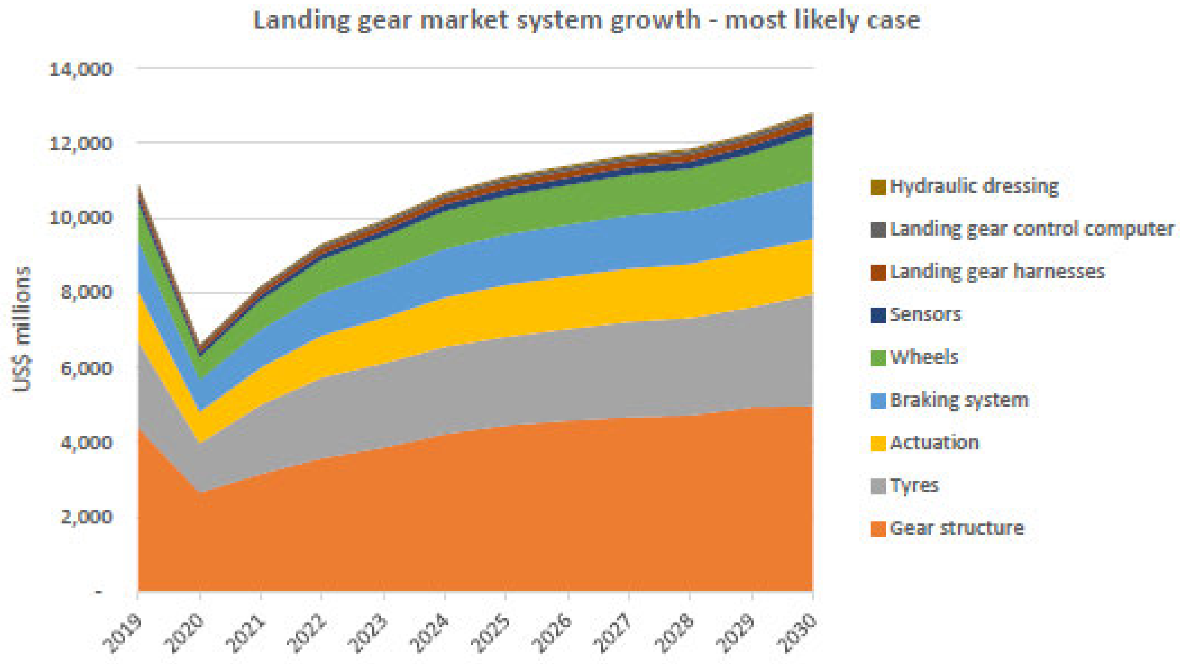

Figure 12. Landing gear market growth by component structure

The market for large commercial aircraft landing gear systems had been concentrated around Collins (Goodrich) and Safran Landing Systems (Messier Bugatti Dowty), but recently Heroux Devtek and Liebherr have increased their shares. However, the market is still dominated by Safran and Collins, which together accounted for 50% of the market in 2020. Heroux Devtek has grown both organically and by acquisition. The breakthrough for Heroux Devtek was winning the Boeing 777 from the incumbent supplier Goodrich in December 2013. This was followed by its acquisition of APPH in the UK which brought with it European defence and helicopter programmes, and CESA in 2017. Liebherr has grown organically from its position as a component supplier and supplier of smaller aircraft gear with a number of breakthrough contracts, particularly the A220, but it has also now established itself as a significant supplier to Boeing. Nevertheless, the market still remains a concentrated market as can be seen from Figure 13.[12]

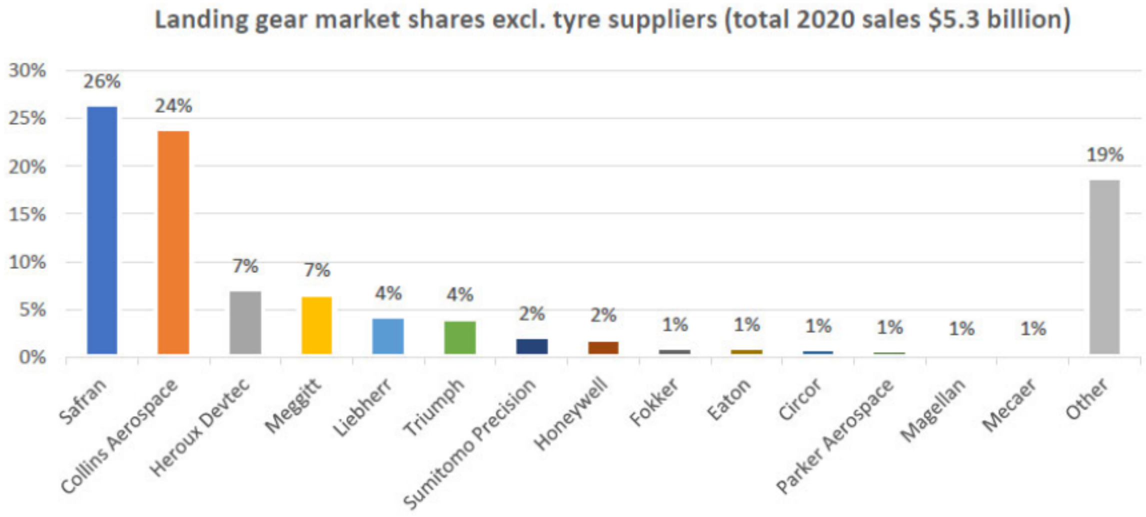

Figure 13. Landing gear market shares in 2020

The applicant estimates that the landing gear market size in Great Britain was [redacted] [100-500] M GBP in 2022. HD's market share is estimated at approx. [redacted] [5-20] % in the GB market. In the UK, the applicant focuses mainly on military products and operating in the country offers the applicant a significant advantage in supporting the UK customers.

3.1.4. Annual volume of the SVHC used

The highest annual forecast tonnage used at the site is the value used in the assessment; [redacted] [0.5-1.5] tonnes chromium trioxide/year ([redacted] [0.25-0.75] tonnes CrVI).

3.2. Efforts made to identify alternatives

As explained in Chapter 3.1.2.2, chromium trioxide based functional chrome plating results in a coating with a unique combination of properties including high surface hardness, wear and corrosion resistance, low coefficient of friction, strong adhesion and lubricant retention properties enabled by the microcracked structure of the coating. Thanks to these properties, the coating increases the durability of components subject to different demanding conditions (e.g. sliding wear, corrosion) and is particularly well suited for gas/oil sealing surfaces.

Over many years, chrome plating has become the industry standard in the aviation industry and is widely used on many different aircraft components to ensure reliable and safe performance for an extend lifetime. Finding a one-to-one replacement for chromium trioxide which fulfils all performance requirements is therefore a challenging task.

3.2.1. Research & development

Extensive research has been ongoing over several decades in the aerospace industry to find suitable replacements for chromium trioxide based functional chrome plating including both civil and military sectors in government funded and corporate research programs (Airbus Industries, Boeing). The possible alternatives investigated do not only include other electroplating processes with alternative substances but also alternatives based on completely different technologies (e.g. thermal spraying, vacuum deposition, thermochemical treatments). This includes the significant work done by the Hard Chrome

Alternative Team (HCAT) which was a joint collaboration between the defense departments of US and Canada, aerospace companies, and military overhaul depots. Previous R&D had already established High Velocity Oxygen Fuel (HVOF) spray coatings as the leading candidates for replacement of hard chrome. The objective of HCAT was to perform the demonstration and validation of HVOF coatings as a replacement for functional chrome plating in the aerospace OEM and military overhaul & repair (O&R) uses.[13] The task force adopted a Joint Test Protocol (JTP) to determine the necessary testing and criteria for success. The tests included corrosion, wear, fatigue, hydrogen embrittlement and impact resistance. Héroux-Devtek participated in the work of HCAT with focus on the research and development of suitable stripping processes for HVOF coatings.[13]

In general, HVOF coatings are considered as the most promising replacement for hard chrome plating and the alternative coatings have been qualified and implemented as a functional chrome plating replacement on specific aircraft components. For example, HVOF WC/CoCr coatings instead of hard chrome are applied on the landing gear of Boeing 767 and 777.[14] However, the transition to HVOF coatings will require significant time as the development of new aircraft landing gears is both lengthy and costly. Functional chrome plating will be needed to produce landing gears for existing aircrafts and to ensure the availability of spare parts. In the report published by the German Federal Institute for Occupational Safety and Health (Bundesanstalt für Arbeitsschutz und Arbetismedizin, BAuA) in 2020, a manufacturer of aerospace landing gear was interviewed.[15] The company uses HVOF for low-alloyed high-tensile steel aviation shock absorbers in individual and small series production while overall ca. 95 % of all parts are still chrome plated.

The substitution efforts at HD are also focused on the implementation of HVOF technology. The HVOF coating WC/CoCr was introduced by HD in Canada on new development programmes [redacted]. The coating was sourced from an external supply chain since the process was not available internally within the company. HD UK is currently starting to deploy HVOF coatings for some of its new development programmes and the in-house qualification process is ongoing for these (see Chapter 4.1.3 for further information). Due to some well-known shortcomings of HVOF technology (see Chapter 3.3.1.4), the alternative cannot replace functional chrome plating 100 % in HD UK's use. This means that at least one additional alternative would have to be identified to completely phase out the use of chromium trioxide in functional chrome plating.

In addition, HD currently has an R&D project aiming [redacted] At the moment the results are unpublished and pending completion of testing.

Over the years, different suppliers have developed alternative coating processes with the aim to replace functional chrome plating, also in use areas where HVOF coatings are not applicable or to provide solutions that provide superior performance compared to both functional chrome plating and HVOF. Hardide Coatings has developed a low-temperature

[13] Sartwell B.D. et al., 2004

[14] Legg K. & Sartwell B.

[15] Müller A. et. al., 2020

Chemical Vapour Deposition (CVD) coating Hardide-A specifically for the aerospace industry. The process is suitable for coating internal surfaces and complex geometries. Nanovate CoP is another alternative developed by Integran Technologies and suggested as a "drop-in" replacement for functional chrome plating. The alternative is an electroplating process involving the deposition of a nanocrystalline cobalt-phosphorus (nCoP) coating. The alternative has been demonstrated and validated by the US DoD.[16]

3.2.2. Consultations with customers and suppliers of alternatives

Extensive consultations have already been undertaken with both alternative providers and technical experts in surface treatment in the search for suitable alternatives for functional chrome plating within the aerospace industry. As explained above, the HVOF coating was originally sourced from an external supply chain when introduced at HD. Since then, HVOF coating lines have been installed at some facilities within the HD Group (outside UK). In preparation of this authorisation application, the websites of alternative providers were also consulted for a review of the latest information on alternatives.

The OEM customers are not actively involved in the identification (including R&D activities) or implementation of chrome plating alternatives in respect of HD's components. The OEM customers demand REACH compliant equipment and proposals from HD UK on how to achieve this. The customers are mainly only involved in the approval of the alternative proposed by HD UK and to interface with the relevant authorities to ensure that the airworthiness of the product is maintained. See Chapter 4.1.3 for further information.

3.2.3. Data searches

Extensive data searches on alternative coating technologies and surface treatment processes used for improving the wear and corrosion resistance properties of steel and other metal products have been made for the identification of possible functional chrome plating replacements in the aerospace industry. HD has closely followed the development of alternatives and results from R&D including sector specific publications.

For the preparation of this authorisation application, publicly available information on possible alternatives for functional chrome plating has been carefully reviewed including scientific papers, public versions of authorisation applications for similar uses and information available on alternative provider websites. Based on the results from R&D projects, consultations and data searches, the complete list of alternatives identified as possible replacements was compiled and a preliminary assessment of their technical feasibility was conducted for the categorisation of the alternatives as presented in Table 10.

3.2.4. Identification of alternatives

Based on the efforts described in Chapters 3.2.1 - 3.2.3, the complete list of alternatives identified by HD UK as possible hard chrome plating replacements for aircraft components is presented in Table 10. The alternatives represent different coating technologies and surface treatment processes used for improving the wear and corrosion resistance

[16] ESTCP (WP-200936), 2017

properties of steel and other metal products. These alternatives are further categorised into shortlisted, potential alternatives not yet assessed and rejected alternatives.

Table 10. List of identified alternatives

Category	No.	Alternative	Description
Shortlisted	1	Thermal spraying (HVOF #B [redacted])	High Velocity Oxygen Fuel (HVOF) is a thermal spray coating process in which the coating material is fed into a chamber with a pre-ignited mixture of oxygen and fuel. The exhaust gas is ejected through a spray gun nozzle at supersonic speeds, accelerating the semi-molten coating material and propelling it towards the substrate surface. #B [redacted]
Potential alternatives not yet assessed	2	Nanocrystalline cobalt-phosphorus (nCoP) electroplating	The nCoP coating is deposited in an electrolytic process using pulse plating technology for controlling and building fully dense, nano-grain size deposits.
	3	Physical Vapour Deposition (PVD)	PVD is a common name for various vacuum technologies in which a coating material in condensed state is first vaporised in a vacuum chamber and then condensed onto the substrate to form a thin coating.
Rejected alternatives	4	Trivalent chromium (CrIII) based functional chrome plating	CrIII based functional plating is an electrolytic process in which a chrome coating is deposited from an electrolyte solution containing CrIII ions instead of CrVI. A nickel underlayer is necessary for increased corrosion resistance and adhesion, as well as a post-plating heat treatment to increase the hardness of the coating.
	5	Nickel and nickel alloy electroplating (including nickel matrix/dispersion coatings)	Nickel electroplating is an electrolytic process in which a nickel or nickel alloy (e.g. nickel phosphorus alloy NiP) coating is deposited from an electrolyte solution containing NiII ions. Dispersion coating consist of a nickel matrix and additive particles (e.g. silicon carbide).
	6	Electroless nickel plating	The NiP coating is deposited in an electroless process by chemical reduction of nickel ions to metallic nickel using a reducing agent such as sodium hypophosphite.
	7	Chemical Vapour Deposition (CVD)	CVD is another vapour deposition method in which the coating material is in gas or vapour phase and reacts with the heated surface of the item to be plated to form a coating via a chemical reaction.
	8	Case hardening	Case hardening is a thermochemical treatment based on the diffusion of specific elements (e.g. nitrogen, carbon, boron) into a metal surface (typically steel) to increase its hardness. Three main variants of the process exist: salt bath nitriding/ nitrocarburising, gas nitriding/ nitrocarburising and plasma nitriding.

Category	No.	Alternative	Description
	9	Laser cladding	Laser cladding uses the energy of a laser beam to melt metallic coating material and metallurgically bond it to the substrate surface. Modern improvements of laser cladding such as the extreme high-speed laser material deposition (EHLA) process are considered as traditional laser cladding is too slow, the coating layers are too thick (> 500 µm) and the surface is too rough.

The process and performance related functionalities defined in Chapters 3.1.2.1 and 3.1.2.2 for functional chrome plating were used as the starting point in the identification and preliminary assessment of possible alternatives. The shortlisted alternative is considered as the most promising alternative and its implementation at HD UK has already started. A detailed assessment is presented in Chapter 3.3. However, in order for an alternative to become suitable and available for deployment at HD UK, it must be successfully qualified, certified and industrialised as explained in Chapter 3.1.2.3. The (re-)qualification will be conducted at either component and/or sub-system level, i.e. landing gear or actuator depending on the part. The same level of demonstration is required for the (re-)qualification of both aircraft and military vehicle components by each customer.

For the rejected alternatives, clear technical and/or economic limitations were identified in the preliminary assessment, which is why these alternatives are not considered to be suitable as functional chrome plating replacements in HD UK's use. The reasons which led to the rejection of Alternatives 4-9 are summarised in Chapter 3.2.5.

In addition, Alternatives 2 and 3 were considered as potential based on the preliminary findings from data searches. A brief discussion of these alternatives is provided in Chapter 3.2.6.

3.2.5. Assessment of rejected alternatives

The reasons which led to the rejection of Alternatives 4-9 are summarised in Table 11. Some of the alternatives have been rejected based on well-known technical limitations while other fail to meet the minimum performance requirements in the aviation sector.

Table 11. Assessment of rejected alternatives

No.	Alternative	Reasons for rejection (technical and/or economic limitations)
4	Trivalent chromium (CrIII) based functional chrome plating	• The coating has a tendency to form macrocracks • The technology readiness level is low and the current experience of CrIII plating technologies is mainly based on laboratory or other small scale testing • Some processes require post-heat treatments at high temperatures which adversely affect the mechanical properties of the base material

No.	Alternative	Reasons for rejection (technical and/or economic limitations)
5	Nickel electroplating (traditional and nickel matrix/dispersion coatings)	• Low hardness • Low wear resistance • Low corrosion resistance • Dispersion coatings: Wear causes surface roughness to increase as softer nickel matrix is removed, exposing the harder reinforcing particles leading to high abrasion on countersurface and/or unacceptable dimensional change • Dispersion coatings: maintaining bath chemistry is more complex, ensuring uniform distribution of additive particles in deposit challenging especially for large volume plating baths • Requires heat treatment at 340–400° for several hours → The high process temperature adversely affects the mechanical properties of the base material • SVHC substance boric acid (toxic for reproduction, Repr. 1B; H360FD) is used as buffer
6	Electroless nickel plating	• Electroless nickel plating is already in use at the applicant for some parts, but the quality of the finished coating can be unpredictable and it is not suitable for gas/oil sealing surfaces • Bath maintenance and pre-treatments more complex compared to functional chrome plating • Low process reliability • Low hardness • Low wear resistance • Difficult to obtain thicker coatings
7	Chemical Vapour Deposition (CVD)	• The high process temperatures (600-1000 °C) adversely affect the mechanical properties of the base material. This is also true for the low-temperature (up to 500 °C) CVD process developed by Hardide Coatings[17] • The process is complex and requires qualified and experienced operators to obtain high-quality coatings. The applicants have no experience in this technology
8	Laser cladding (EHLA process)	• The high process temperatures adversely affect the mechanical properties of the base material • Only applicable to rotationally symmetrical objects (not possible to coat internal diameters, complex geometries) • Post-treatment challenging (time-consuming and costly) • The process is complex and requires qualified and experienced operators to obtain high-quality coatings. The applicant has no experience in this technology • Very expensive compared to CrVI based functional chrome plating

[17] https://hardide.com/hardide-a-coating-for-aerospace/

No.	Alternative	Reasons for rejection (technical and/or economic limitations)
9	Case hardening	• The high process temperatures (400-600 °C) adversely affect the mechanical properties of the base material • The corrosion protection is insufficient even after additional post-oxidation treatment • Traditional case hardening treatments lower the corrosion resistance of base material due to formation of chromium carbides (this can be avoided in low-temperature processes) • The process does not result in an additional coating layer on top of the substrate which means that extensive dimensional re-design would be required and the alternative is not suitable for component rebuilds • Toxic cyanide salts are used in case of salt bath nitriding/ nitrocarburising

3.2.6. Shortlisted and potential alternatives

As already mentioned, the thermal spraying technology High Velocity Oxygen Fuel (HVOF) is currently in use at HD UK for some of its new development programmes. In addition to shortlisted Alternative 1, Alternatives 2-3 have been identified as potential replacements for functional chrome plating in HD UK's use. Since HD UK has to date not conducted any internal R&D on these potential alternatives, no conclusion can be made on the technical feasibility of these alternatives in HD UK's use at this time. As HD UK's current substitution efforts are focused on the shortlisted alternative, possible R&D efforts on Alternatives 2 and 3 are likely to only start in the future once the substitution potential of Alternative 1 across the applicant's product portfolio has been reviewed.

Table 12. Shortlisted and potential alternatives

Category	No.	Alternative	Description
Shortlisted	1	Thermal spraying (HVOF [redacted])	High Velocity Oxygen Fuel (HVOF) is a thermal spray coating process in which the coating material is fed into a chamber with a pre-ignited mixture of oxygen and fuel. The exhaust gas is ejected through a spray gun nozzle at supersonic speeds, accelerating the semi-molten coating material and propelling it towards the substrate surface. [redacted]
Potential alternatives not yet assessed	2	Nanocrystalline cobalt-phosphorus (nCoP) electroplating	The nCoP coating is deposited in an electrolytic process using pulse plating technology for controlling and building fully dense, nano-grain size deposits.
	3	Physical Vapour Deposition (PVD)	PVD is a common name for various vacuum technologies in which a coating material in condensed state is first vaporised in a vacuum chamber and then condensed onto the substrate to form a thin coating.

A brief discussion of the potential alternatives and their technical feasibility is provided below based on results from data searches.

Alternative 2: Nanocrystalline cobalt-phosphorus (nCoP) electroplating

Electroplated nanocrystalline cobalt-phosphorus (nCoP) coating (commercial name Nanovate CoP) has been developed by the alternative provider Integran Technologies as a functional chrome plating replacement to provide corrosion resistance, wear resistance or to rebuild and restore the dimensions of damaged substrates. As the coating is deposited from an aqueous plating solution, it is suitable for coating of both external surfaces and internal/non-exposed surfaces. Based on conclusions from US DoD's Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) projects, the nCoP coating exhibits properties equal to or in some cases even superior to that of electroplated chrome. A summary of the coating properties in comparison to functional chrome plating is provided below:[16, 18]

- **Wear resistance:** Improved performance in pin-on-disc sliding wear testing due to lower **coefficient of friction** (against Al_2O_3 ball), reduced performance in Taber abrasive wear testing, equivalent performance in rod-seal testing
- **Hardness:** The hardness of the nCoP coating as deposited is 550-600 HV. The hardness can be increased to 700-750 HV by a heat treatment (annealing), but is still lower compared to hard chrome (coating hardness typically 800-1200 HV)
- **Surface finish:** Coating microstructure is fully dense and free of pore and cracks
- **Adhesion:** similar performance in adhesion testing
- **Layer thickness:** Uniform nCoP coatings with thicknesses between 0.0002" (5 µm) and 0.040" (1000 µm) can be deposited

In addition, nCoP offers the following process related advantages:[16, 18]

- The overall plating efficiency is much higher (ca. 90 %) compared to functional chrome plating (< 35 %) leading to energy savings
- The deposition rate of nCoP is 5 times faster (up to 0.008" per hour [200 µm/h]) compared to functional chrome plating (up to 0.0016" per hour [40 µm/h]) leading to higher process throughput
- Electrolyte is stable and can be controlled with periodic maintenance and adjustments to plating bath chemistry. However, the plating bath is susceptible to contaminants otherwise benign in functional chrome plating
- The process is compatible with existing plating infrastructure (pre- and post-treatments). Current grinding procedures for chrome are applicable to nCoP coatings

[18] Prado R.A. et al., 2009

- Lead anodes (used in functional chrome plating) replaced with safe anodic material
- The production labour, material and supplies costs are higher for nCoP, but the lower utilities and environmental costs suggest that the total cost per unit area for nCoP is about a third to that of hard chrome

The process is covered by the Aerospace Materials Specification AMS2428 issued by SAE (Society of Automotive Engineers) International and the U.S. DoD Mil-Spec MIL-DTL-32502. The main disadvantages are the inferior abrasion resistance and the lower coating hardness. Based on above information, HD UK considers Alternative 2 as a potential replacement for hard chrome. However, the data currently available for this coating in public literature is very limited. Consequently, a test campaign would be required to determine whether this alternative coating is a suitable alternative to functional chrome plating on HD UK's designs.

Alternative 3: Physical Vapour Deposition (PVD)

PVD coatings have attracted the interest of aerospace industry as potential functional chrome plating replacements. One example is BALINIT C from alternative provider Oerlikon Balzers. The alternative is a tungsten carbide/carbon (WC/C) coating deposited using PVD sputter technology. A summary of the coating properties based on information from the alternative provider is provided below:[19]

- **Wear resistance:** The coating provides resistance against fretting, sliding and general surface wear. The wear volume is low due to the low layer thickness
- **Hardness:** The coating has a high hardness (10-15 GPa)
- **Corrosion resistance:** The coating offers corrosion resistance but this is insufficient due to the low layer thickness
- **Coefficient of friction:** The coating has a low coefficient of friction which helps to reduce sliding wear
- **Adhesion:** The coating forms a strong metallic bond with the component surface offering stronger adhesion to metal substrates than hard chrome
- **Layer thickness:** The coating thickness is between 1-5 µm and is therefore only applicable to limited use areas

The coating is very thin and has a limited load-bearing capacity. The corrosion resistance is also insufficient due to the thin coating. As Alternative 2 fails to fulfil many of the key requirements it is not considered to become suitable as a general replacement in HD UK's use. The process is limited to treating components with maximum dimensions of 250 x 1000 mm (D x L). These coatings could be potentially used to avoid galling when two similar metallic materials are in contact.

[19] Aerospace Manufacturing and Design, 2019

3.3. Assessment of shortlisted alternatives

In this chapter, the shortlisted alternative is assessed in terms of its availability, safety, technical feasibility and economic feasibility as a functional chrome plating replacement for HD UK. The requirements for the key process and performance related functionalities as defined in Chapters 3.1.2.1 and 3.1.2.2 form the assessment criteria for technical feasibility. This assessment is based on information on HD UK's current experience of the alternative coating process as well as information found through literature searches. The following colour codes are used in the assessment of the technical feasibility of the shortlisted alternatives.

Table 13. Colour codes used for assessment of alternatives

Colour	Description
	Technical requirement fulfilled
	Criteria fulfilment partial/unclear
	Technical requirement not fulfilled

3.3.1. Alternative 1: Thermal spraying (HVOF #B [redacted])

3.3.1.1. General description of Alternative 1

High velocity oxygen fuel (HVOF) #B [redacted] A typical HVOF installation consists of:[13]

- a soundproof booth with a separate operator control room, an observation window and a high-volume air handling system drawing air and dust out of the booth
- a spray gun and control panel
- a powder feeder
- an industrial robot to manipulate the spray gun
- a supply of oxygen and fuel (e.g. hydrogen, ethylene or kerosene)
- dust extractor and bag-house filter system
- dry, oil-free compressed air for cooling the component and gun
- water cooling for gun (in most cases)

During use, a fuel and oxygen are mixed and ignited inside the combustion chamber of the spray gun. The resulting extremely high temperature (2700-3100 °C) and pressure gas is then accelerated by ejecting through the spray gun nozzle at extremely high speed (1500-2000 m/s). The coating material in the form of fine powder is fed into the gas stream, which accelerates and partially melts the coating material. Automation is used to direct the spray gun towards the surface of the part to be coated, which is rotated evenly along its longitudinal axis (see Figure 14).

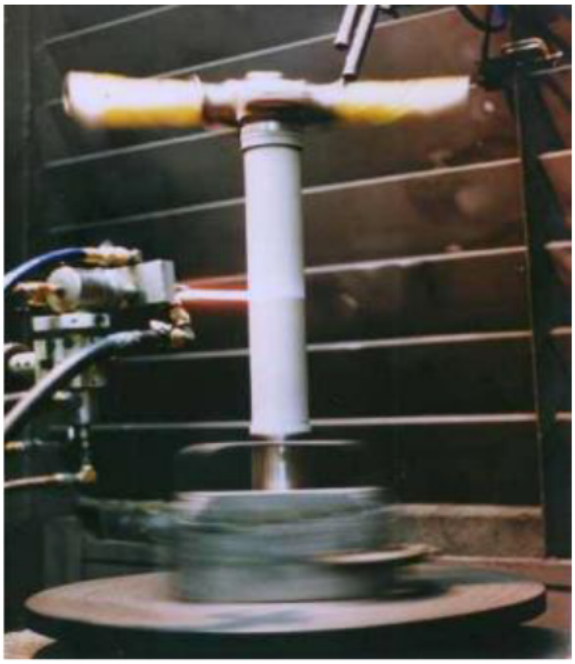

Figure 14. HVOF spray of landing gear inner cylinder[13]

#B [redacted]

HVOF #B [redacted] spraying are complex and sensitive processes where the quality of the coating depends on many variables in the deposition process (e.g. powder size, powder feed rate, gas flow, ratio of fuel gas to oxygen/air, spray distance, traverse speed) and preparation of the substrate prior to thermal spraying.[13] The operating conditions must be optimised for the coating material used and adjusted for different components to ensure correct coating speed and gun traverse rate. For this reason, qualified and experienced operators are required to create masking and to develop correct spray parameters and gun motions to achieve a high coating quality. This means that chrome plating line personnel require extensive retraining to successfully operate an HVOF #B [redacted] system. The operation itself is generally easy, since commercial HVOF #B [redacted] systems are programmable.

Prior to coating, the parts need to undergo specific pre-treatments, which involve degreasing and surface roughening. Surface roughening can be done by grit blasting and is needed to improve the adhesion between the coating and the substrate by creating irregularities on the substrate surface. After the applying the coating, the parts need to be grinded and polished in order to obtain the desired surface finish and to meet the dimensions of according to part design.

HVOF is a versatile technology that allows for the deposition of a wide range of coating materials such as pure metals, ceramics, metal alloys and cermets (composite materials made of ceramic and metal materials). [redacted] The coating can be tailored to specific use areas and the functional needs thereof. Common HVOF [redacted] coatings include the cermets tungsten carbide/cobalt (WC/Co) and tungsten carbide/cobalt-chrome (WC/CoCr). These coatings have also been most extensively studied as functional chrome plating replacements in the aerospace industry.[13] At HD UK, the HVOF coating WC/CoCr is being implemented.

3.3.1.2. Availability of Alternative 1

The equipment and coating materials needed for HVOF technology are commercially available from different suppliers[20] and the alternative can be considered as available in general. However, in order for HVOF technology to become available for HD UK as a functional chrome plating replacement, it must be successfully qualified for the aircraft components. A qualified alternative must be certified and industrialised in order to become available for deployment.

It should also be noted that the metals commonly used in HVOF coatings pose a supply risk. Both cobalt (Co) and tungsten (W) are included in the European Commission's list of critical raw materials.[21] Co is generally mined as a by-product of other elements.[22] Most of the Co reserves are in the seafloor, and not economically efficient to mine. In 2018, around 70% of all Co produced worldwide was from Congo and the country accounts for more than 50% of the Co reserves.[23]

3.3.1.3. Safety considerations related to using Alternative 1

HVOF [redacted] spraying eliminate the use of hexavalent chromium. Any chromium contained in the coating material is present in the metallic form (Cr0), which is non-hazardous. The HVOF [redacted] coatings WC/Co and WC/CoCr contain cobalt, which is classified as a Category 1B carcinogen.[24]

Table 14. Harmonised classification of cobalt

Cobalt (CAS 7440-48-4)	
Skin Sens. 1	H317
Resp. Sens. 1	H334
Muta. 2	H341
Carc. 1B	H350
Repr. 1B	H360F
Aquatic Chronic 4	H413

[20] https://www.twi-global.com/technical-knowledge/faqs/faq-what-types-of-hvof-spraying-equipment-are-available
[21] COM/2020/474 final
[22] https://www.cobaltinstitute.org/about-cobalt/cobalt-life-cycle/cobalt-mining/
[23] https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-cobalt.pdf
[24] Classification according to Annex VI of Regulation (EC) No 1272/2008

Unlike hexavalent chromium in chrome plating, cobalt is not emitted into air. There is a significant amount of overspray with HVOF [redacted] spraying and the spray booth must be equipped with an efficient dust extraction and bag-house filter system to capture the excess coating powder containing cobalt. Respiratory protective equipment should be worn when handling cobalt-containing powders, working in the booth or grinding the coating after deposition.

HVOF [redacted] spraying is a very loud process associated with unsafe noise levels of 130 dB. To give some context, a jackhammer emits sound at 130 dB. This level of noise can cause immediate pain and ear damage. For this reason, HVOF spraying must be carried out in a soundproof booth with remote control of the spray gun.

Some of the coating materials used in HVOF [redacted] spraying involve cobalt which raises concerns since cobalt itself is classified as a Category 1B carcinogen and some cobalt compounds are also included in the REACH candidate list for substances of very high concern. Overall, the transition to HVOF could lead to a reduction in risks when operated in an appropriate soundproof booth equipped with a sufficient extraction system.

3.3.1.4. Technical feasibility of Alternative 1

The technical feasibility of HVOF coatings is assessed against the requirements for the key process and performance functionalities defined in Chapters 3.1.2.1 and 3.1.2.2. The exact properties of the HVOF coatings are obviously dependent on the selected coating material. This assessment discusses both HVOF WC/Co and WC/CoCr coatings which have been qualified within the aerospace sector as replacements for functional chrome plating for specific aircraft components.[14] The latter is being implemented at HD UK for new development programmes and it is expected that this alternative coating can be deployed on both aircraft and military vehicle components.

[redacted]

Process temperature

Thermal spray methods cause local heating, which in some cases can be a problem since high process temperature adversely affects the mechanical properties of the base material. However, careful consideration of cooling methods and substrate-gun motion can usually hold temperatures at acceptable levels. [redacted]

Compatibility with component geometry

HVOF spraying is restricted to coating of rotationally symmetric components. As line-of-sight processes, coating of non-exposed surfaces such as internal diameters of cylinder-shaped components is not possible. HVOF requires a spray distance of at least 150-300 mm. These inherent properties of the technology restrict the type of components that can be coated with HVOF technology. [redacted]

[redacted] However, this cannot be confirmed without a comprehensive review of all HD UK's drawings.

[redacted]

In conclusion, HVOF is not suitable for coating of components with complex geometries and/or non-exposed surfaces and the requirement is not fulfilled.

Component rebuilding / repairs

HVOF is in use at overhaul depots in the aerospace sector for MRO activities including rebuild or repair of worn aircraft components. HVOF WC/Co and WC/CoCr coatings can be chemically stripped without damaging the base material or causing dimensional distortion of the component.[13] Grinding off the coating would be too labour intensive and could also damage the base material.

HVOF cannot easily be used for MRO activities on worn or corroded components originally manufactured with chrome plating for existing aircrafts. The successful re-qualification and customer approval is a pre-requisite. Due to the different properties of HVOF coatings and hard chrome, the impact of the replacement on other interacting aspects of the design must also be considered to ensure component compatibility in the assembly. For example:

- Where the chrome is replaced with HVOF for gas or oil sealing it is highly probable that the seals, seal glands and bearings may also have to be changed.
- HVOF cannot be used to repair non-line-of-sight surfaces, e.g. internal bores which mate with seals to contain a nitrogen gas volume. Although it is unclear which alternative could replace chrome plating in these cases, the alternative coating / surface treatment will have an effect on the separator piston which typically houses the seal and the bearing.
- Where the chrome is replaced in dynamic joint, the material of the mating part must be considered to ensure not only that friction is minimised but also there is no galling or galvanic effects etc. between the mating surfaces.

Another challenge is the configuration control of the OE and legacy equipment. Replacing chrome would be considered as a change to either the fit, form or function of the landing gear. Therefore, a whole new set of parts numbers and assemblies would have to be created for the 'HVOF variants' for each of the existing variants. For the legacy equipment supply spare parts are likely only supplied to the customers as required or as part of an overhaul. Therefore, HVOF and their mating parts will be introduced on an 'ad hoc' basis onto the equipment leading to difficulties in controlling the configuration. Both of these configuration aspects will require close cooperation of all of HD UK's customers and management of cut in will be logistically very difficult and time consuming.

In conclusion, this criterion can be considered as fulfilled for new aircraft component designs, but it is not fulfilled for existing aircraft components including OE equipment for aircrafts still in production and legacy equipment for aircrafts still in service but no longer

25 [redacted]

in production. Functional chrome plating is needed for MRO of existing aircrafts and to ensure the availability of spare parts.

Wear resistance

The wear rate of HVOF coatings is typically 3-5 times lower than hard chrome. The HCAT team estimated that thanks to this superior wear resistance of HVOF WC/Co and WC/CoCr the implementation would lead to a 50% extension of service life compared to the service life of chrome plated components.[13] HD UK considers the requirement for wear resistance to be fulfilled for the HVOF WC/CoCr coating.

HVOF coatings can suffer from selective wear or leaching of the cobalt binder which exposes the hard tungsten carbide (WC) grains, which are highly abrasive for seals and other countersurfaces.

Hardness

The hardness of the HVOF coating depends on the coating material and also the thermal spraying method. The HVOF WC/Co (microhardness ca. 900-1400 HV) and WC/CoCr (microhardness ca. 1000-1400 HV) coatings are harder compared to hard chrome. The criterion is therefore fulfilled.

It should be noted however, that the higher hardness makes machining more challenging (expensive diamond wheels needed) and also makes it necessary to change the materials of mating surfaces to ensure tribological compatibility. This is also mentioned in the report from BAuA.[15] The increased hardness also makes the coating more rigid and brittle.

Corrosion resistance

The results from corrosion resistance testing (including salt spray test according to ASTM B117) performed by HCAT, the corrosion resistance of functional chrome plating outperformed that of HVOF WC/CoCr and WC/Co coatings, while HVOF WC/CoCr performed better compared to WC/Co.[13] Although the performance of the HVOF coatings in the standard ASTM B117 salt spray test is inferior to that of functional chrome plating, the actual corrosion performance in service is much better.[26]

#B [redacted], the corrosion protection provided by the coating was not as good as expected. However, improvements were brought to the process over the last decade and the corrosion protection is not an issue anymore. The requirement for this functionality is fulfilled for the HVOF WC/CoCr coating.

Coefficient of friction

HD UK considers the requirement for coefficient of friction as generally fulfilled with regards to the HVOF WC/CoCr coating. It should be noted however that the chrome plated parts are often used in dynamic joints and therefore can only be adequately demonstrated from a friction perspective as part of the whole system. These tests involve the 'stroking'

[26] Legg K., 2007

of the assemblies through a number of agreed cycles. It is expected that similar tests will be required where the chrome plating is substituted.

Surface finish

HVOF coatings are typically very rough as deposited and require mechanical post-processing (diamond grinding or superfinishing) to achieve desired surface finish. A rough and hard coating on a hydraulic rod would quickly damage the seal it runs against. Due to the higher hardness, a much finer surface finish is required for HVOF coatings #B [redacted] For gas/oil sealing surfaces, the much more demanding surface finish requirement can lead to processing difficulties or premature seal wear. However, with the correct surface finish and selection of sealing material it is possible to achieve extended seal life for HVOF coated hydraulic components.[13, 14]

In conclusion, the criterion is considered to be fulfilled for the HVOF WC/CoCr coating provided that the correct surface finish is achieved and impacts on the design needs including choice of sealing technology are taken into account.

Adhesion

Unlike chrome plating where the coating is metallurgically bonded to the substrate, HVOF coatings require a physical lock on the surface, which is achieved by a grit blasting pre-treatment prior to spraying. This mechanical bonding is not as strong as the bonding of the chrome coating but is still adequate for almost all practical purposes.[27] The requirement for this functionality is therefore considered to be fulfilled for the HVOF WC/CoCr coating.

It should be noted that residual stress can build up during the coating process, especially in case of the typically thicker HVOF coatings. Spalling, delamination or cracking of the more brittle HVOF coatings can occur under very high loads and high cyclic fatigue conditions.[28]

Layer thickness

It is not possible to obtain a HVOF coating with uniform thickness, particularly on larger items. It is therefore necessary to deposit a thicker coating than what is ultimately wanted and then machine it down to obtain a uniform layer thickness. Due to high coating hardness, grinding HVOF WC/Co coating requires a diamond grinding wheel, which are very expensive. HVOF coatings can be deposited from typical OEM thicknesses of #B [redacted] and thus the HVOF coatings can match the layer thickness of the hard chrome coating.[27] The requirement for this functionality is therefore considered to be fulfilled.

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[27] Legg K.O., Sartwell B., 2004

[28] Gui M. et al., 2015

Conclusion

Table 15 summarises the technical feasibility assessment of Alternative 1. As can be seen, the HVOF WC/CoCr coating mostly fulfils the process and performance requirements identified in Chapter 3.1.2.

Table 15. Assessment overview of the technical feasibility of Alternative 1

Process temperature	Compatibility with component geometry	Component rebuilding	Wear resistance	Hardness	Coefficient of friction	Corrosion resistance	Surface finish	Adhesion	Layer thickness
🟢	🔴	🟡	🟢	🟢	🟢	🟢	🟢	🟢	🟢

The main disadvantages of the HVOF coatings are the inability to coat components with complex geometries and/or non-exposed surfaces (internal surfaces/bores), the more demanding surface finish requirement and the risk of coating spallation under high loads. HVOF coatings are more easily applied to new equipment being developed as the equipment design can be tailored around this technology taking into account its specific design parameters rather than those of chrome plating. In most cases, the hard chrome coating cannot be replaced with a HVOF coating without additional re-design of the component and other parts of the assembly, which is time-consuming. The replacement is in all cases also only possible after successful re-qualification and customer approval. The configuration control of 'hard chrome and HVOF variants' of OE and legacy equipment is also challenging.

In addition to the process and performance related criteria discussed in this chapter, HVOF coatings offer other advantages compared to functional chrome plating as documented by HCAT[13, 27]:

- Simplified masking: less masking is required compared to functional chrome plating. However, the waxes and tapes used for masking in functional chrome plating cannot be used. HVOF uses hard masks (usually metal shim), often made for the specific parts being coated, which means that an inventory of these masks must be built up efficient production.
- HVOF offers improved deposition quality adjacent to holes and keyways.
- Minimum impact on the substrate fatigue performance, equal or better fatigue performance compared to functional chrome plating.[29]

[29] Fatigue strength is the strength a material can withstand for a given number of cycles without breaking. Chrome plating is known to cause a very significant fatigue debit (i.e. the fatigue strength of chrome plated substrate is lower than that that of uncoated substrate).

In conclusion, the HVOF coating WC/CoCr is considered as the most promising replacement for functional chrome plating at HD UK. However, the alternative is not applicable to all components due to geometric restrictions and the transition from functional chrome plating to HVOF coatings is not possible to complete in the short-term due to the qualification, certification and industrialisation requirements in the aviation and military industries.

In addition to HVOF technology, HD is also investigating the thermal spraying technology [redacted] as a functional chrome plating replacement. As mentioned, the testing is currently ongoing, and the results have not yet been published.

3.3.1.5. Economic feasibility of Alternative 1

Assuming that a single HVOF line would be able to fulfil the current production capacity of HD UK's chrome plating line including [redacted], the initial cost for the installation would be approximately [redacted] [£1-10M]. This is an estimate based on other facilities within the HD group, but the cost may be slightly different at HD UK based on the production capacity needs and number of parts affected. A breakdown of the costs is provided in the table below.

Table 16. Breakdown of HVOF installation costs (#C for all redactions in the table)

Cost item	Cost
Parts preparation	
Automatic grit blasting machine	[redacted]
Part fixtures (ca. £30.000 per part number (PN). Assuming a total of 2 PN per LRU[30] and 3 LRUs per Platform)	[redacted]
Parts inspection	[redacted]
New FPI line to inspect the coating after grinding	[redacted]
Coating coupons inspection line, including coupons cutting, polishing, pressing and microscope	[redacted]
Coating booth	[redacted]
HVOF system	[redacted]
Gasses installation	[redacted]
H&S adaptions	[redacted]
HVOF Grinding	[redacted]
Gap bed grinding machine	[redacted]
Coating validation test campaign	[redacted]
Procurement of coupons	[redacted]

[30] A line-replaceable unit (LRU) is an essential support item which is removed and replaced at the field level to restore the end item to an operational ready condition. Conversely, a non-LRU is a part, component, or assembly used in the repair of an LRU / LLRU, when the LRU has failed and has been removed from the end item for repair.

Cost item	**Cost**
Coupons process	[redacted]
Test / analysis	
Training	
[redacted]	
[redacted]	
[redacted]	
TOTAL	[redacted] [£1-10M]

#B, #C [redacted]. As HD UK does not own the building, approval from the landlord is a prerequisite for the required modification. Otherwise, HD UK would not be able to fit the HVOF process within the current premises.

The high investment will remain unjustified until there is a sufficient number of HVOF coated equipment successfully qualified, certified and industrialised, resulting in a need to increase production capacity. #B [redacted]

It is difficult to estimate the change in production costs as this is highly dependent on the size and geometry of the component. In general, the production cost for HVOF spraying is higher compared to functional chrome plating. One example on cost comparison of functional chrome plating and HVOF coating per aircraft is shown graphically in Figure 15 for a military repair depot.[27] The higher costs are mainly due to the very high costs of the HVOF coating powders. The cost of HVOF is about 50% higher compared to functional chrome plating.

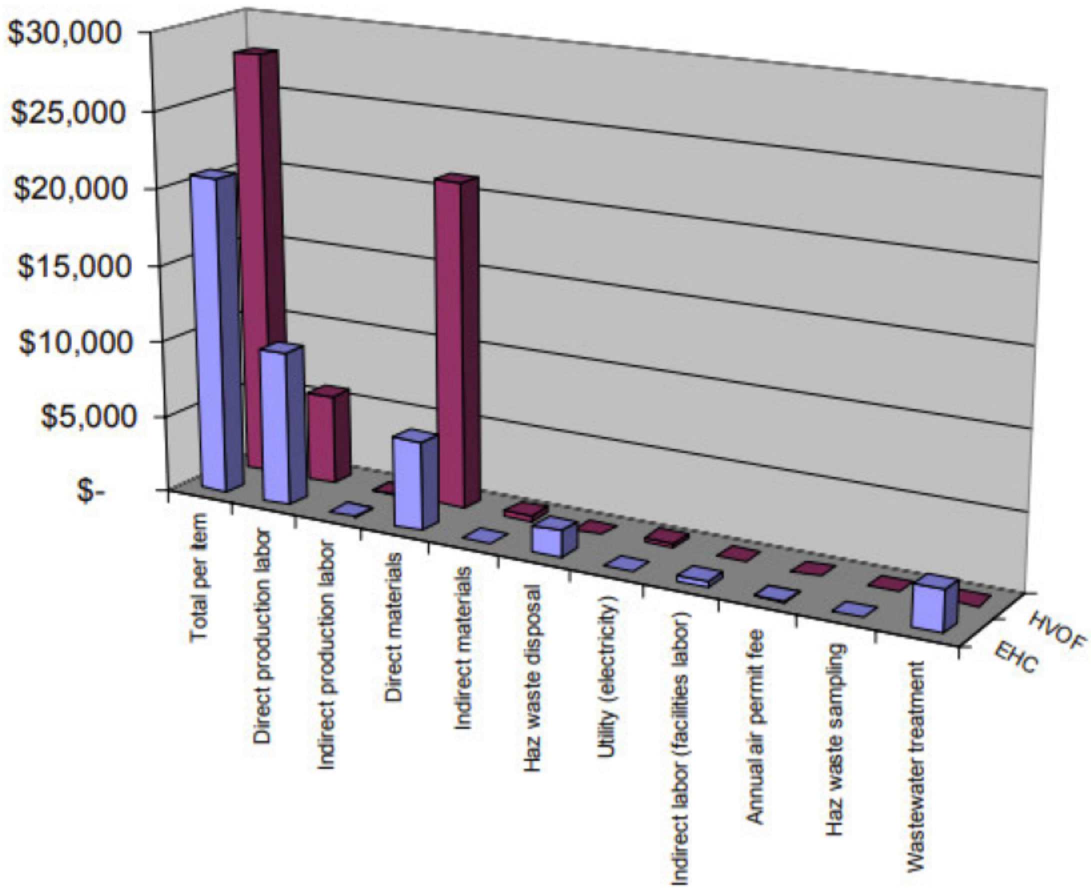

Figure 15. Breakdown of direct cost per aircraft for HVOF vs hard chrome (EHC) at a repair depot[27]

The total process time of HVOF coating deposition is shorter compared to functional chrome plating which results in a much lower turnaround time. The increased wear resistance and fatigue performance can also extend the time between overhauls (TBO) of HVOF coated equipment compared to chrome plated, thus lowering the total life cycle costs.

It should also be noted that for existing aircraft components, the lengthy and costly testing, validation, component re-design and contract changes with customers form a barrier for the implementation of this alternative, especially for legacy aircrafts no longer in production. The time needed for the re-design and re-qualification is very similar to the time needed for new landing gear products which requires ca. [redacted]#B [2-5] years of work per landing gear from design to start of production. The cost will be in the range of millions £ per programme depending on the size of the landing gear. The table below presents the basic activities that would need to be undertaken for each LRU to substitute functional chrome plating with HVOF coating as well as the duration and costs of these activities.

Table 17. Basic activities required for each LRU to substitution with HVOF coating and the related durations and costs

Activity	Hours Estimate	Cost Estimate[31]
Investigation of BOM to Identify Hard Chrome Plating	[redacted]	[redacted]
Design Study Into Alternatives		
Substantiation Report for Customer		
Customer Validation/Impact Assessment		
Re-design of New Components		
Detail Drawing Creation & Checking		
Assembly of Test Articles		
Qualification Test Instructions (compile and check)		
Qualification Testing (4 tests)		
Rig Costs for Internal Tests (x2)		
External Testing Costs (2 tests)		
Qualification Test Reports (compile and check)		
Re-Issue of Airworthiness Documentation (safety etc.)		
Upstroke of Assemblies		
Revision of Component Maintenance Manuals (CMM)		
Total		

The substitution cost for each LRU would be approximately [redacted]. These costs have been validated with other sites within the HD Group, where the chrome coating has been replaced with HVOF. At the Spanish HD site, chrome plating was replaced with a HVOF coating for an existing actuator and the costs associated with this were in excess of [redacted].

As mentioned in Chapter 3.1.3.1, [redacted] including the nose landing gear (NLG), main landing gear (MLG) and retract actuator. The total substitution costs would be in the region of [redacted]. Aside from the major LRU's, there will be numerous other components / lower level sub-assemblies that will need to go through the re-design that will increase the cost significantly. **Please also note that test specimen costs are not included in this figure**, which will significantly increase the costs of re-qualification. Based on previous projects, the average cost **per qualification** is [redacted] when starting a new programme from scratch. For re-qualifications, the true costs are probably somewhere in the middle, but it is difficult to pinpoint due to the different complexity of units / programmes worked on at HD UK.

[31] The costs are based on £70/hr cost rate

A major risk to this re-qualification activity is the availability of the test specimens or test rigs as the original test equipment will have been disposed of. Therefore, to conduct the testing, new rigs will have to be purchased and test specimens sourced, probably from the customer (the cost of the test specimens has been excluded for the cost breakdown in Table 17). **This will add additional costs and risk the possibility that the re-qualification testing cannot be conducted if the specimens are not available.**

3.3.1.6. Suitability of Alternative 1 for the applicant in general

In conclusion, HVOF coatings show equivalent or superior performance on many of the key performance functionalities including hardness, wear resistance and corrosion resistance. HVOF coatings are being implemented as functional chrome plating replacements within the aerospace industry. However, the suitability must be assessed on component basis. In order to become suitable, a CrVI-free alternative must perform in such a way as to allow the aviation industry to continue to comply with the strict airworthiness standards established by Regulation 2018/1139 and its associated Implementing Rules. An alternative can only be deemed available once it has passed through the extensive approval process by which compliance with this regulation is demonstrated.[7] For existing aircraft components, the re-qualification of an alternative requires a complete assessment of the alternative coating against all original qualification criteria. For further information on the qualification and certification processes, please see Chapter 3.1.2.3.

HVOF is also in the focus of HD UK's substitution efforts and is currently in use on some of HD UK's new development programmes for which the in-house qualification process is ongoing. #B [redacted]

3.4. Conclusion on shortlisted alternatives

In conclusion, HVOF coatings are considered as the most promising replacements for functional chrome plating in the aerospace sector. #B [redacted] As a line-of-sight technology, HVOF is not a universal replacement and does not allow complete phase-out of chromium trioxide in functional chrome plating at HD UK. This means that at least one additional alternative would have to be implemented. Alternatives 2 and 3 (discussed in Chapter 3.2.6) have been identified as potential replacements for functional chrome plating in HD UK's use. Alternative 2 is applicable to non-line-of-sight surfaces. These potential alternatives have not yet been assessed by HD UK and no conclusion on their technical and economic feasibility can be made at this time. Possible R&D efforts on Alternatives 2 and 3 are likely to only start in the future once the substitution potential of Alternative 1 across the applicant's product portfolio has been reviewed.

In addition, the replacement of functional chrome plating on existing aircraft components is much more challenging compared to the implementation on new development programmes. The lengthy and costly testing, validation, component re-design and contract changes with customers form a barrier for the implementation of this alternative, especially for legacy aircrafts no longer in production.

4. SOCIO-ECONOMIC ANALYSIS

4.1. Continued use scenario

4.1.1. Summary of substitution activities

In summary, the search for functional chrome plating replacements in the aerospace industry has been ongoing for many decades. The HCAT concluded that HVOF coatings are the best available alternative and HVOF coatings have already been implemented as a functional chrome plating replacement on specific aircraft components. HVOF is also in the focus of HD UK's substitution efforts and is currently in use on some of HD UK's new development programmes for which the in-house qualification process is ongoing. #B [redacted]

4.1.2. Conclusion on suitability of available alternatives in general

In conclusion, HVOF coatings are already in use within the aerospace industry, including landing gear components for specific aircrafts. The alternative can thus be considered as suitable and available in general. A substitution plan is therefore presented in the next chapter. For HD UK, an alternative will only become available once it has passed through the lengthy qualification, certification, and industrialisation processes (see Chapter 3.1.2.3 for more information).

As a line-of-sight technology, HVOF coatings are not applicable for components with complex geometries and/or non-exposed surfaces. This means that the alternative technology cannot substitute functional chrome plating 100 % in the use applied for and at least one additional alternative would have to be implemented for the complete phase-out of chromium trioxide in functional chrome plating at HD UK.

For existing aircraft components, the lengthy and costly testing, validation, component re-design and contract changes with customers form a barrier for the implementation of this alternative, especially for legacy parts for aircrafts no longer in production.

4.1.3. Substitution plan

4.1.3.1. Factors affecting substitution

As already explained, HD UK is currently starting to deploy HVOF coatings on new development projects. Based on the results and learnings of this work, HD UK intends to replace the hard chrome coating of existing aircraft components with HVOF coatings where (technically and economically) possible. The factors affecting the actions needed and/or the timing of substitution at HD UK are summarised below.

- In order for an alternative to become suitable for HD UK, it must be successfully qualified, certified and industrialised before production can start. It generally takes ca. #B [redacted] [2-5] years of work per landing gear from designing a new gear to start of production. A similar timeframe is also needed for the replacement of functional chrome plating on an existing landing gear.

- As a line-of-sight technology, HVOF spraying is not suitable for coating of internal diameters/bores. [redacted] Substituting chrome plating for these components will require the identification and implementation of an additional alternative. This activity could start as soon as HD UK has recruited an aerospace qualified Materials and processes engineer for the role.

- For gas/oil sealing surfaces, the surface finish requirement is much more demanding compared to chrome plating and can lead to processing difficulties or premature seal wear.

- HVOF coatings can be more easily applied to new development programmes as the equipment design can be tailored to its use as the outset rather than to chrome plating. Implementing an alternative coating on components for existing aircraft requires complete re-qualification and may also require extensive re-design including the component itself as well as other parts of the assembly to ensure compatibility. For example, if the chrome coating is replaced with a HVOF coating on gas/oil sealing surfaces, it is highly probably that the seals, seal gland and bearings also have to be changed. Each component that currently uses hard chrome ([redacted] unique part numbers) needs to be reviewed for its functionality, connectivity with other parts, wear mechanism, lubrication needs, and environmental operating conditions. This analysis is necessary as no one-to-one replacement for hard chrome has been identified.

- Prior to starting the process of replacing functional chrome coating for existing aircraft components with an alternative coating, detailed plans must be agreed with HD UK's national and international customers together with their certification authorities to agree the acceptable Means of Compliance (MOC).

- HD UK must ensure the availability of spare parts for existing aircrafts in service for continued airworthiness. At HD UK, landing gears are produced for many customers where the existing aircrafts have remaining lifetime of up to 25 years for MRO. All legacy programmes have more than 12 years life left on them.

- The resource burden across the engineering function to execute the re-design and re-qualification tasks will be in the range of [redacted] per LRU (see Table 17 for more information). This excludes the costs of test specimens and test rigs which likely have to be purchased and significantly increase the re-qualification costs. In comparison, the average cost for new landing gear development is approximately [redacted] [£25-60M] of which approximately [redacted] is attributable to qualification testing only.

- A major risk to the re-qualification activity is the availability of the test specimens or test rigs as the original test equipment will have been disposed of. Therefore, to conduct the testing, new rigs will have to be purchased and test specimens sourced, probably from the customer (the cost of the test specimens has been excluded for the cost breakdown in Table 17). **This will add additional costs and risk the possibility that the re-qualification testing cannot be conducted if the specimens are not available.**

- The global distribution of legacy equipment and the associated spare parts and overhaul policies (i.e. who is responsible for the overhaul or supply of spare/replacement parts) means that the introduction of an alternative coating could lead to multiple configurations of the same landing gear requiring complex logistic management. This would have to be developed in multi-party agreements in conjunction with both customers and suppliers.

- The high initial cost of the HVOF installations remain unjustified until a sufficient number of new development programmes have been successfully qualified, certified and industrialised with HVOF, resulting in the need for increased production capacity for the alternative coating process. Once HVOF has been integrated at HD UK, relevant operators must be trained in the alternative coating process before they can start operation.

Based on the above considerations, and on the assumption that HVOF was a "drop-in" alternative for functional chrome plating, it is expected that the phasing in of this change will require a great deal of time and effort to implement and will therefore not be possible to complete within the "normal review period" of 7 years. HD UK is requesting a review period of 12 years. The following chapter gives more details on the actions and timelines involved in the substitution.

4.1.3.2. List of actions and timetable with milestones

HD UK has already identified HVOF coatings (Alternative 1) as the most promising replacement for functional chrome plating in its use. In order for the alternative to become suitable and available for HD UK, it must be successfully qualified, certified and industrialised before production can start. The HVOF tungsten carbide coating WC/CoCr is currently being deployed at HD UK for new development programmes. As already explained, each landing gear requires ca. #B [2-5] years of work from design to start of production.

Based on the results from ongoing development programmes, learnings of this work (e.g. coating recipe, process methods, thickness, surface finish etc.) can be deployed on further programmes and where (technically and economically) practical, the replacement of the hard chrome coating of existing aircraft components with HVOF in old programmes. As already mentioned, implementing HVOF for old programmes is far more difficult than for new development programmes due to the high level of re-design needed as well as the configuration control of OE and legacy equipment.

Figure 16 shows the timeline for the basic activities involved in substitution of functional chrome plating for old programmes. For **a single LRU**, the substitution time will be approximately #B **[32-60] months**. As mentioned in Chapter 3.1.3.1, there are approximately #A OEM/MRO aircraft platforms which are dependent on the use of chromium trioxide at HD UK, each with a minimum of 3 LRUs including the nose landing gear, main landing gear and retract actuator. #A, #B [redacted] (e.g. if the NLG from a particular platform is tested, similarity to the MLG could be potentially claimed). However, all LRU's would still need to undergo all re-design activities. Some of the activities could run in parallel for different LRU's and HD UK is looking to perform the testing on [redacted] platforms at a time (i.e. [redacted] LRU's) if possible, as this would be dependent on test rig availability and impact on other new development programmes. However, based simply on the engineering planning (see Figure 16), the substitution will require **at least 12 years**. It should also be noted that this plan is for indication only as there are many dependencies on the activities in terms of supply chain availability, customer approvals, availability of test specimens and so on.

#B [redacted]

Figure 16. [redacted][32]

[32] Please note that the dates presented are not the actual project dates.

The substitution activities involved in the replacement of functional chrome plating for old programmes involving existing aircrafts are described below in more detail.

Re-design

As explained in Chapter 3.3.1.4, the different properties of the HVOF coatings and hard chrome plating may result in incompatibility of the HVOF coated component with other components part of the same assembly and will usually require a high level of re-design. For example:

- Where the chrome is replaced with HVOF for gas or oil sealing it is highly probable that the seals, seal glands and bearings may also have to be changed.
- HVOF cannot be used for non-line-of-sight surfaces, e.g. internal bores which mate with seals to contain a nitrogen gas volume. Although it is unclear which alternative could replace chrome plating in these cases, the alternative coating / surface treatment will have an effect on the separator piston which typically houses the seal and the bearing.
- Where the chrome is replaced in dynamic joint, the material of the mating part must be considered to ensure not only that friction is minimised but also there is no galling or galvanic effects etc. between the mating surfaces.

Each assembly will therefore have to be assessed and potentially re-designed to ensure that the original design intent of the limits and fits are maintained. This exercise will have to be performed across all platforms. #B [redacted].

Re-qualification

The re-qualification is a combination of analysis and testing, and the purpose is to generate the demonstration evidence needed for customer approval. The re-qualification of an alternative for the aircraft and military components requires a complete assessment of the alternative coating against all original qualification criteria. These include but are not limited to fatigue strength, endurance performance (including temperature testing) as well as corrosion resistance and Sand and Dust testing according to RTCA/DO-160 (see Table 18). The re-qualification will be conducted at either the component and/or sub system level, i.e. landing gear or actuator depending on the component.

The re-qualification testing is conducted in house with the possible exception of the Salt Spray Test and Sand and Dust Test which may be sub-contracted to an external test house specialised in these types of tests. For any external tests, HD UK will write the test instructions and approve the test report data compiled by the external party before submitting it to the customer.

In summary, for each aircraft platform it is assumed that the following qualification tests need to be conducted:

Table 18. Re-qualification tests

	Fatigue Test	Endurance Test	Salt Spray Test	Sand and Dust Test
Shock Absorber	Internal Test	Internal Test	N/A	N/A
Hydraulic Actuator	Internal Test	Internal Test	External Test	External Test

The time needed for the re-qualification depends on the level of demonstration demanded by each customer. If restricted to demonstration by analysis, each re-qualification could take around [redacted]. However, if qualification testing is required this could take in excess of [redacted], particularly if fatigue testing is required. It is envisaged that the substitution process would require the same period of time for both aircraft and military vehicle components as the same level of demonstration to the original requirements would be required by each customer.

Customer approval & certification

Prior to starting the process of replacing functional chrome coating for existing aircraft components with an alternative coating, detailed plans must be agreed with HD UK's national and international customers together with their (airworthiness) certification authorities to agree the acceptable Means of Compliance (MOC). Once the necessary demonstration evidence has been generated during the re-qualification process, it is supplied to each customer for review and approval. The duration of the customer approval can be up to approximately [redacted]

Introduction of new configuration standard & supply chain alignment

The product structure of all affected equipment would have to be revised to introduce a new configuration standard. Replacing chrome would be considered to be a change to either the fit, form or function of the landing gear and thereby, a whole new set of part numbers and assemblies would have to be created for the 'HVOF variants' for each of the existing variants. These would then have to be managed by each of HD UK's customers onto each of their respective platforms.

For the legacy equipment, HD UK is only likely to supply spare parts to the customers as required or as part of an overhaul. Therefore, the HVOF coated components and their mating parts will be introduced on an 'ad hoc' basis onto equipment leading to difficulties in controlling the configuration.

Both of these configuration aspects will require close cooperation of all of HD UK's customers and managing the cut in will be logistically very difficult and time consuming. The supply chain would have to be aligned to be able to supply the 'HVOF variants' and all the applicable Component Maintenance Manuals (CMMs) that are currently written for the 'chrome plated variants' would require updating and re-distribution to HD UK's customer base.

The plan presented in Figure 16 should be read in conjunction with other inputs as this represents mainly the engineering activities. [redacted]

HVOF units have been installed at some of the sites within the HD group. HD UK is currently undergoing viability studies around HVOF installations for the Runcorn site. For cost estimates, please refer to Chapter 3.3.1.5. The integration of HVOF at HD UK is dependent on a sufficient number of its new development programs with HVOF coating being successfully qualified, certified and industrialised, leading to a need to increase HVOF production capacity. Once this condition is fulfilled the estimated timeline for integration of HVOF at HD UK would then take approximately [redacted] [2-5] years. Once installed, a coating validation test campaign must also be completed, and the relevant operators must be trained in the coating process including the pre- and post-treatments.

An overview of the timetable of the substitution activities is presented in below table. At this time, it is not possible to develop a more detailed timeline since the progression of the substitution is dependent on the results from implementing HVOF for new development programmes. However, HD UK is committed to continuing the substitution work already started and gradually transition from functional chrome plating to the HVOF WC/CoCr coating where technically possible (line-of-sight limitation) and, especially for the old programmes, economically feasible taking into consideration the high economic burden of the re-design and re-qualifications.

Due to geometric restrictions, HVOF is not applicable for [redacted] of the components currently chrome plated at HD UK. This means that at least one additional alternative would have to be implemented in order to completely phase-out the use of chromium trioxide in functional chrome plating at HD UK. This alternative has not yet been identified. Once the implementation of HVOF coatings for HD UK's components progresses and the applicability of this alternative for different types of components is better understood, the requirements for an additional alternative can also be better defined. Since HD UK currently has no experience in additional alternatives, test campaigns will have to be conducted to assess the technical feasibility, which is estimated to take [redacted] [2-7] years. This activity could start as soon as HD UK has recruited an aerospace qualified Materials and Processes engineer. HD UK is currently trying to recruit for this role. Based on the current jobs market, it is expected that it will take up to another [redacted] before the recruitment is completed.

Table 19. Overview of substitution timetable (#B for all redactions in the table)

Phase	Status	Duration
Implementing HVOF coatings on new development programmes.	Ongoing	Ca. [redacted] [2-5] years per programme
Integration of HVOF at HD UK.	Viability studies ongoing	[redacted] [2-5] years
Implementing HVOF coatings for old programmes.	Not started	[redacted] [32-60] months for the basic substitution activities per LRU (total duration can be closer to [redacted] [2-5] years per programme)
Identification of additional alternative for components were HVOF coatings are not applicable.	Not started	[redacted] [2-7] years for test campaigns

4.1.3.3. Monitoring of the implementation of the substitution plan

HD UK is certified according to the international quality management standard ISO 9001 and aerospace industry specific quality system standards (BSI registration BSEN-ISO9001, AS9100 & AS9110). The certified quality management system also governs the project management at HD UK. Internal IT systems are used to support the set-up of project timelines and milestones as well as monitor and control the progression and develop action plans in case of delays etc.

Before the work starts for new development programmes or re-qualification of existing components, the testing programme for qualification and certification is planned together with customers and certification authorities. In each case, HD UK is expected to submit a full qualification and implementation plan to the customer for approval. This plan clearly documents each step of the project and is punctuated by "go/no go" stage gates to control the progress and is mapped against a suitable timeline. This plan provides the schedule against which progress would be monitored and recorded both internally and externally.

Different teams will be involved in the implementation of the different phases of the substitution plan including engineering, production and sales departments etc. The team leaders will report on updates on a regular basis to the project manager and company management and regular meetings will also be set up.

All results from process development and in-house validation and qualification tests of the HVOF process and resulting coatings are carefully documented. Test results together with analysis and conclusions are filed to allow for timely monitoring of the progress internally and decision-making for next steps. The results are shared with the relevant teams and managers during periodical meetings. This is also important for financial planning and budgeting purposes, ensuring that the necessary financial resources are in place for the required high investments.

4.1.3.4. Conclusions

In conclusion, HD UK is committed to substituting chromium trioxide in the functional chrome plating and is currently deploying the HVOF WC/CoCr coating for new development programmes. However, HVOF WC/CoCr is not a "drop-in" replacement for hard chrome and the replacement involves many challenges, including the high level of re-design needed, the mandatory re-qualification and certification processes that must be followed to fulfil airworthiness requirements as well as the number of LRUs involved. Similar re-qualification and certification requirements exist for the military vehicle components. HD UK is requesting a review period of 12 years, based simply on the time-consuming activities by the engineering function required for replacing the chrome coating with HVOF (see Figure 16). The lengthy and costly testing, validation, component re-design and contract changes with customers form a barrier for the implementation of this alternative, especially for legacy parts for aircrafts no longer in production. The viability of the replacement must be reviewed on component basis.

As explained earlier, for HD UK to fully phase-out the use of chromium trioxide in functional chrome plating, at least one additional alternative would have to be implemented. This alternative has not yet been identified.

4.2. Risks associated with continued use

4.2.1. Impacts on humans

Chromium trioxide is included in Annex XIV based on two intrinsic properties: carcinogenicity (category 1A) and mutagenicity (category 1B). The focus of the current health impacts assessment has been placed on the risks related to the carcinogenicity. The most important potential routes of exposure and target organs are inhalation causing lung cancer and oral exposure causing intestinal cancer. The assessment of cancer risk is required to evaluate the human health risk[33]. The quantitative assessment includes monetised value for cancer cases related to the excess lifetime risk.

Worker exposure

The risk assessment for workers exposed is restricted to inhalation of airborne residues of chromium trioxide (lung cancer) in accordance with the CSR (Chapter 9.1). At the site, the assessment considered #C [5-50] plant operators and #C [2-20] external maintenance operators who have tasks where there is potential for exposure to CrVI. In addition, the applicant employs at the Runcorn site in total #C [100-200] workers who have no tasks in the plating hall.

Table 20 outlines the WCSs related to worker exposure at the applicant's site.

[33] European Chemicals Agency, 2011

Table 20. Worker contributing scenarios related tasks at the applicant's site

Worker Contributing Scenario (WCS)	Task
1	Delivery and storage of CrO_3
2	Manual chrome plating operations
3	Sampling chromate baths
4	Concentration adjustment of baths
5	Regular maintenance
6	Rare maintenance
7	Waste and wastewater management
8	Far field exposure – tasks done in the hall

The operators doing the tasks described in the WCSs can be grouped into the 2 groups. Group 1 includes the #C [5-50] operators who work daily in the plating hall over 3 shifts. Group 2 includes external contractors who do specific tasks under rare maintenance in the hall. Excess risks are calculated based on modelled and measured data and all the workers in groups 1-2 are considered in the exposure assessment and risk characterisation. Dose response factors presented in the CSR (Chapter 9.1.2.2) are used to derive excess risk.

Worker exposure and excess risk values by worker groups are given in Table 21 for the applicant's site. Estimated statistical cancer cases are given for all groups as they are separately taken forward in the assessment and aggregated only at the monetisation phase.

Table 21. Exposure and excess risk to workers (#C for all redactions in the table)

Worker groups	Number of workers	WCS	Aggregated exposure value over 8h corrected for duration, frequency, RPE as relevant ($\mu g/m^3$)	Excess risk	Estimated statistical cancer cases (time adjusted for 12 years)
Group 1	[redacted] [5-50] hall plating operators	1-8	2.19E+00	8.74E-03	[redacted] [<1.5E-01]
Group 2	[redacted] [2-20] external service providers	6a, 6b	2.13E-02	8.51E-05	[redacted] [<5.5E-04]

Man via environment exposure

For the general population, exposure is possible through the "man via environment" route. This includes inhalation exposure to CrVI and oral exposure to CrVI via the food chain which are taken into account in the risk estimation. Exposure was estimated with EUSES based on emission monitoring data to air. Chapter 9.3 in the CSR summarise the predicted exposure concentrations by the two routes of exposure to humans via the environment for the local population.

Table 22 presents the exposure, excess cancer risk values and estimated statistical cancer cases for the general population via the environment for the applicant's sites. Note that regional population is excluded from the assessment as the risk and the monetised risk per year calculated with EUSES default 20 M population is minimal (combined inhalation and oral route approx. 215 GBP)[34].

Table 22. Exposure and excess risk to workers not in the production hall and general population
(#C for all redactions in the table)

Parameter	Exposure	Group exposed	Excess cancer risk	Estimated statistical cancer cases (time adjusted for 12 years)
Local				
Human via environment - inhalation	Local PEC: 4.43E-06 mg/m³	Local population ([redacted] [455-555] persons):	1.28E-04*	[redacted] [<1.30E-02]
Human via environment - oral	Local daily dose: 1.38E-08 mg/kg bw/day	Local population ([redacted] [455-555] persons):	1.10E-08**	[redacted] [<1.20E-06]

* Applying the population excess lifetime lung cancer mortality risk for the general population exposed to 70 years (24h/day, 7 days/week)
** Applying the population excess lifetime intestinal cancer mortality risk for the general population exposed to 70 years (24h/day, 7 days/week)

4.2.1.1. Number of people exposed

Worker

At the site, there are in total #C [5-50] operators who have daily tasks with the chrome plating production. At the site, #C [2-20] external contractors may do specialist maintenance work ca. 1.5 days per year. The applicant employs #C [100-200] workers who have no tasks in the plating hall at the site. These #C [100-200] workers may be indirectly exposed via the environment and are included with the local population.

Local people exposure

Local people exposure is considered for workers who have no tasks in the plating hall and the nearby neighbourhood with 1 km diameter as it is considered more realistic than the default local population value from EUSES, 10,000. The EUSES value is considered overestimating the size of the population. The applicant has in total #C [100-200] workers at the site who have no tasks in the plating hall. The area near the applicant's facility is mostly industrial area with a low population density within 1 km diameter. Table 23 outlines the population density of the area derived earlier in Table 3, and the number of exposed people within 1 km diameter. The number of the exposed people in the nearby area is 355. Therefore, total number of possibly exposed workers at the site who have no

[34] Risk and monetisation are present in a spreadsheet available on request

tasks in the plating hall and people in the area nearby the applicant's facility is #C [455-555] (355 + #C [100-200]).

Table 23. The number of exposed people in the nearby area

Geographical Scope	Population density (population per km²)	People exposed within 1 km diameter[35]
Cheshire	452	355

4.2.2. Impacts on environmental compartments

Environmental impacts are not relevant for the proposed identification of the substance as an SVHC in accordance with article 57 (a & b).

4.2.3. Compilation of human health and environmental impacts

As outlined above, exposure to the general population is estimated based on modelled data and worker risk level is based on measured occupational exposure data and modelled data.

Starting point of the monetisation of the human health impacts is lower and upper limits for Value of Statistical Life (VSL) and Value of Cancer Morbidity (VCM) outlined in Table 24 below.

Table 24. VSL and VCM in 2012 Price level in EUR

2012 Price level	Lower limit, M EUR	Upper limit, M EUR
Value of Statistical Life (VSL)	3.5	5
Value of Cancer Morbidity (VCM)	0.41	0.41

The values given in Table 24 are converted from EUR to GBP in Table 25[36].

Table 25. VSL and VCM in 2012 Price level in GBP

2012 Price level	Lower limit, M GBP	Upper limit, M GBP
Value of Statistical Life (VSL)	3.11	4.44
Value of Cancer Morbidity (VCM)	0.36	0.36

[35] Population density multiplied with 0.785

[36] EUR Values provided by ECHA have been converted to GBP with a rate of 0.8889 (2021; https://www.ons.gov.uk/economy/nationalaccounts/balanceofpayments/timeseries/thap/diop)

These values are first discounted with latency periods. Discounting rates of 4 % and 2 % are used in the following calculations. For lung cancer the latency period is 10 years and for intestinal cancer it is 26 years. Fatal cancer assessment accounts both VSL and VCM. Non-fatal assessment accounts only VCM:

$$\text{Fatal cancer case value} = (1 + 0.04\ or\ 0.02)^{-(latency)} \times (VSL + VCM)$$

$$\text{Non-fatal cancer case value} = (1 + 0.04\ or\ 0.02)^{-(latency)} \times (VCM)$$

The lower and upper limit for discounted values of fatal and non-fatal cancer cases in 2012 price level are outlined Table 26.

Table 26. Discounted cancer case values in 2012 price level

Discounted value of cancer case, 2012 price level	Lower limit, M GBP	Upper limit, M GBP
Lung fatal	2.35	3.95
Lung non-fatal	0.25	0.30
Intestinal fatal	1.25	2.87
Intestinal non-fatal	0.13	0.22

To avoid underestimation due to inflation, these monetary values are adjusted to 2022 price level by multiplying them by a price adjuster of 1.21 (HICP index)[37]. Values in 2022 price level are outlined in Table 27.

Table 27. Discounted cancer case values in 2022 price level

Discounted value of cancer case, 2021 price level	Lower limit, M GBP	Upper limit, M GBP
Lung fatal	2.84	4.77
Lung non-fatal	0.30	0.36
Intestinal fatal	1.52	3.48
Intestinal non-fatal	0.16	0.26

FATAL

The estimated statistical cancer cases of each group from Table 21 and Table 22 are multiplied by the relevant (lung or intestinal) fatal lower and upper limit values. Per year values are derived from lower and upper limit values by dividing them with the requested

[37] https://ec.europa.eu/eurostat/web/hicp/data/database?p_p_id=NavTreeportletprod_WAR_Nav
2012: 98.19, 2022: 118.82. Price adjuster: 118.82 / 98.19 = 1.21

review period, 12 years. The aggregated results are outlined in Table 28 below. Note that the row of directly exposed workers aggregates the per group values below it.

Table 28. Monetisation of fatal cancer cases (#C for all redactions in the table)

FATAL	2022 price level GBP			
Cancer case monetisation	Lower limit	Upper limit	Lower limit per year	Upper limit per year
Directly exposed worker all groups (inhalation)	[redacted] [<400k] £	[redacted] [<650k] £	[redacted] [<35k] £	[redacted] [<55k] £
Group 1	[redacted] [<400k] £	[redacted] [<650k] £	[redacted] [<35k] £	[redacted] [<55k] £
Group 2	[redacted] [<1.5k] £	[redacted] [<2.5k] £	[redacted] [<150] £	[redacted] [<250] £
Local population (inhalation)	[redacted] [<35k] £	[redacted] [<60k] £	[redacted] [<3k] £	[redacted] [<5k] £
Local population (oral)	[redacted] [<5] £	[redacted] [<5] £	< 1 £	< 1 £

NON-FATAL

Before monetising the estimated statistical non-fatal cancer cases, the number of additional non-fatal cancer cases need to be derived. This is done via fatality rates of lung and intestinal cancers. The fatality rate of lung cancer is assumed to be 80 % as ECHA's guidance suggests[38]. According to ECIS[39] database an average survival rate of both sexes and all age groups for small intestine cancer is 53 %. Conversely this equal to a fatality rate of 47 % which is used to estimate additional non-fatal cancer cases for intestinal cancer. Additional share of non-fatal cancer cases is calculated with the following formula:

$$\text{Additional share of non-fatal cancer cases} = \frac{(1 - fatality\ rate)}{fatality\ rate}$$

For lung cancer the formula yields an additional share of 0.25 and for intestinal cancer 1.14.

The estimated statistical fatal cancer cases for each group (Table 21 and Table 22) are multiplied by the relevant additional share of non-fatal cancer cases (0.25 or 1.14) to obtain the estimated statistical non-fatal cancer cases. The estimated statistical non-fatal cancer cases are then monetised otherwise similarly than the fatal cases but multiplying each group by the relevant (lung or intestinal) non-fatal lower and upper limit values. Per year values are derived from lower and upper limit values by dividing them with the

[38] https://echa.europa.eu/documents/10162/13630/echa_review_wtp_en.pdf/dfc3f035-7aa8-4c7b-90ad-4f7d01b6e0bc

[39] ECIS: https://ecis.jrc.ec.europa.eu/explorer.php?$0-2$1-AEE$2-All$4-1,2$3-11$6-0,14$5-2000,2007$7-1$CRelativeSurvivalAgeGroup$X0_14-$X0_15-RSC$CRelativeSurvivalFollow$X1_14-$X1_-1-$X1_15-RSC

requested review period, 12 years. The aggregated results are outlined in Table 29 below. Note that the row of directly exposed workers aggregates the per group values below it.

Table 29. Monetisation of non-fatal cancer cases (#C for all redactions in the table)

NON-FATAL	**2022 price level GBP**			
Cancer case monetisation	Lower limit	Upper limit	Lower limit per year	Upper limit per year
Directly exposed worker (inhalation) all groups	[redacted] [<10k] £	[redacted] [<12k] £	[redacted] [<850] £	[redacted] [<1000] £
Group 1	[redacted] [<10k] £	[redacted] [<12k] £	[redacted] [<850] £	[redacted] [<1000] £
Group 2	[redacted] [<40] £	[redacted] [<50] £	[redacted] [<5] £	[redacted] [<5] £
Local population (inhalation)	[redacted] [<1000] £	[redacted] [<1200] £	[redacted] [<80] £	[redacted] [<100] £
Local population (oral)	< 1 £	< 1 £	< 1 £	< 1 £

SUMMARY

The details and results of the monetisation of the fatal cancer cases are outlined in Table 30 below. Note that the excess lifetime cancer risk for directly exposed workers is a weighted average of the risks by groups outlined in Table 21.

Table 30. Summary of fatal cancer cases (#C for all redactions in the table)

FATAL	**Excess lifetime cancer risk**	**Number of exposed people**	**Estimated statistical cancer cases**	**Value per statistical cancer case M GBP, upper bound 2022 price level.**	**Monetised excess risk per year GBP, upper bound 2022 price level**
Workers					
Directly exposed workers	5.99E-03	[redacted] [7-70]	[redacted] [<1.30E-01]	Lung: 4.77	[redacted] [<55k] £
Indirectly exposed workers	n.a.	n.a.	n.a.	n.a.	n.a.
Sub-total	5.99E-03	[redacted] [7-70]	[redacted] [<1.30E-01]	Lung: 4.77	[redacted] [<55k] £
General population					
Local	1.28E-04	[redacted] [455-555]	[redacted] [<1.30E-02]	Small intestine: 3.48 Lung: 4.77	[redacted] [<5k] £
Regional	n.a.	n.a.	n.a.	n.a.	n.a.
Sub-total	1.28E-04	[redacted] [455-555]	[redacted] [<1.30E-02]	Small intestine: 3.48 Lung: 4.77	[redacted] [<5k] £
Total cancer risk	6.11E-03	[redacted] [462-625]	[redacted] [<1.40E-01]	Small intestine: 3.48 Lung: 4.77	36,132 £
Latency	10 years for lung cancer, 26 years for intestinal cancer				

As can be seen from the table above, the monetised fatal risk per year to workers is #C [redacted] [<55k] GBP and to general population #C [redacted] [<5k] GBP. Total fatal cancer risk per year is 36,132 GBP. This rounds down to 0.036 M GBP.

The details and results of the monetisation of the non-fatal cancer cases are outlined in Table 31 below.

Table 31. Summary of non-fatal cancer cases (#C for all redactions in the table)

NON-FATAL	Excess lifetime cancer risk	Number of exposed people	Estimated statistical cancer cases	Value per statistical cancer case M GBP, upper bound 2022 price level.	Monetised excess risk per year GBP, upper bound 2022 price level
Workers					
Directly exposed workers	1.50E-03	[redacted] [7-70]	[redacted] [<3.30E-02]	Lung: 0.36	[redacted] [<1000] £
Indirectly exposed workers	n.a.	n.a.	n.a.	n.a.	n.a.
Sub-total	1.50E-03	[redacted] [7-70]	[redacted] [<3.30E-02]	Lung: 0.36	[redacted] [<1000] £
General population					
Local	3.20E-05	[redacted] [455-555]	[redacted] [<3.10E-03]	Small intestine: 0.26 Lung: 0.36	[redacted] [<100] £
Regional	n.a.	n.a.	n.a.	n.a.	n.a.
Sub-total	3.20E-05	[redacted] [455-555]	[redacted] [<3.10E-03]	Small intestine: 0.26 Lung: 0.36	[redacted] [<100] £
Total cancer risk	1.53E-03	[redacted] [462-625]	[redacted] [<3.60E-02]	Small intestine: 0.26 Lung: 0.36	[redacted] [<1000] £
Latency	10 years for lung cancer, 26 years for intestinal cancer				

As can be seen from the table above, monetised non-fatal risk per year to workers is #C [<1000] GBP and to general population #C [<100] GBP. Total non-fatal cancer risk per year is #C [<1000] GBP. This rounds up to 0.001 M GBP.

The sum of the monetised risk of the fatal and non-fatal cancer risk to workers is 32,030 GBP and to general population 4,786 GBP. Total cancer risk per year is therefore 36,816 GBP for the applicant's continued use. This rounds up to 0.037 M GBP. The rounded figure is used in the benefit to cost comparison.

4.3. Non-use scenario

The aviation industry operates in environments which are highly challenging, due to the varied conditions in which aircraft are operated, such as extremes of temperature and humidity, where the stringent aviation safety requirements must be met. Hard chromium plating has been the industrial standard guaranteeing airworthiness in aeronautics for decades as a surface treatment to increase the durability of the products protecting the surfaces from the corrosion and wear. Hard Chromium is broadly used on landing gears, mainly but not limited to rods or areas under friction efforts such as shock absorbers, wheel axles, structural pins, and others. HD's customers demand landing gear systems / products that function, on wing, for as long as possible, without having to remove the landing gears often for maintenance. To enable this, HD's products have been designed, tested and simulated to perform for thousands of cycles (a cycle means a "take off" and a "landing"). In terms of "time", this could be 10 years in flight where other factors such as "corrosion" come into play. Hard chrome plating is key to wear & corrosion resistance, and this is why it is the industry standard.

Due to the authorisation requirement for CrVI, new coatings are being developed to replace hard chromium. As outlined in Chapter 3.3.1.6 HVOF (High-Velocity Oxygen Fuel) coating technology replaces plated chrome with tungsten carbide in a chromium matrix for certain components. HVOF coatings can be introduced on new designs but their introduction in old programs is not viable due to the high level of redesign needed and the interminability of the new components with the old ones, which would generate a massive problem for maintaining the current fleet on service eliminating the availability of spares as well as the overhaul of the flying components. HVOF is not a "drop-in" replacement for hard chrome and the replacement involves many challenges, including the high level of re-design needed, the mandatory re-qualification and certification processes that must be followed to fulfil airworthiness requirements as well as the number of LRUs involved. The lengthy and costly testing, validation, component re-design and contract changes with customers form a barrier for the implementation of this alternative, especially for legacy parts for aircrafts no longer in production. The viability of the replacement must be reviewed on component basis. #B [redacted] The applicant is still producing landing gears with CrVI coated items for a large number of customers as the production of one type of aircraft may last more than 50 years. These landing gears will then have a remaining lifetime of up to 25 years for repair & overhaul. Currently, all HD UK's legacy programs have more than 12 years life left on them, some even 30 years. For further details, please refer to the substitution timeline given in Chapter 4.1.3.2.

Considering a refused authorisation scenario, the applicant would have to stop using CrVI based plating in production and MRO operation. This would result in a shutdown of the HD UK facilities as the HVOF share of production is small compared to the CrVI production. Without authorisation to use CrVI in chrome plating, the applicant cannot produce its equipment, repair the equipment, or sell any spare components to replace in the assembly. HD UK's business is 100 % dependent on chrome plating. In the most likely non-use scenario, the parent company, HD, would relocate HD UK's production and MRO operation to its existing facilities (if capacity is available) or build a new facility (if capacity is not available) outside of Great Britain.

Outsourcing the chrome plating activity outside the GB and keeping other production and assembly in the GB is not feasible for HD UK. The volume and type of work with complex and large components required to support the Runcorn business with chrome plating would not make outsourcing possible. Components used in Runcorn production have multiple chrome plated areas with multiple potential operation sequences and intermediate operations. In general, outsourcing can be considered when the operation is simple in terms of the components/service in a loosely regulated environment. This is clearly not the case with landing gears in the aviation industry. In addition, complex restrictions and authorisations relating to MRO operation make outsourcing unfeasible for HD UK.

HD UK's customers, OEMs, are dependent on the applicant's products, since the HD UK's strategy is to design, qualify and own outright the IP to the end product (airline prefix designated parts). The cost to redesign and re-qualify a landing gear is prohibitive for the customers, hence the applicant has not seen an example of this practice to date. If HD could not provide landing gears, some of their end customers would not be able to re-source to a new supplier, as the IP is owned by HD. A new supplier would also need to conduct a lengthy requalification process. A long production gap for HD UK's customers would be inevitable. The production gap would be similar to designing a new gear, manufacturing prototypes, testing it, qualifying it and then manufacturing production units. It is estimated to take around [redacted] [2-5] years' worth of work. The related cost is dependent on the size of the gear, averaging approx. [redacted] [25-60] M GBP [redacted]

In addition, the non-use scenario would lead to severe implications for UK based end-users as the HD UK's MRO operations would stop. It is likely that this would result in a situation where aircrafts of for example [redacted] could be grounded due to lack of maintenance until a new supplier has been requalified. This is because no change is possible in the short-term to the manufacture and maintenance of current aircraft fleet, which is based on approved designs and certification.

The applicant, HD UK, would face business closure in the most likely non-use scenario. Their business, production and MRO operation of landing gears, is dependent on chrome plating. The parent company, HD, would relocate HD UK's production and MRO operation to its existing facilities or build a new facility outside of Great Britain. This would result in a production and maintenance gap for HD UK's customers in Great Britain and possible keep end-users' fleet grounded for an extensive period of time in Great Britain. The main monetised impacts on the GB society would be producer surplus and employment losses incurring from the closure of the applicant's Nottingham and Runcorn sites. It can be concluded that in case of a refused authorisation, the applicant's use would be taken up by the market actors using the same substance outside Great Britain.

4.3.1. Summary of consequences of non-use

Suppliers of chromium trioxide, other raw material and components

The most likely non-use scenario for the applicant's supplier of CrVI is to focus on selling other substances to other customers. Likewise, the suppliers of other raw material and components will focus on other customers in the non-use scenario. These suppliers will potentially face minor profit losses and business rearrangement costs due to the loss of purchases from the applicant. These costs are not analysed quantitatively in this analysis since it is assumed that they are eventually compensated with other sales.

However, there is one small sized (10 to 50 employees) local component manufacturer whose main customer HD UK is. Approx. 90 % of this company's order book is HD UK supply. It is likely that they will go out of business if HD UK must close business due to non-authorisation. The related costs are not analysed quantitatively in this analysis because this company was not surveyed.

Applicant

The applicant's production and MRO operation is dependent on chrome plating. New coatings such as HVOF have been developed to replace hard chromium. Due to the stringent aviation safety requirements, long service life of operating and legacy aircraft fleets, the high level of redesign needed and the interminability of the new components with the old ones, and the MRO requirements, HVOF coatings may only be introduced on new designs. #B [redacted]

Therefore, if CrVI based chrome plating is not authorised, the applicant's sites in the GB would be shutdown, business closed, and the related production and MRO operation relocated to other facilities of the parent company outside of the GB. This will result in producer surplus losses, unemployment of 320 people and decommissioning costs of the production facilities in the GB.

OEMs – Aircraft manufacturers

In the most likely non-use scenario, OEMs have to stop sourcing landing gears produced by the applicant in the UK. The parent company would relocate the production outside of Great Britain and the OEMs would source from these entities. It is likely that the OEMs face a production gap for as long as the applicant's UK production capacity is being transferred to other entities. In the worst-case scenario, this could take years if a new site needs to be built. HD UK's customers are bound to HD as HD UK owns outright the IP for all airline prefix designated parts. The cost to redesign and re-qualify a landing gear is prohibitive for the customers. If HD could not provide landing gears, some of their end customers would not be able to switch to a new supplier, as IP is owned by HD. In this case a new supplier would also need to conduct a lengthy requalification process. An extensive production gap for HD UK's customers would be inevitable if they wanted to change their landing gear supplier.

The non-use scenario for OEMs translates to a likely production gap. HD would aim to relocate as fast as possible to maintain production and service to its customers without gaps. However, in the worst-case scenario extensive production gaps are likely. In case of a lengthy production gap the economic impacts on the OEMs are likely significant. Due to uncertainty in the scale of the implications for this scenario, the related cost to OEMs is not monetised in this socio-economic analysis.

End-users – Airlines and MoDs

The most likely non-use scenario for end-users is to source aircrafts with landing gears produced and repaired outside Great Britain. The parent company, HD, can provide these in time. However, in short term there is likely to be a production gap as it takes time to relocate the production and MRO operation of HD UK to other locations or build a new site. The end-users in Great Britain would likely be severely impacted because HD UK would stop MRO operations in the country. This may result in a situation where for example the #A [redacted] aircrafts are grounded due to lack of maintenance until a new operator has been requalified. This is because no change is possible in the short-term to the manufacture and maintenance of current aircraft fleet, which is based on approved designs and certification.

The economic and social impact of this would be significant within the GB society. However, due to uncertainty in the scale of implications of this scenario, the related cost to end-users is not monetised in this socio-economic analysis.

4.3.2. Identification of plausible non-use scenarios

In addition to the complete shutdown of the UK facilities and relocating the production to other HD facilities outside the GB, the applicant has identified 2 other potential non-use scenarios. These are:

- Using an alternative coating method
- Partial shutdown of the UK facilities and outsourcing of chrome plating outside of the GB

The plausibility of the non-use scenarios for the applicants is analysed in Table 32. The table outlines the analysed non-use scenarios and assigns a plausibility factor.

Table 32. Plausibility of non-use scenarios for the applicant

Non-use scenario
Non-use scenario 1. HD shutdown the UK facilities completely and relocates the production to other HD facilities outside the GB. In case of a refused authorisation, the applicant would have to stop using CrVI in chrome plating. This would result in a shutdown of the HD UK facilities as the HVOF share of production is so small compared to the CrVI production. Without CrVI the applicant cannot produce its equipment, repair the equipment, or sell any spare components to replace in the assembly. Their business is 100% dependent on chrome plating. In this scenario, the parent company, HD, would relocate HD UK's production and MRO operation to its existing facilities or build a new facility outside of Great Britain. **Plausible**
Non-use scenario 2. Using alternative coating method The applicant's production and MRO operation is dependent on chrome plating. New coatings based on HVOF technology have been developed and qualified to replace hard chromium. As outlined in Chapter 4.1.3.1, due to the stringent aviation safety requirements, the long service life of operating and legacy aircraft fleets, the high level of redesign needed and the interminability of the new components with the old ones, and the MRO requirements, those new coatings may only be deployed for new designs. Currently the applicant #B [redacted] HVOF is not a "drop-in" replacement for hard chrome and the replacement involves many challenges, including the high level of re-design needed, the mandatory re-qualification and certification processes that must be followed to fulfil airworthiness requirements as well as the number of LRUs involved. The lengthy and costly testing, validation, component re-design and contract changes with customers form a barrier for the implementation of this alternative, especially for legacy parts for aircrafts no longer in production. The viability of the replacement must be reviewed on component basis. **Not plausible**
Non-use scenario 3. HD partially shutdown the UK facilities and chrome plating is outsourced from outside the GB. Outsourcing the chrome plating activity outside the GB is not feasible for HD UK. The volume and type of work with complex and large components required to support the Runcorn business with chrome plating would not make outsourcing possible. Components used in Runcorn production have multiple chrome plated areas with multiple potential operation sequences and intermediate operations. In general, outsourcing can be considered when the operation is simple in terms of the components/service in a loosely regulated environment. This is clearly not the case with landing gears in aviation industry. In addition, complex restrictions and authorisations relating to MRO production make outsourcing unfeasible for HD UK. **Not plausible**

4.3.3. Conclusion on the most likely non-use scenario

The most likely non-use scenario can be concluded as follows:

- The HD UK sites will stop production and MRO operation, and close their business,
- HD relocates the UK production and MRO operation to its existing facilities or build a new facility outside of Great Britain,
- Chemical supplier and other suppliers will focus on other customers,

- OEMs will source the landing gears from outside the GB,
- End-user will source aircrafts with landing gears produced and repaired outside Great Britain.

The applicant's use would be taken up by market actors operating outside the GB.

4.4. Societal costs associated with non-use

4.4.1. Economic impacts on the applicant

The main economic impacts of the non-use scenario on the applicants are:

- producer surplus – profit foregone in the GB,
- decommissioning cost in the sites.

Producer surplus - Profit foregone

Producer surplus represents the gain to trade a producer receives from the supply of goods or services less the cost of producing the output (i.e. the margin on additional sales). In the event of a refusal of authorisation to use an Annex XIV substance, there are expected to be negative impacts on producer surplus at those firms facing regulatory action (which may be partially offset by positive impacts on other firms). The loss of producer surplus at an affected firm can be estimated by an evaluation of foregone profits at the firm. The loss of profits arises from the premature retirement of productive tangible or intangible assets, the value of which should be equivalent to the discounted stream of future profits over the remaining life of the assets, minus any value recouped from the sale, scrappage or redeployment of existing capital assets (tangible or intangible). The cost of those capital assets is considered sunk at the point of retirement, such that only future returns (rather than costs) are foregone when the asset is retired. For SAGA cases, SEAC recommends using 2 years of profit losses.

As mentioned in Chapter 3.1.3.2, the demand for landing gears is growing rapidly currently as the industry is recovering from the covid-related crash (at 18 % CAGR). For the next 5 years the applicant expects to grow on average [redacted] [between 4-30 %]. This forecast is based on known orders and new work in the pipeline that has been forecasted to materialise. After that and until the end of the review period the annual growth is assumed to be [redacted] per year. These rates are used in the calculations. 100 % of the applicant's revenue would be lost due to business closure. Consequently, the related profit is lost. The profit lost due to the business closure is the profit foregone used in the calculation for producer surplus loss in the GB.

The gross profit margin reported here is from the applicant's internal financial reporting and comes from subtracting the production cost from the revenue.

The average profit between 2018 and 2022 ([redacted] [5-20] M GBP), together with an annual growth rate of [redacted] and a discount rate of [redacted] are used as a basis for the calculation of the SAGA producer surplus loss outlined in Table 33. 2023 is the base year for discounting.

Table 33. Profit foregone in present value (#C for all redactions in the table)

Profit foregone		**Base year: 2023**	**Average of 2024-2035**	**2-year SAGA proxy**	**Per-year value of 12-year period**
Annual growth rate	[redacted]				
Discount factor	[redacted]				
Discounted annual gross profit		[redacted] [5-20] M GBP	[redacted]	[redacted]	[redacted] [2-10] M GBP

The average annual profit foregone in the non-use scenario is #C [redacted] GBP present value between 2024-35. This is the annual profit foregone used in the calculation for producer surplus loss in the GB. This is multiplied by 2 (SAGA) to have a proxy (#C [redacted]) for the change in producer surplus for the whole review period requested. To have a rough approximation for the per-year value, this is further divided by 12 which yields #C [redacted] [2-10] M GBP for the annual profit loss. This value represents the negative producer surplus in the GB if authorisation was not granted and is taken forward as annual profit loss value in the impact calculation.

Decommissioning cost

In the non-use scenario, the applicant must decommission its production sites. The main components of this cost are different disposal and cleaning costs. The applicant estimates that all plating lines & equipment would have zero re-sale value as they are optimised for chrome plating. However, there are some pieces of equipment used for machining the components pre & post plate that would have re-sale value – estimated #C [redacted] at maximum.

The applicant estimates that the total decommissioning costs reach approx. #C [redacted] GBP in the GB facilities. Detailed breakdown of the costs classes is outlined in Table 34.

Table 34. Decommissioning cost

Decommissioning cost	**Total GB facilities**
Disposal of baths	#C [redacted]
Disposal of contaminated material	
Disassembly and disposal of equipment	
Site cleaning	
Land remediation	
Redundancy	
Re-sale	
Total decommissioning cost	

Present value is calculated with the following formula:

$$PV = \frac{C}{(1+r)^n}\ , where$$

- PV = Present Value
- C = Cash Flow at a period
- n = number of periods
- r = rate of return

The present value of the aggregated total cost [redacted] % discount rate and 12-year period, is [redacted] GBP. Annualising, this gives [redacted] 0.30 M GBP.

Summary of monetised impacts on the applicants

The total negative economic impact on the applicant is summarised in Table 35.

Table 35. Summary of economic impact

Cost item	Annualised
Producer surplus lost in the GB	[redacted] [2-10] M GBP per annum
Decommissioning cost	0.30 M GBP per annum

4.4.2. Economic impacts on the supply chain

Economic impacts of the non-use scenario on the chromium trioxide supplier, other raw material and component suppliers are likely to be negligible since they will focus on other sales which compensate the applicant's purchases in time. Except on the one local component manufacturer mentioned in Chapter 4.3.1 who will likely go out of business. HD UK's customers, OEMs, will likely face a production gap. In case of a lengthy production gap, the economic impacts on the OEMs are significant. Similarly, the economic impacts on the end-users may be significant if their fleet cannot be maintained and are grounded.

The parent company would face additional costs in the non-use scenario. It would have to transfer the HD UK's production and MRO operation to other entities, most likely in North America. These facilities would have to invest on new equipment such as test rigs and build fixtures. In addition, there would be cost for FAIR's[40], sealed routing approvals, customer audits for approval, test pieces for approval and so on. The applicant estimates that the additional investment cost is in the region of [redacted] M GBP. The location of these sites is not optimal for some of the customers due to increased shipping and logistics costs. Therefore, the related extra shipping fee is estimated as [redacted] cost of annual sales. These costs are not included in the analysis as they take place outside of the GB and are thus out of the scope.

[40] A First Article Inspection Report (FAIR) is documentation that proves a product has been manufactured to the required specifications.

4.4.3. Economic impacts on competitors

CrVI based chrome plating of the components for the finished landing gear system is required by the end-use industry due to the stringent regulations for airworthiness. In the non-use scenario the applicant cannot use CrVI in the GB. This gives an advantage to those landing gear manufacturers who can use CrVI.

The impact is already accounted for in the producer surplus loss in Chapter 4.4.1.

4.4.4. Wider socio-economic impacts

Quantified social impacts

The applicant employs 320 people in the GB. In the non-use scenario, all these jobs will be lost. Job types and gross salaries including taxes and social security payments of these jobs are outlined in Table 36.

In the following calculation, the scope is the GB. A guidance provided by ECHA[41] notes that tax rate of the country, average salary and default value for job lost should be taken into account when calculating the social impacts.

The total costs of social impacts are calculated with formula provided by ECHA:

$$Social\ impact = jobs\ lost \times average\ gross\ annual\ salary \times (1 - employer\ tax\ rate) \times default\ value\ for\ one\ job\ lost$$

The societal impacts for the applicant are summarised in Table 36.

[41] ECHA, 2016: https://echa.europa.eu/documents/10162/13555/unemployment_report_en.pdf/e0e5b4c2-66e9-4bb8-b125-29a460720554

Table 36. Monetised societal cost (#C for all redactions in the table)

The applicant	**Value**			
Country	Great Britain			
Default value for one job lost	2.09			
Employer tax rate	11 %			
Job related variables	Type	Average annual gross salary, GBP	Lost jobs	Total societal cost[42]
	Manager level jobs	[redacted]	8	[redacted]
	Mid manager level jobs	[redacted]	5	[redacted]
	Office worker jobs	[redacted]	174	[redacted]
	Production manager level jobs	[redacted]	4	[redacted]
	Production mid manager level jobs	[redacted]	8	[redacted]
	Production worker jobs	[redacted]	121	[redacted]
Total societal cost	[redacted]			
Annualised societal cost	[redacted] [1.5-2.5] M GBP			

The negative social impacts of a refused authorisation are in approx. #C [redacted] for the society in the GB. Annualised to the review period applied for (12 years), this equals to approx. #C [redacted] [1.5-2.5] M GBP.

Wider economic impacts

Wider economic impacts include macro-economic features related to the international trade and competition. In this scale, impacts of a business discontinuation of one company, are negligible and don't affect the wider economy on the country level in a stand-alone assessment. However, a refused authorisation for the use of CrVI in chrome plating of landing gears at the Runcorn site may lead to a following sequence of actions on a country level.

MRO operation of aircraft components using chromium trioxide in chrome plating would need to occur outside of the GB as the use is not authorised in the country. There would likely be a significant increase in the size of inventories of these components held at maintenance facilities in the GB, because of the inability to continue on-site maintenance using chrome plating. No maintenance, routine or unexpected, would be possible of airframes, so this would have to be undertaken outside of the GB – for unexpected maintenance, the aircraft would have to be grounded and physically shipped, or flown with a special permit (Permit to Fly) issued by the State of Registry of the aircraft. Clearly, with

42 Calculated: annual gross salary * (1- tax rate of the UK) * number of lost jobs * 2.09 = total societal cost

only component replacement and non-CrVI maintenance of components and aircraft being possible in the GB, this would significantly affect the economic viability of GB-based maintenance operations, and the most likely scenario would be that all maintenance facilities in the GB would be closed (at least eventually) and relocated. In addition, if one step of the repair process is no longer permitted, the whole process is likely to be outsourced, since it will likely not be economically viable to undertake such closely related tasks in separate and distant geographical locations. Ultimately, the entire repair process of aircrafts will probably be shipped elsewhere. Moreover, the non-use scenario would result in production disruption and additional logistical costs involved in shipping large quantities of components into the GB, and large aircraft structures out of the GB. This would have an impact on long and complex supply chains - since if some work has to be moved outside the GB, it may be more economical to align the supply chains within this new region, with knock-on effects on the original locations in terms of loss of employment and reductions in economic activity. Eventually, money flows and trade balance will consequently shift in favour of other countries.

4.4.5. Compilation of socio-economic impacts

Societal costs associated with the non-use are outlined in Table 37.

Table 37. Societal costs associated with non-use (#C for all redactions in the table)

Description of major impacts	**Monetised impacts**
1. Monetised impacts	**Annualised**
Producer surplus loss due to ceasing the use applied for in the GB	[redacted] [2-10] M GBP per year
Decommissioning cost	0.30 M GBP per year
Social cost of unemployment	[redacted] [1.5-2.5] M GBP per year
Sum of monetised impacts	[redacted] **[3.8-12.8] GBP per year**

4.5. Combined impact assessment

To make the impacts comparable, the following comparison uses annualised figures instead of figures over period since the periods are different (e.g. 2 years for producer surplus and 12 years for decommissioning cost and human health impacts). Societal costs of non-use and risk of continued use are outlined in Table 38.

Table 38. Societal costs of non-use and risks of continued use (#C for all redactions in the table)

Societal costs of non-use		Risks of continued use	
Monetised impacts	[redacted] [3.8-12.8] M GBP per year	Monetised excess risks to directly exposed workers	0.032 M GBP per year
Additional quantitatively assessed impacts	n.a.	Monetised excess risks to the general population	0.005 M GBP per year
Qualitatively assessed impacts	n.a.	Qualitatively assessed risks	n.a.
Summary of societal costs of non-use	[redacted] [3.8-12.8] M GBP per year	**Summary of risks of continued use**	0.037 M GBP per year

In conclusion, the societal cost of non-use outweighs the risk on continued use significantly ([redacted] [3.8-12.8] M GBP versus ca. 0.037 M GBP). The benefit-cost ratio compares how many times the benefits outweigh the costs, and the result is approx. [redacted] [100-350] times.

4.6. Sensitivity analysis

Several assumptions were made when preparing this application. Table 39 summarises the evaluation of those assumptions. The assumptions are evaluated based on the level of uncertainty (low-medium-high). The last column summarises how the assumptions impact the risk-benefit calculation of the continued use.

Table 39. Uncertainties on assumptions (#C for all redactions in the table)

Assumption	Evaluation	Uncertainty	Impact
Working days (353)	Not taking into account holidays, bank holidays, illness.	Medium	Overestimate risks
The highest exposure value for one group of workers is used to estimate the risk to all workers	Exposure values differ across the groups. Taking the highest value for one group and applying it to all groups is a conservative approach.	Medium	Overestimates monetised risk to workers
Population densities of a region used instead of a city.	The plating site is located at an industrial area in the outskirts of Runcorn. Using the population density of Cheshire gives thus more accurate estimation than the density of Runcorn.	Low	May underestimate risks
Profit calculation assumes constant profits and linearity between profits and revenue.	Revenue and profit are expected to increase in the future. Future estimations are based on current market information, good experience of forecast available and understanding of the market. Changes in the market might negatively or positively affect the profit calculation.	Medium	Affects benefits
Growth rate after five years is [redacted]	Growth rate is an estimation of the future trend. There are many factors on the market which affects this. Growth rate affects the profit estimation over the period used for producer surplus calculation. Total profit might be lower/higher which changes the magnitude of overall impact lower/higher. However, the rate used after 5 years, [redacted] is relatively conservative so the risk of overestimation is low. This might affect benefit-risk ratio.	Medium	Affects benefits
The impacts of a likely business closure of one local component manufacturer not quantified in the non-use scenario.	It is very likely that this company will close down its business in the non-use scenario as it loses 90 % (HD UK equivalent) its revenue. This company was not surveyed so the impacts were not included in the monetisation.	Medium	Underestimates the benefits of continued use

4.7. Information to support for the review period

The applicants have considered the criteria presented in the publication from the ECHA[43] on setting review periods as starting points for deriving their review period. The justifications for a long review period are summarised in Table 40.

Table 40. Justifications for a long review period against the criteria set by RAC & SEAC
(#C for all redactions in the table)

Criterion	Situation for the applicant
The applicant's investment cycle is demonstrably very long (i.e. the production is capital intensive) making it technically and economically meaningful to substitute only when a major investment or refurbishment takes place.	HD UK has a demonstrably long investment cycle on its chrome plating line and equipment. The existing chrome plating line has been in situ since the Runcorn site opened 25 years ago. The applicant invests CAPEX annually for tank replacements based on the condition of the tanks across all of the plating lines. The lined steel tanks were replaced with plastic tanks approximately 8 years ago and the crane system that supports the plating lines was replaced in 2022 and the control panel in 2021. The applicant forecasts that this process would continue. The plating line is not expected to become obsolete but will require annual upgrades. The production of one aircraft model may last for more than 50 years. HD UK produces landing gears involving chrome plated components for many customers where the existing aircrafts have remaining lifetime of up to 25 years for MRO. All legacy programmes have more than 12 years life left on them, some even 30 years. HD UK does not foresee that its chrome plating line would become obsolete during the time of this production. The implementation of the shortlisted alternative cannot utilise any of the existing plating equipment as it comprises a completely different coating technology. The initial investment for the HVOF installations is ca. [redacted] [£1-10M]. An additional [redacted] is required for a major modification of the current facility to fit the HVOF installations. Once chromium trioxide is phased out, the decommissioning costs of the chrome plating line will also have to be considered, which are not insignificant.
The costs of using the alternatives are very high and very unlikely to change in the next decade as technical progress (as demonstrated in the application) is unlikely to bring any change. For example, this could be the case where a substance is	The high costs for integrating HVOF at HD UK will remain unjustified until a sufficient number of new development programmes have been successfully qualified, certified and industrialised with HVOF, leading to a need to increase HVOF production capacity. The mandatory qualification and certification processes required for fulfilment of airworthiness and military requirements make substitution extremely costly in the aviation and military industries. For existing aircraft components, the lengthy and costly testing, validation, component re-design and contract changes with

[43] European Chemicals Agency, 2013

Criterion	Situation for the applicant
used in very low tonnages for an essential use and the costs for developing an alternative are not justified by the commercial value.	customers form a barrier for the implementation of this alternative, especially for legacy parts for aircrafts no longer in production. The process costs of HVOF are expected to be higher compared to functional chrome plating, mainly due to the very high costs of the coating powders. Please see Chapter 3.3.1.5 for more information.
The applicant can demonstrate that research and development efforts already made, or just started, did not lead to the development of an alternative that could be available within the normal review period.	As explained in Chapter 3.1.2.3, an alternative will only become available once it has passed through the lengthy qualification, certification, and industrialisation processes. The (re-)qualification must be completed on component or sub-system level. Due to the lengthy approval process, an alternative will not be available to replace functional chrome plating across the applicant's entire portfolio within the normal review period, considering the number of LRUs involved. See Chapter 4.1.3.2 for more information on the substitution timeline.
The possible alternatives would require specific legislative measures under the relevant legislative area in order to ensure safety of use (including acquiring the necessary certificates for using the alternative).	As explained in Chapter 3.1.2.3, a possible alternative must pass full qualification, certification and industrialisation to comply with very strict standards in the aviation sector regarding **airworthiness** and to ensure the aircraft's **suitability for safe flight** established in airworthiness regulations (e.g. EU Regulation No 2018/1139, retained in UK domestic law). Similar qualification and certification processes have been adopted in the military sector.
The remaining risks are low and the socio-economic benefits are high, and there is clear evidence that this situation is not likely to change in the next decade.	The aggregated annualised socio-economic benefits are [redacted] [3.8-12.8] M GBP annually, and the related aggregated monetised risks are 0.037 M GBP annually. Thus, the benefits of continued use outweigh the risks by ca. [redacted] [100-350] times. The situation is unlikely to change in the next decade, and the risk assessment already takes into account the highest forecast annual tonnage over the review period applied for.

In conclusion, **HD UK is requesting a review period of 12 years** to continue its use of chromium trioxide functional chrome plating and ensure the availability of chrome plated components for the production of aircrafts and military vehicles as well as MRO activities until an alternative has been successfully qualified, certified and industrialised. This is justified based on the criteria set for determining the length of the review period by the Committees for Risk Assessment and Socio-Economic Analysis.

5. CONCLUSION

Chromium trioxide based functional chrome plating results in a coating with a unique combination of properties including high hardness, resistance against wear and corrosion, low coefficient of friction and strong adhesion. These properties are key for ensuring the successful operation of the aircraft and military vehicle components in very harsh, challenging and safety critical environments. Thanks to these properties and the inherent crack pattern which provides lubricant retention, functional chrome plating is particularly suited for coating of gas/oil sealing surfaces. Finding a one-to-one replacement for chromium trioxide which fulfils all technical requirements for the specific use is therefore a challenging task.

Extensive R&D efforts over the last few decades have been undertaken within the aerospace industry to find suitable replacements for functional chrome plating. As a result from these efforts, HVOF coatings are considered as the most promising replacement for hard chrome plating and the alternative coatings have been qualified and implemented as a functional chrome plating replacement on specific aircraft components. Thus, the alternative can be considered as suitable and available in general. HD UK is also currently implementing the HVOF coating WC/CoCr for its new development programmes. However, in order HVOF WC/CoCr (or any other alternative) to become available for HD UK, it must be successfully qualified, certified and industrialised before production can start due to the strict regulations on airworthiness requirements.

HVOF coatings are more easily applied to new equipment being developed as the equipment design can be tailored around this technology taking into account its specific design parameters rather than those of chrome plating. In most cases, the hard chrome coating cannot be replaced with a HVOF coating without additional re-design of the component and other parts of the assembly, which is time-consuming. HD UK foresees that the replacement of functional chrome plating will take at least 12 years based simply on the time-consuming activities by the engineering function (ca. #B [redacted] [32-60] months per LRU) and considering the number of components covered by this use (ca. #B [redacted]). In addition, it should be noted that as a line-of-sight technology, HVOF will not become applicable for all components chrome plated at HD UK due to geometric restrictions. This means that at least one additional alternative would have to be implemented to fully phase-out the use of chromium trioxide. This alternative has not yet been identified.

In the most likely non-use scenario (NUS), HD would shutdown the UK facilities completely and relocate the production to other HD facilities outside the GB, resulting in the following economic impacts:

- Producer surplus loss due to ceasing the use applied for in the GB: #C [redacted] [2-10] M GBP per year
- Decommissioning cost: 0.30 M GBP per year
- Social cost of unemployment of 320 people in the GB: #C [redacted] [1.5-2.5] M GBP per year

To avoid the negative socio-economic consequences, **HD UK is requesting a review period of 12 years** to continue its efforts to substitute its use of chromium trioxide in functional chrome plating of aircraft and military vehicle components. This is justified, since the aggregated socio-economic benefits of the continued use are [redacted] [3.8-12.8] M GBP annually, and the related aggregated monetised risks are 0.037 M GBP annually. Thus, the benefits of continued use outweigh the risks by ca. [redacted] [100-350] times.

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