ANALYSIS OF ALTERNATIVES
and
SOCIO-ECONOMIC ANALYSIS

Complete version

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Submitted by:	Wesco Aircraft EMEA Ltd on behalf of the Aerospace and Defence Chromates Reauthorisation Consortium
Date:	December 2022
Substances:	- Chromium trioxide (includes "Acids generated from chromium trioxide and their oligomers", when used in aqueous solutions) - Sodium dichromate - Potassium dichromate - Dichromium(tris) chromate
Use title:	Chemical conversion coating using chromium trioxide, sodium dichromate, potassium dichromate, and/or dichromium(tris) chromate in aerospace and defence industry and its supply chains.
Use number:	1

Note

This submission includes no confidential information declared in this document. All information contained in this document can be made public. There is no accompanying document which provides confidential information, as a result there are no justifications for claiming any information confidential.

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Abbreviations

ADCR – Aerospace and Defence Chromates Reauthorisation

A&D – Aerospace and Defence

AfA – Application for Authorisation

AoA – Analysis of Alternatives

AoG – Aircraft on the Ground

BCR – Benefit to Cost Ratio

BtP – Build-to-Print manufacturer

CCC – Chemical Conversion Coating

CCST – Chromium VI Compounds for Surface Treatment

CMR – Carcinogen, Mutagen or toxic for Reproduction

Cr(VI) – Hexavalent chromium

CSR – Chemical Safety Report

CT – Chromium trioxide

CTAC – Chromium Trioxide Authorisation Consortium

DtB – Design-to-Build manufacturer

DtC – Dichromium tris(chromate)

EASA - European Aviation Safety Agency

EBITDA - Earnings before interest, taxes, depreciation, and amortization

ECHA – European Chemicals Agency

EEA – European Economic Area

ESA – European Space Agency

GCCA – Global Chromates Consortium for Authorisation

GDP – Gross domestic product

GOS – Gross operating surplus

ICAO – International Civil Aviation Organisation

MoD – Ministry of Defence

MRL – Manufacturing readiness level

MRO – Maintenance, Repair and Overhaul

NADCAP - National Aerospace and Defence Contractors Accreditation Program

NATO – North Atlantic Treaty Organisation

NUS – Non-use scenario

OELV - Occupational Exposure Limit Value

OEM – Original Equipment Manufacturer

RAC – Risk Assessment Committee

REACH - Registration, Evaluation, Authorisation and restriction of Chemicals

RR - Review Report

SC – Sodium chromate

SD – Sodium dichromate

SEA – Socio Economic Analysis

SEAC – Socio Economic Analysis Committee

SME – Small and medium-sized enterprises

SVHC – Substance of Very High Concern

T&E – Testing and Evaluation

TRL – Technology Readiness Level

UK – United Kingdom

WCS – Worker contributing scenario

Glossary

Term	Description
Active Corrosion Inhibition	The ability of a corrosion protection system to spontaneously repair small amounts of chemical or mechanical damage that exposes areas of metal without any surface protection (“self-healing properties”). Active corrosion inhibition can be provided by soluble corrosion inhibitors.
Adhesion promotion	The ability of the treatment to improve and maintain the adhesion of subsequent layers such as paints, primers, adhesives, and sealants. It also includes the adhesion of the coating to the substrate.
Aeroderivative	Parts used in power generation turbines used to generate electricity or propulsion in civil and defence marine and industrial applications that are adapted from the design/manufacturing processes and supply chains that produce parts for the aerospace industry. Typical applications include utility and power plants, mobile power units, oil and gas platforms and pipelines, floating production vessels, and for powering marine/offshore vessels such as Naval warships.
Aerospace	Comprises the civil and military aviation, and space industries.
Aerospace and Defence (A&D)	Comprises the civil and military aviation, space industries and the public organisations and commercial industry involved in designing, producing, maintaining, or using military material for land, naval or aerospace use.
Aircraft	A vehicle or machine able to fly by gaining support from the air. Includes both fixed-wing and rotorcraft (e.g. helicopters).
Airworthiness	Airworthiness is defined by the International Civil Aviation Organisation as "The status of an aircraft, engine, propeller or part when it conforms to its approved design and is in a condition for safe operation". Airworthiness is demonstrated by a certificate of airworthiness issued by the civil aviation authority in the state in which the aircraft is registered, and continuing airworthiness is achieved by performing the required maintenance actions.
Airworthiness Authority	The body that sets airworthiness regulations and certifies materials, hardware, and processes against them. This may be for example the European Union Aviation Safety Authority (EASA), the Federal Aviation Administration (FAA), or national defence airworthiness authorities.
Airworthiness regulations	Set performance requirements to be met. The regulations are both set and assessed by the relevant airworthiness authority (such as EASA or national Ministry of Defence (MoD) or Defence Airworthiness Authority).
Alternative	Test candidates which have been validated and certified as part of the substitution process.
Article	An object which during production is given a special shape, surface or design which determines its function to a greater degree than does its chemical composition
Assembly	Several components or subassemblies of hardware which are fitted together to make an identifiable unit or article capable of disassembly such as equipment, a machine, or an Aerospace and Defence (A&D) product.
Aviation	The activities associated with designing, producing, maintaining, or flying aircraft.
Benefit-Cost Ratio (BCR)	An indicator showing the relationship between the relative costs and benefits of a proposed activity. If an activity has a BCR greater than 1.0, then it is expected to deliver a positive net present value.
Build-to-Print (BtP)	Companies that undertake specific processes, dictated by the OEM, to build A&D components.
Certification	The procedure by which a party (Authorities or MOD/Space customer) gives written assurance that all components, equipment, hardware, services, or processes have satisfied the specific requirements. These are usually defined in the Certification requirements.

Term	Description
Coefficient of friction	Friction is the force resisting the relative motion of solid surfaces sliding against each other. The coefficient of friction is the ratio of the resisting force to the force pressing the surfaces together.
Complex object	Any object made up of more than one article.
Component	Any article regardless of size that is uniquely identified and qualified and is either included in a complex object (e.g. frames, brackets, fasteners and panels), or is a complex object itself (e.g. an assembly or sub-system)
Compound annual growth rate	The mean annual growth rate of an investment over a specified period of time, longer than one year.
Corrosion protection	Means applied to the metal surface to prevent or interrupt chemical reactions (e.g. oxidation) on the surface of the metal part leading to loss of material. The corrosion protection provides corrosion resistance to the surface.
Defence	Comprises the public organisations and commercial industry involved in designing, producing, maintaining, or using military material for land, naval or aerospace use.
Design	A set of information that defines the characteristics of a component (adapted from EN 13701:2001).
Design owner	The owner of the component/assembly/product detailed design. For Build-to-Print designs, the design owner is usually the OEM or military/space customer. For Design-to-Build, the supplier is the design owner of the specific hardware, based on the high-level requirements set by the OEM (as their principal).
Design-to-Build (DtB)	Companies which design and build components. Also known as “Build-to-Spec".
Embrittlement	The process of becoming degraded, for example loss of ductility and reduction in load-bearing capability, due to exposure to certain environments.
Fatigue	Progressive localised and permanent structural change that occurs in a material subjected to repeated or fluctuating strains at stresses less than the tensile strength of the material. The “permanent structural change” is in the form of microcracks in the crystal structure that can progressively lead to potentially catastrophic macro-cracking and component failure.
Flexibility	The ability to bend easily without breaking or permanently deforming.
Formulation	A mixture of specific substances, in specific concentrations, in a specific form.
Formulator	Company that manufactures formulations (may also design and develop formulations).
Gross Domestic Product (GDP)	The standard measure of the value added created through the production of goods and services in a country during a certain period. As such, it also measures the income earned from that production, or the total amount spent on final goods and services (less imports).
Gross Operating Surplus	Equivalent to economic rent or value of capital services flows or benefit from the asset.
Gross Value Added	The value of output less the value of intermediate consumption; it is a measure of the contribution to GDP made by an individual producer, industry or sector.
Hardness	Ability of a material to withstand localized permanent deformation, typically by indentation. Hardness may also be used to describe a material’s resistance to deformation due to other actions, such as cutting, abrasion, penetration and scratching.
Heat resilience	The ability of a coating or substrate to withstand repeated cycles of heating and cooling and exposure to corrosive conditions. Also known as cyclic heat-corrosion resistance.
Hot corrosion resistance	The ability of a coating or substrate to withstand attack by molten salts at temperatures in excess of 400°C.
Industrialisation	The final step of the substitution process, following Certification. After having passed qualification, validation and certification, the next step is to industrialise the qualified material or process in all relevant activities and operations of production, maintenance, and the supply chain. Industrialisation may also be referred to as implementation.
Layer thickness	The thickness of a layer or coatings on a substrate.

Term	Description
Legacy parts	Any part that is already designed, validated, and certified by Airworthiness Authorities or for defence and space, or any part with an approved design in accordance with a defence or space development contract. This includes any part in service.
Material	The lowest level in the system hierarchy. Includes such items as metals, chemicals, and formulations (e.g. paints).
Maintenance, Repair and Overhaul (MRO)	The service of civilian and/or military in-service products. Term may be used to describe both the activities themselves and the organisation that performs them.
NACE	The Statistical Classification of Economic Activities in the European Community. It is part of the international integrated system of economic classifications, based on classifications of the UN Statistical Commission (UNSTAT), Eurostat as well as national classifications.
NADCAP	National Aerospace and Defence Contractors Accreditation Program which qualifies suppliers and undertakes ISO audits of their processes.
Net Present Value	Valuation method to value stocks of natural resources. It is obtained by discounting future flows of economic benefits to the present period.
Original Equipment Manufacturer (OEM)	Generally large companies which design, manufacture, assemble and sell engines, aircraft, space, and defence equipment (including spare parts) to the final customer. In addition, an OEM may perform MRO activities.
Part	Any article or complex object.
Pickling	The removal of surface oxides and small amounts of substrate surface by chemical or electrochemical action.
Present Value	The discounted sum of all future debt service at a given rate of interest. If the rate of interest is the contractual rate of the debt, by construction, the present value equals the nominal value, whereas if the rate of interest is the market interest rate, then the present value equals the market value of the debt.
Pre-treatment	Pre-treatment processes are used, prior to a subsequent finishing treatment (e.g. chemical conversion coating, anodising), to remove contaminants (e.g. oil, grease, dust), oxides, scale, and previously applied coatings. The pre-treatment process must also provide chemically active surfaces for the subsequent treatment. Pre-treatment of metallic substrates typically consists of cleaning and/or surface preparation processes.
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).
Proposed candidate	A formulation in development or developed by a formulator as a part of the substitution process for which testing by the design owner is yet to be determined. In the parent applications for authorisation, this was referred to as a 'potential alternative'.
Qualification	1. Part of the substitution process following Development and preceding Validation to perform screening tests of test candidate(s) before determining if further validation testing is warranted 2. The term qualification is also used during the industrialisation phase to describe the approval of suppliers to carry out suitable processes.
Requirement	A property that materials, components, equipment, or processes must fulfil, or actions that suppliers must undertake.
Resistivity	Property that quantifies how a given material opposes the flow of electric current. Resistivity is the inverse of conductivity.
Social Cost	All relevant impacts which may affect workers, consumers and the general public and are not covered under health, environmental or economic impacts (e.g. employment, working conditions, job satisfaction, education of workers and social security).
Specification	Document stating formal set of requirements for activities (e.g. procedure document, process specification and test specification), components, or products (e.g. product specification, performance specification and drawing).
Standard	A document issued by an organisation or professional body that sets out norms for technical methods, processes, materials, components, and practices.

Term	Description
Sub-system	The second highest level in the system hierarchy. Includes such items as fuselage, wings, actuators, landing gears, rocket motors, transmissions, and blades.
Surface morphology	The defined surface texture of the substrate.
System	The highest level in the system hierarchy. Includes such items as the airframe, gearboxes, rotor, propulsion system, electrical system, avionic system, and hydraulic system.
System hierarchy	The grouping/categorisation of the physical elements that comprise a final product (such as an aircraft), according to their complexity and degree of interconnectedness. Comprises materials, parts/components, assemblies, sub-systems, and systems.
Temperature resistance	The ability to withstand temperature changes and extremes of temperature.
Test candidate	Materials which have been accepted for testing or are currently undergoing testing by a design owner, as a part of the substitution process. In the parent applications for authorisation, this was referred to as a 'candidate alternative'.
Type certificate	Document issued by an Airworthiness Authority certifying that an Aerospace product of a specific design and construction meets the appropriate airworthiness requirements.
Validation	Part of the substitution process following Qualification and preceding Certification, to verify that all materials, components, equipment, or processes meet or exceed the defined performance requirements.
Value of statistical life	Values the impact of risks to the length of life.
Verification	The process of establishing and confirming compliance with relevant procedures and requirements.
Wear resistance	The ability of a surface to withstand degradation or loss due to frictional movement against other surfaces.
Sources: GCCA and ADCR consortia	

DECLARATION

We, the Authorisation Holders, are aware of the fact that further evidence might be requested by HSE to support 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 11 November 2022 the information is not publicly available and, in accordance with the due measures of protection that we have implemented, a member of the public should not be able to obtain access to this information without our consent or that of the third party whose commercial interests are at stake.

Signature: mazin.badri@incora.com
14/11/2022
SES Simple electronic signature
Signed on Skribble.com

Date: 11 November 2022

1 SUMMARY

This combined AoA/SEA uses some terms in a manner specific to the aerospace and defence sector. Please see the glossary for explanations of the specific meaning of commonly used words, such as component, and other technical terms within the context of this report.

1.1 Introduction

The Aerospace and Defence Chromates Reauthorisation (ADCR) Consortium on behalf of the applicants has developed several review reports and new applications. These review reports or new applications cover all uses of soluble chromates considered to be relevant by the ADCR consortium members. Although formally they are upstream applications submitted by manufacturers, importers or formulators of chromate-containing chemical products, the applications are based on sector-specific data and detailed information obtained from actors throughout the supply chain.

For the purposes of this document, the term 'aerospace and defence' comprises the civil aviation, defence/security and space industries, as well as aeroderivative products. The aerospace and defence (A&D) industry has been working towards the substitution of Cr(VI) across various uses for the past 25-30 years. Although there have been numerous successes and levels of use have decreased significantly, the specific use of hexavalent chromium compounds in chemical conversion coating[1] is still required for many products. This remains critical to both flight safety and to military mission readiness, and hence to society. The socio-economic impacts of a refused authorisation are therefore significant not just for the sector but also for the EEA and UK societies and economies more generally. Furthermore, at the EU level, the A&D sector is one of the 14 sectors highlighted by the EU's New Industrial Strategy[2] as being important to innovation, competition and a strong and well-functioning single market.

The parent authorisations to this combined AoA/SEA covered multiple surface treatments and different individual chromates. This combined AoA/SEA covers only one of the currently authorised types of surface treatment – chemical conversion coating – and therefore adopts a narrower definition of "use" compared to the original Chromium Trioxide Authorisation Consortium (CTAC), Chromium VI Compounds for Surface Treatment (CCST) and Global Chromates Consortium for Authorisation (GCCA) applications. The other surface treatments that are still being supported by the ADCR are covered by separate, complementary submissions for each "use".

A narrower definition of the uses of the chromates has purposely been adopted by the ADCR to ensure greater clarity on the risks posed by continued use, the availability of alternatives and the socio-economic impacts of non-use.

1 Combined AoA/SEAs are also being submitted by the ADCR covering ten other uses of the chromates in formulation and other specific surface treatment activities as more narrowly defined by the ADCR.

2 https://op.europa.eu/en/publication-detail/-/publication/52904a0b-ae95-11eb-9767-01aa75ed71a1/language-en

The specific use covered by this combined AoA/SEA is defined as:

1) *Chemical conversion coating of metallic components using chromium trioxide, sodium dichromate, potassium dichromate and/or dichromium tris(chromate) in the Aerospace and Defence industry and its supply chains to meet functional requirements.*

The "applied-for-use" of chemical conversion coatings involves the continued use of chromium trioxide, sodium dichromate, potassium dichromate and/or dichromium tris(chromate) across the EEA and the UK for a further 12-year review period.

These four chromates were included into Annex XIV of Regulation (EC) No 1907/2006 due to their intrinsic properties (mutagenic, carcinogenic, toxic for reproduction; depending on the chromate). According to Article 62 (4)(d) of this Regulation, the chemical safety report (CSR) supporting an Application for Authorisation (AfA) needs to cover only those risks arising from the intrinsic properties specified in Annex XIV. The carcinogenicity, mutagenicity and reproductive toxicities of CT, its acids, SD, PD, and DtC are driven by the chromium VI (Cr(VI)) ion released when the substances solubilise and dissociate.

A grouping approach has therefore been adopted for the CSR and is also adopted here for the combined AoA/SEA. From the CSR perspective, grouping is appropriate because:

- All substances share this common toxic moiety (Cr(VI)), and are therefore expected to exert effects in an additive manner;
- At many sites various chromates are used in parallel, the exposures of which are additive; and
- For some uses, different chromates may be used for the same process where demanded by a component's or final product's certification requirements.

Grouping is also appropriate to the analysis of alternatives. The key determinant of functionality is the presence of the Cr(VI) component delivered by the chromate substance. As a result, the four chromates deliver one or more of the same key functionalities in each use and the same families of potential alternatives are relevant to substitution.

With respect to the SEA, the grouping approach ensures that there is no double-counting of economic impacts and the social costs of unemployment. This would occur if the assessment was carried out separately for each chromate's use in CCC due to the fact that some of the formulations used in CCC contain more than one of the chromates, and different chromates may be used for CCC carried out via immersion versus CCC touch-up and brush activities.

The potential for double counting is significant given that approximately 350 sites in the EEA and 80 sites in Great Britain are anticipated as undertaking CCC. This includes sites involved in the production of components and end products, as well as maintenance, repair and overhaul services for both civil aviation and military bodies, as well as aeroderivative uses.

It is estimated that these sites consume the following maximum quantities of each of the four chromates of relevance, with some sites using more than one chromate in CCC activities. These figures are based on the maximum consumption per site identified from the CSR, Article 66 notifications and the percentage of sites using each of the chromates as identified in responses to the SEA questionnaire and from discussions with formulators and distributors.

Table 1-1: Maximum tonnages used in CCC formulations				
	Chromium trioxide	**Sodium dichromate**	**Potassium dichromate**	**Dichromium tris(chromate)**
EEA	Up to 125 t/y	Up to 40 t/y	Up to 18 t/y	Up to 2.6 t/y
UK	Up to 30 t/y	Up to 7 t/y	Up to 6 t/y	Up to 1 t/y

1.2 Availability and suitability of alternatives

For the past several decades, ADCR members who are "design owners" [including Original Equipment Manufacturers (OEMs) and Design-to-Build manufacturers (DtB)] selling products used in civil aviation and military aircraft, ground and sea-based defence systems, and aeroderivatives have been searching for alternatives to the use of the four chromates in chemical conversion coating as a specific use. At the current time, the remaining uses form part of an overall system, with the key functionalities of the chromate-based formulations in CCC being as follows (see also Section 3.2):

- Corrosion resistance (self-healing);
- Chemical resistance;
- Adhesion promotion/adhesion to subsequent layer;
- Layer thickness;
- Electrical resistivity;
- Temperature resistance; and
- Pre-treatment compatibility.

Other factors which are taken into account include pre-treatment compatibility and visibility of the coating which is taken into account when assessing test candidate alternatives.

Chemical conversion coating (CCC) is a key use of the chromates by the A&D industry. It is a chemical process that introduces a chemical coating or changes to the surface of a substrate to improve the substrate properties. It is applied to substrates such as aluminium, magnesium and titanium, and produces a superficial layer containing a compound of the substrate metal and at least an anion from the chemistry applied to it.

The conversion coating forms an adherent, fixed, insoluble, inorganic crystalline or amorphous surface film of complexes from oxides and hydroxides or phosphates that become an integral part of the metal surface by means of a chemical reaction between the metal surface and the solution. The typical thickness of the coating is 0.05-2.00 microns (µm), with coatings typically being in the lower thickness range (i.e. below 0.5 µm).

A&D products operate in highly challenging, extreme environments over extended timeframes. Due to these challenges, alongside engineering-based solutions, the A&D industry must use numerous high-performance mixtures which have passed through an extensive approval process to demonstrate their suitability for use.

OEMs (as design owners), in particular, have responsibility for certification of alternatives and have conducted a full analysis of their requirements into the future, taking into account progress of R&D, testing, qualification, certification and industrialisation activities. The companies are at different stages in the implementation of alternatives, with some indicating that they expect to be able to substitute the above chromates in chemical conversion coating across some of their current components, final products and MRO (maintenance, repair and overhaul) processes within the next four to seven years; while others have not yet been able to identify technically feasible alternatives for all components and final products and MRO processes that meet performance requirements, and will require a further 12 years to gain certifications and then implement current test candidates; a further set are constrained by military and MRO requirements which may mean that it will take at least 12 years to implement technically feasible substitutes.

Furthermore, obtaining such certification across hundreds of components is a time-consuming and costly process, given the strict testing regimes that must be adhered to achieve the qualification, validation and certification of components using an alternative. At the sectoral level, therefore, and to ensure minimisation of supply chain disruption and associated business risks, a 12-year review period is requested. Business risks arise from the need for alternatives to be available and deployed across all components and suppliers to ensure continuity of manufacturing activities across the supply chain. A shorter period would impact on the functioning of the current market, given the complexity of supply chain relationships.

Companies engaged in maintenance, repair and overhaul (MRO) activities face particular substitution difficulties, as they are mandated to continue use of chromium trioxide, sodium dichromate, potassium dichromate and/or dichromium tris(chromate) in chemical conversion coating if this is specified in the Maintenance Manuals provided to them by the OEMs. MROs (military and civilian) are legally obliged to carry out their activities in line with the requirements set out in Maintenance Manuals, given the importance of these to ensuring airworthiness and the safety and reliability of final products. As a result, they rely on the completion of the R&D, testing and certification activities of the OEMs and the update of the Maintenance Manuals before they are able to adopt alternative substances or processes.

As a result of the different requirements outlined above, at the sectoral level, there will be an on-going progression of substitution over the requested 12-year review period. By the end of year seven (2031), significant reductions in the use of the chromates are anticipated, with use phased-out by year 12 assuming there are no set-backs in the planned substitutions. The potential need for more than 12 years has been identified by a small number of OEMs due to difficulties in developing technically feasible alternatives to date, or due to the need by MROs and MoDs for continued use in the maintenance and repair of in-service (legacy) final A&D products.

The expected progression of ADCR members' substitution plans to replace Cr(VI) in conversion coating is shown below.

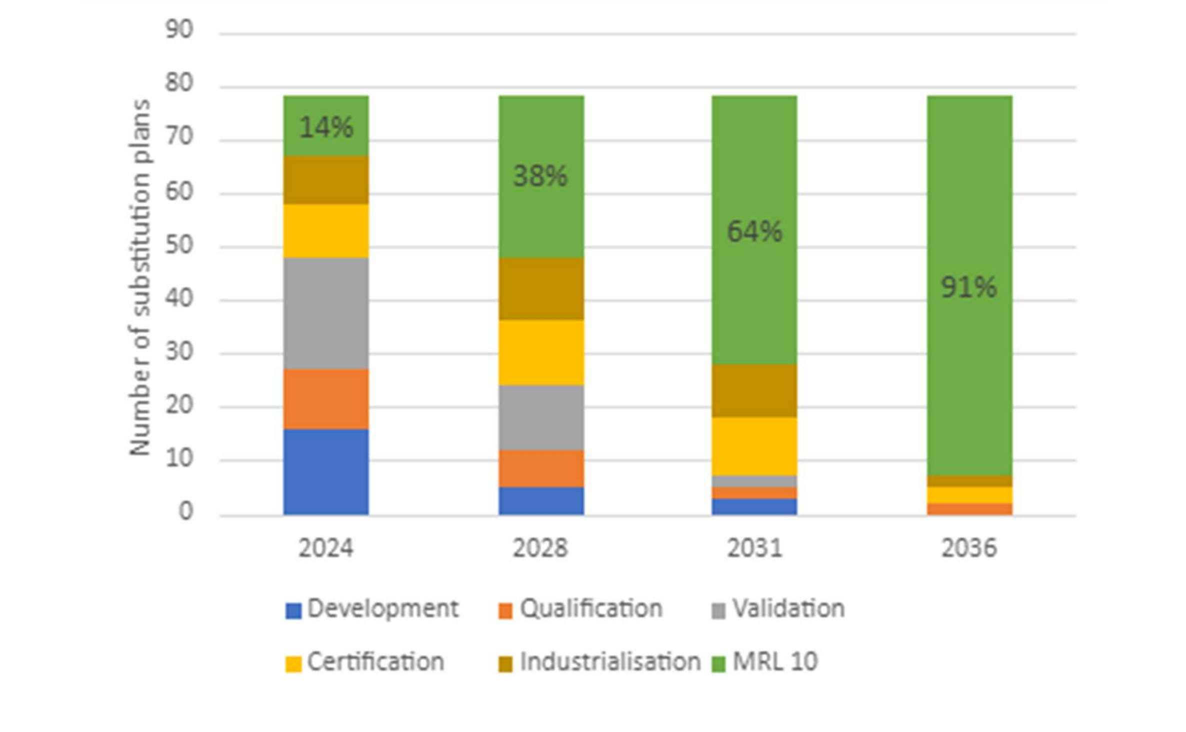


Figure 1-1: Expected progression of substitution plans for the use of Cr(VI) in conversion coating, by year. The vertical axis refers to number of substitution plans (some members have multiple substitution plans for conversion coating). The percentage value shown on each of the green bars indicates the proportion of substitution plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which there is expected to be a significant reduction in Cr(VI) usage.
Source: **RPA analysis, ADCR members**

1.3 Socio-economic benefits from continued use

The continued use of the four chromates in chemical conversion coating specifically (ADCR Use #1) over the review period will confer significant socio-economic benefits to ADCR members, their suppliers and to their end customers which include civil aviation, the military, space, emergency services. It will also ensure the continued functioning of the aerospace and defence supply chains in the EEA and UK, conferring the wider economic growth and employment benefits that come with this.

The benefits can be summarised as follows (with the detailed calculations set out in Section 5):

- Importers of the chromates and formulators of the mixtures used in chemical conversion coating will continue to earn profits from sales to the A&D sector. These are not quantified in this SEA but are detailed in the linked Formulation AoA/SEA;
- OEMs will be able to rely on the use of chromates by their EEA and UK suppliers and in their own production activities. The profit losses[3] to these companies under the non-use scenario would equate to between €4.5 - 11.2 billion for the EEA and €0.62 – 5.1 billion for the UK, over a 2-year period (starting in 2025, PV discounted at 4%). These figures exclude the potential

[3] Two different approaches have been used to calculate economic impacts to produce lower and upper bound estimates. Profit losses are discounted over two years at 4% per annum.

profits that could be gained under the continued use scenario from the global increase in demand for air transport;

- Build-to-Print (BtP) and Design-to-Build (DtB) suppliers would be able to continue their production activities in the EEA/UK and meet the performance requirements of the OEMs. The associated profit losses that would be avoided under the non-use scenario for these companies are calculated at €0.67 – 2.2 billion for the EEA and €0.16 – 0.41 billion for the UK over a 2-year period (starting in 2025, PV discounted at 4%);

- Under the non-use scenario, MRO companies which provide maintenance and repair services to both civil aviation and/or military forces, would be forced to move some operations outside the EEA/UK, with the consequent profit losses equating to between €0.71 – 0.76 billion for the EEA and €0.12 – 0.17 billion for the UK over a 2-year period (starting in 2025, PV discounted at 4%);

- Continued high levels of employment in the sector, with these ensuring the retention of highly skilled workers paid at above average wage levels. From a social perspective, the benefits from avoiding the unemployment of workers involved in chemical conversion coating are estimated at €7.92 billion in the EEA and €1.07 billion in the UK. These benefits are associated with the protection of over 71,600 jobs in the EEA and 12,800 jobs in the UK;

- Critically, civil aviation and emergency services will benefit from the continued flight safety and availability of aircraft and other equipment;

- Military forces will be able to repair and maintain existing aircraft and other equipment to ensure operational readiness and the ability to respond to missions as required; and

- The general public will benefit from continued safe flights, fewer flight delays, the on-time delivery of cargo and goods, and the economic growth provided by the contributions of these sectors to the economic development, as well as R&D and technological innovation, while alternatives are qualified, certified and industrialised.

It is clear that the level of disruption that would be caused through the inability to continue chemical conversion coating activities to A&D customers and society would outweigh the losses to A&D companies across the value chain (including OEMs, DtBs, BtP suppliers, MROs and MoDs).

1.4 Residual risk to human health from continued use

The parent authorisations placed conditions on the continued use of the four chromates in surface treatments, including in CCC. The A&D sector has made huge efforts to be compliant with these conditions, investing not only in risk management measures but also improved worker and environmental monitoring.

Furthermore, significant technical achievements have been made in developing and qualifying alternatives for use on some components/final products, although there remain technical challenges for other components and final products. As a result, it is projected that from 2024, based on current company specific substitution plans where technically and economically feasible, consumption of the chromates by ADCR members and their suppliers will decline significantly over the requested 12-year review period. For the purposes of the human health risk assessment, however, it has been assumed that the quantities used and the number of sites using the chromates remains constant over the 12-

year period. This will lead to an overestimate of the residual risks to both workers and humans via the environment.

Risks to workers have been estimated based on the use of exposure monitoring data, supplemented by modelling data as appropriate. Across the 350 EEA sites where chromate-based CCC is anticipated as taking place, an estimated total of 9,450 workers (including 1,400 highly skilled machinists and 2,100 incidentally exposed workers) may be exposed to Cr(VI); for the 80 UK sites where CCC takes place, approximately 2,160 workers may be exposed (including 320 highly skilled machinists and 480 incidentally exposed workers).

Exposures for humans via the environment have been calculated for the local level only. Based on the population density of the different countries within which chemical conversion coating is considered to take place, an estimated 165,700 people in the EEA and 106,600 people in the UK[4] are calculated as potentially being exposed to Cr(VI) due to chromate-based CCC activities. Again, these figures are conservative due to the on-going substitution of CCC formulations with alternatives.

The predicted number of cancer cases per annum and the annualised economic value of these social costs for both workers and humans via the environment are[5]:

- EEA: 2.69 fatal cancers and 0.65 non-fatal cancers over the 12-year review period, at a total social cost of €3.93 million;

- UK: 0.91 fatal cancers and 0.24 non-fatal cancers over the 12-year review period at a total social cost of €1.33 million.

1.5 Comparison of socio-economic benefits and residual risks

The ratios of the total costs of non-Authorisation (i.e. the benefits of continued use) to the residual risks to human health are as follows for the EEA and UK respectively:

- EEA: 3,526 to 1 for the lower bound of profit losses and unemployment costs or 5,620 to 1 for the upper bound profit losses and unemployment costs, where economic impacts are assessed over two years and residual risks over 12 years;

- UK: 1,521 to 1 for the lower bound of profit losses and unemployment costs or 5,053 to 1 for the upper bound profit losses and unemployment costs, where economic impacts are assessed over two years and residual risks over 12 years.

The above estimates represent a significant underestimate of the actual benefits conferred by the continued use of chromium trioxide, sodium dichromate, potassium dichromate and dichromium (tris)chromate in CCC, as it only encompasses benefits that could be readily quantified and monetised. The true benefit-cost ratios must be assumed to also encompass:

- The significant benefits to civil aviation and military customers, in terms of flight readiness and military preparedness of aircraft and equipment;

[4] Although the number of people exposed under the local scenario appears disproportionate for the UK compared to the EU population exposed, this is due to the UK's high population density.

[5] Discounted over 12 years at 4% per annum, and assuming a 20 year lag in effects.

- The avoided impacts on air transport – both passenger and cargo – across the EEA and the UK due to stranded aircraft on the ground (AoG), reductions in available aircraft, increased flight costs, etc.;

- The avoided impacts on society more generally due to impacts on air transport and the wider economic effects of the high levels of unemployment within a skilled workforce, combined with the indirect and induced effect from the loss of portions of the A&D sector from the EEA and UK as they either cease some activities or relocate relevant operations; and

- The avoided economic and environmental costs associated with increased transporting of components in and out of the EEA/UK for maintenance, repair and overhaul (whether civilian or military) and production activities.

1.6 Factors to be considered when defining the operating conditions, risk management measures, and/or monitoring arrangements

A range of factors should be taken into account when considering the need for additional risk management measures and/or monitoring requirements:

- Occupational exposure monitoring requirements were placed on downstream users within the applicants supply chain as part of the granting of the parent authorisations. The A&D industry has responded to these requirements by increasing the level of monitoring carried out, with this including increases in expenditure on worker monitoring and adaptations to the way in which monitoring was previously carried out.

- As demonstrated in Section 4, since 2017 companies have invested in new equipment to reduce exposures to workers and to reduce environmental emissions. This has included investment in new, better performing production equipment as well as increased exhaust ventilation and other measures.

- A Binding Occupational Exposure Limit Value (OELV) has been introduced under EU Directive 2004/37/EC that will become more stringent after January 17th, 2025; this Binding OELV was recommended by the Tripartite Advisory Committee on Safety and Health based on consensus and will provide an additional level of protection for workers undertaking Cr(VI)- based CCC The sector is working with formulators to reduce the volume of chromates used in chemical conversion coating activities and, as indicated in the Substitution Plan, companies are progressing towards the certification and implementation of substitutes across on-going uses. Many sites only use very small volumes of the chromates in CCC, in particular, dichromium tris(chromate), in touch-up activities.

- The current "blanket" monitoring requirements are difficult to apply to dichromium tris(chromate) used in small pen sticks for touch-up surface preparation, which may be used infrequently, in very small volumes, for very short durations, and where such uses cannot be pre-planned or predicted. ADCR members are aware of cases within their supply chains of companies undertaking "dummy" spray or brush on scrap parts in order to meet the monitoring requirements because they otherwise did not have a scheduled use of the chromate by when the monitoring deadline was mandated.

1.7 Factors to be considered when assessing the duration of a review period

The ADCR's requirements for continued use meet the criteria set out by the ECHA Committees for Authorisation review periods longer than normal (7 years), as follows:

- **The applicants' downstream users face investment cycles that are demonstrably very long**, with this recognised in various European Commission reports. Final products in the A&D sector can have lives of over 50 years (especially military equipment), with there being examples of contracts to produce parts for out-of-production final products extending as long as 35 years. MROs and MoDs in particular require the ability to continue servicing older, out-of-production but in-service aircraft and equipment. The inability to continue servicing such final products will not only impact upon civil aviation but also emergency vehicles and importantly on operationally critical military equipment. Thus, although new aircraft and military equipment designs draw on new materials and may enable a shift away from the need for chemical conversion coating, there will remain a stock of in-service aircraft and equipment that will require its use as part of repairs, maintenance and overhaul activities.

- **The costs of moving to alternatives are high**, not necessarily due to the cost of the alternative substances but **due to the strict regulatory requirements that must be met to ensure airworthiness and safety for military use**. These requirements mandate the need for testing, qualification, validation and certification of components using the alternatives, with this having to be carried out for all components and then formally implemented through changes to design drawings and maintenance manuals. In some cases, this requires retesting of entire end products for extensive periods of time, which is not only costly but may also be infeasible (due to the age of the final product, lack of testing facilities, age of available test vehicles (engines, aircraft, defence equipment, etc.). On a cumulative basis, the major OEMs and DtB companies that act as the design authorities could not afford to undertake action across the range and numbers of components that still require the qualification, certification and industrialisation of the alternatives at the same time. These activities themselves are costing the companies hundreds of millions of Euros across all uses of Cr(VI), and several tens of millions for CCC alone.

- **The strict regulatory requirements that must be met generate additional, complex requalification, recertification, industrialisation activities,** to ensure the continued airworthiness of aircraft and the safety and reliability of defence equipment (including air, naval and land-based systems). These requirements mean that there is no simple or single drop-in replacement for the chromates in chemical conversion coating processes, which can be considered to be "generally available" following the European Commission's definition[6]. The A&D industry has been undertaking R&D into alternatives for the past 30 years. This includes participation in research initiatives partially funded by the European Commission and national governments. Considerable technical progress has been made in developing, validating qualifying and certifying components for the use of alternatives, however, it is not technically nor economically feasible for the sector as a whole to have achieved full substitution within a four or seven year period. Although some companies have been able to qualify and certify alternatives for some of their components, others are still in the early phases of testing and development work due to alternatives not providing the same level of

[6] As defined with respect to the "legal and factual requirements of placing on the market" in the EC note of 27 May, 2020, available at: 5d0f551b-92b5-3157-8fdf-f2507cf071c1 (europa.eu)

performance to the chromates. They will not be able to qualify and certify a proposed or a test candidate for some components within a four or seven year time frame. It is also of note that CCC is used throughout the supply chain and by large numbers of smaller suppliers. As a result, sufficient time will be required to fully implement alternatives through the value chain once they have been certified.

- Even then, **it may not be feasible for military MROs to move completely away from the use of the chromates in chemical conversion coating due to mandatory maintenance, repair and overhaul requirements**. MROs must wait for OEMs or MoDs to update Maintenance Manuals with an appropriate approval for each treatment step related to the corresponding components or military hardware. The corresponding timescale for carrying out such updates varies and there can be significant delays while OEMs/MoDs ensure that substitution has been successful in practice. In this respect, it is important to note that the use of the chromates in CCC is required (and may be required beyond 12 years) to ensure the operational capabilities of the military and the ability to comply with international obligations as partner nations at the EU level and in a wider field, e.g. with NATO.

- Given the above, **an Authorisation of appropriate length is critical to the continued operation of aerospace and defence manufacturing, maintenance, repair and overhaul activities in the EEA and UK**. The sector needs certainty to be able to continue operating in the EEA/UK using chromates until adequate alternatives can be implemented. It is also essential to ensuring the uninterrupted continuation of activities for current in-service aircraft and defence equipment across the EEA and UK.

- As highlighted above and demonstrated in Section 5, **the socio-economic benefits from the continued use of chromium trioxide, sodium dichromate, potassium dichromate and dichromium tris(chromate) in chemical conversion coating significantly outweigh the risks of continued use**. The European A&D sector is a major exporter of final products and is facing a growing market for both its civilian and defence products which it can only serve if it retains its current strong industrial and supply chain base in the EEA and UK. It will not be able to respond to this increased market demand if the continued use of the four chromates in CCC is not authorised while work continues on developing, qualifying and certifying alternatives.

- Finally, the global nature of the aerospace and defence sector must be recognised. The EU and UK A&D sector must ensure not only that it meets regulatory requirements in the EU and UK, but also that it meets requirements in other jurisdictions to ensure that its final products can be exported and used globally.

2 AIMS AND SCOPE OF THE ANALYSIS

2.1 Introduction

2.1.1 The Aerospace and Defence Chromates Reauthorisation Consortium

This combined AoA/SEA is based on a grouping approach and covers all the soluble chromates relevant for the specific use in chemical conversion coating of metallic components by the ADCR consortium members and companies in their supply chain. Chemical conversion coating of metallic components, also called chromate conversion coating, is used to provide moderate corrosion resistance and/or to promote adhesion to subsequent layers such as primer or paint while in some applications also ensuring chemical resistance, electrical conductivity and other benefits. It is applied as a main treatment, mainly on bare metal substrates.

The use of the chromates in chemical conversion coatings is limited to those situations where it plays a critical (and currently irreplaceable) role in meeting product performance, reliability, and safety standards, particularly those relating to airworthiness set by European Aviation Safety Agency (EASA). This is also true with respect to the use of CCC in defence, space and in aerospace derivative products, which include non-aircraft defence systems, such as ground-based installations or naval systems. Such products and systems also have to comply with numerous comparable requirements including those of the European Space Agency (ESA) and of national MoDs.

This is an upstream application submitted by manufacturers, importers and/or formulators of chromate-containing chemical products. It is an upstream application due to the complexity of the A&D supply-chain, which contains many small and medium-sized enterprises (SME). The ADCR was specifically formed to respond to this complexity and to benefit the entire supply chain, thereby minimising the risk of supply chain disruption. The aim is also to provide the industry's major OEMs and DtB manufacturers with flexibility and to enable them to change sources of supply for the manufacture of components and assemblies; it also helps ensure that choice of supply, competition and speed of change is maintained. The importance of this type of risk minimisation has become only too apparent due to the types of supply chain disruption that has arisen due to COVID-19.

As a result, the analysis presented here is based on an extensive programme of work funded and carried out by the main OEMs and DtBs, and key suppliers where this includes small, medium and other large actors within the sector. It is based on sector-specific data and detailed information obtained from the ADCR members (which includes OEMs, DtBs, BtPs, MROs and MoDs) and collected from their A&D suppliers throughout the supply chain. In total, data were collected from companies covering over 260 A&D sites in the EEA and UK, with data for 160 of those sites used in developing this combined AoA/SEA.

It is also important to confirm that three of the parent AfAs (0045-02, 0096-01, 0116-01) in the scope of this combined AoA/SEA include the use of the chromates in chemical conversion coating as part of the production of aeroderivative gas turbines and engines, referred to simply as "aeroderivatives". These are products that use components and designs adapted from the designs and rely on the supply chains that produce aircraft gas turbines. Aeroderivative products make up a small percentage (1 – 2%) of the total A&D hardware volume in the European Union (EU) (UK figures are unavailable but are likely to be higher) and are used to generate electricity or propulsion in civil and defence marine, oil and gas, and industrial applications. As the components used in aeroderivatives are designed to the same thresholds as aerospace and produced in the same manufacturing lines, the same arguments for the use of the components treated with chromates in the aerospace industry apply to aeroderivatives. High performance requirements are mandatory for aeroderivatives, as well as for aerospace components due to operation in harsh and corrosive environments (e.g. at sea). Aeroderivatives are distinct from pure industrial engines and similar support equipment which are not covered by this combined AoA/SEA.

In addition, to ensure consistency and continuity of global supply chains under both EU REACH and UK REACH, this document covers the requirements of A&D supply chains in both the EEA and the UK[7]. Where important, information is separated out for the EEA and UK, so that authorities in both jurisdictions have a clear view of impacts.

2.1.2 Aims of the combined AoA and SEA document

The downstream users supporting the ADCR consortium have no qualified (from a technical perspective) and economically feasible alternatives for use on all of their components and final products which can be fully implemented, across all products, components and MRO processes before the expiry of the original authorisations; they must continue to use the chromates in chemical conversion coating activities carried out within the EU and UK, including in formulations, as they are fundamental to achieving the required technical performance of aerospace components. They form part of an overall system aimed at ensuring the compulsory airworthiness requirements of aircraft and military equipment.

Although the A&D sector has been successful in implementing alternatives in certain applications with less demanding requirements, the aim of this combined AoA/SEA is to enable the continued use of the chromates in chemical conversion coating beyond the end of the existing review period which expires in September 2024 for chromium trioxide, sodium dichromate and potassium dichromate and January 2026 for dichromium (tris) chromate, for the processes where alternative implementation has not yet been successful. It demonstrates the following:

- The technical and economic feasibility, availability, and airworthiness (i.e. safety) challenges in identifying an acceptable alternative to the use of the chromates, which does not compromise the functionality and reliability of the components treated with chemical conversion coating and which could be validated by OEMs and gain certification/approval by the relevant aviation and military authorities across the globe;

- The R&D that has been carried out by the OEMs, DtBs and their suppliers towards the identification of feasible and suitable alternatives for the chromates in conversion coatings. These research efforts include EU funded projects and initiatives carried out at a more global level, given the need for global solutions to be implemented within the major OEMs supply chains;

- The efforts currently in place to progress proposed candidate alternatives through Technology Readiness Levels (TRLs), Manufacturing Readiness Levels (MRLs) and final validation/certification of suppliers to enable final implementation. This includes treatment of components for civilian and military aircraft and defence equipment that continue to be produced, as well as for maintenance, repair and overhaul of those products and out-of-production civilian and military aircraft and other defence systems;

- The socio-economic impacts that would arise for ADCR downstream users and their suppliers, their upstream and downstream supply chains and, crucially, for the EEA and UK more

[7] Both ECHA and the UK HSE agreed to this approach in pre-submission discussions.

generally, if the applicants were not granted Re-authorisations for the continued use of the chromates over an appropriately long review period; and

- The overall balance of the benefits of continued use of the chromates and risks to human health from the carcinogenic and reprotoxic effects that may result from exposures to the chromates.

It should be noted that this combined AoA/SEA is one of a set of combined AoA/SEAs that have been prepared by the ADCR Consortium to cover the range of different uses of the chromates that continue to be required by the EEA (and UK) A&D industries.

2.2 The Parent Applications for Authorisation

This combined AoA and SEA covers the use of the following chromates in chemical conversion coating:

• Chromium trioxide (includes "Acids generated from chromium trioxide and their oligomers", when used in aqueous solutions)	EC 215-607-8	CAS 1333-82-0
• Sodium dichromate	EC 234-190-3	CAS 10588-01-9
• Potassium dichromate	EC 231-906-6	CAS 7778-50-9
• Dichromium tris(chromate)	EC 246-356-2	CAS 24613-89-6

The chromates shown were included into Annex XIV of Regulation (EC) No 1907/2006 due to their intrinsic properties (carcinogenic, mutagenic, toxic for reproduction, depending on the chromate).

Chromium trioxide (CT) was included in Annex XIV of REACH (Entry No. 16) due to its carcinogenic (Cat. 1A) and mutagenic properties (Cat. 1B). As CT is mainly used in aqueous solution in chemical conversion coating, this combined AoA/SEA also covers the acids generated from CT and their oligomers (Entry No. 17). In the remainder of this document, references to CT always include the acids generated from CT and their oligomers. Sodium dichromate (SD; Entry No. 18) and potassium dichromate (PD; Entry No. 19) have been included in Annex XIV of REACH due to their CMR properties as they are all classified as carcinogenic (Cat. 1B), mutagenic (Cat. 1B) and reproductive toxicants (Cat. 1B). Dichromium tris(chromate) (DtC) has been included in Annex XIV of REACH (Entry No. 28) due to its carcinogenic properties as it is classified as carcinogenic (Cat. 1A).

These four chromates were granted authorisations for use in chemical conversion coating across a range of applicants and substances. **Table 2-1** summarises the initial applications, which are the parent authorisations for this combined AoA/SEA.

It is important to note that it is not the intention of this combined AoA/SEA and the grouping of both applicants and substances, to expand the scope of the authorisation(s) held by any of they applicants. Each is applying only for a renewal of their original parent authorisation. Where one of these applicants is also seeking to cover new substance-use combinations, they will be submitting a new application for authorisation under the ADCR.

Table 2-1: Overview of Initial Parent Applications and Authorisations					
Application ID/ authorisation number (EU then UK)	**Substance**	**CAS #**	**EC #**	**Applicants**	**Parent Authorisation – Authorised Use**
0032-04 REACH/20/18/14, REACH/20/18/16 REACH/20/18/18	Chromium trioxide	1333-82-0	215-607-8	ChemServices as OR for Brother; Boeing Distribution Ltd; Cromital (CTAC consortium)	Surface treatment for applications in the aeronautics and aerospace industries, unrelated to functional chrome plating or functional chrome plating with decorative character, where any of the following key functionalities is necessary for the intended use: corrosion resistance/active corrosion inhibition, chemical resistance, hardness, adhesion promotion (adhesion to subsequent coating or paint), temperature resistance, resistance to embrittlement, wear resistance, surface properties impeding deposition of organisms, layer thickness, flexibility, and resistivity
0032-05 REACH/20/18/21 REACH/20/18/23 REACH/20/18/25	Chromium trioxide	1333-82-0	215-607-8	ChemServices as OR for Brother; Boeing Distribution Ltd; Cromital (CTAC consortium)	Surface treatment (except passivation of tin-plated steel (electrolytic tin plating - ETP)) for applications in architectural, automotive, metal manufacturing and finishing, and general engineering industry sectors, unrelated to functional chrome plating or functional chrome plating with decorative character, where any of the following key functionalities is necessary for the intended use: corrosion resistance/ active corrosion inhibition, layer thickness, humidity resistance, adhesion promotion (adhesion to subsequent coating or paint), resistivity, chemical resistance, wear resistance, electrical conductivity, compatibility with substrate, (thermo) optical properties (visual appearance), heat resistance, food safety, coating tension, electric insulation or deposition speed
0096-01 REACH/19/29/0 17UKREACH/19/29/0	Chromium trioxide	1333-82-0	215-607-8	HAAS GROUP INTERNATIONAL SP. Z.O.O (GCCA consortium)	Chemical conversion and slurry coating applications by the aerospace sector, where any of the following key functionalities or properties is necessary for the intended use: corrosion resistance, active corrosion inhibition, adhesion promotion and reproducibility (for chemical conversion coating), corrosion protection, heat resilience, hot corrosion resistance, resistance to humidity and hot water, thermal shock resistance, adhesion and flexibility (for slurry coating).
0043-02 REACH/20/5/3	Sodium dichromate	10588-01-9	234-190-3	Brenntag Chemicals Distribution (Ireland) Ltd	Use for surface treatment of metals (such as aluminium, steel, zinc, magnesium, titanium, alloys), composites and sealings of anodic films for the aerospace sector in surface treatment processes in which any of the key functionalities listed in the

Table 2-1: Overview of Initial Parent Applications and Authorisations					
Application ID/ authorisation number (EU then UK)	Substance	CAS #	EC #	Applicants	Parent Authorisation – Authorised Use
REACH/20/5/5 24UKREACH/20/5/3				AD International BV (CCST consortium)	Annex is required (those of relevance to CCC depending on substrate): Corrosion resistance, adhesion to subsquent layer, chemical resistance, active corrosion inhibition, resisitivity, layer thickness
0044-02 REACH/20/3/1 22UKREACH/20/3/1	Potassium dichromate	7778-50-9	231-906-6	Brenntag Chemicals Distribution (Ireland) Ltd (CCST consortium)	Surface treatment of metals (such as aluminium, steel, zinc, magnesium, titanium, alloys), composites and sealings of anodic films for the aerospace sector in the surface treatment processes in which any of the key functionalities listed in the Annex is required (of relevance to CCC depending on substrate): Corrosion resistance, adhesion to subsquent layer, chemical resistance, active corrosion inhibition, resisitivity, layer thickness
0045-02 REACH/20/1/3	Dichromium tris (chromate)	24613-89-6	246-356-2	Henkel Global Supply Chain B.V. (CCST consortium)	Surface treatment of metals (such as aluminium, steel, zinc, magnesium, titanium, alloys), composites and sealings of anodic films for the aerospace sector in surface treatment processes in which any of the key functionalities listed in the Annex is required (of relevance to CCC depending on substrate): Corrosion resistance, adhesion to subsquent layer, chemical resistance, active corrosion inhibition, resisitivity, layer thickness
0116-01 REACH/20/10/0 32UKREACH/20/10/0	Dichromium tris (chromate)	24613-89-6	246-356-2	HAAS GROUP INTERNATIONAL SP. Z.O.O (GCCA consortium) (GCCA consortium)	Use in chemical conversion coating applications by aerospace and defence sector where any of the following key functionalities or properties is necessary for the intended use: corrosion resistance, active corrosion inhibition, adhesion promotion, chemical resistance, layer thickness, electrical properties

2.3 Scope of the analysis

2.3.1 Brief overview of uses

2.3.1.1 Process description

Chemical conversion coating (CCC) by the A&D industry and its supply chain in the EEA and the UK involves the use of CT, SD, PD and DtC in the surface treatment of metal components against corrosion.

Due to the substitution efforts that have already taken place, sodium chromate is no longer required for chemical conversion coating by ADCR members and their supply chains as substitution has already taken place.

Chemical conversion coating within the sector is performed exclusively in industrial installations. It is used to protect bare metallic components or to repair anodised metallic components, where the applied chromate oxidizes the metal substrate to form a chemically inert oxide. In the case of aluminium substrates, for example, the applied chromate oxidizes the aluminium to form chemically inert aluminium oxide.

A chemical reaction occurs between the metallic surface of the component and the coating solution, "converting" the natural oxide present on the substrate into a fixed and insoluble surface film. This surface layer consists of a complex of oxides and hydroxides of chromium and metal, forming an integral portion of the metallic surface. The result is a protective layer (active corrosion inhibition) based on chromate anions, absorbed in the mixed Cr(III) and base metal oxide layer. The thickness of the coating is typically between 0.05 to 2 µm, with coatings typically being in the lower thickness range (below 0.5 µm). It may also be used to protect or repair uncoated areas on a metallic component, mainly on an aluminium substrate. The applied chromate oxidizes the exposed bare metal to form chemically inert aluminium or magnesium oxide.

It is typically carried out, either by:

- Immersion of a metallic component in an aqueous solution containing dissolved chromates, together usually with acid compounds such as sulphuric acid or nitric acid;

- Or by filling components (cavities), or as a local treatment on small, localised areas, or for touch-ups/repairs of a metallic surface. For local treatments, the application is made by brush, swab, wipe, syringe or pen.

The treatment baths for CCC typically are positioned in a large hall where baths for other immersion processes are also present; some of these baths might also involve the use of Cr(VI) although they may be unrelated to CCC. The immersion tanks can be placed individually or within a line of several immersion tanks. Usually, at least one rinsing tank with water is positioned after an immersion tank, for rinsing off the conversion coating solution from the component(s).

CCC by local application can be performed in several areas, on a workbench, close to the immersion process lines or in a dedicated room. Touch-ups with brushes, swabs, wipes, syringes or pen can also be carried out in machining or mechanical workshops, maintenance depots, or inside or outside an aircraft hangar.

2.3.1.2 Choice of chromate

Chromium trioxide, sodium dichromate, potassium dichromate, dichromium tris(chromate) or a mixture thereof may be used in CCC. The reason why one or the other is used is, in most cases, due to a formulation containing particular chromates having proven performance in a component, final product or a system on its own or in combination with other treatments. Design owners' performance requirements or drawings (in BtP) may identify a specific chromate, but normally it is not the chromate that is specified but a formulation that contains the chromate.

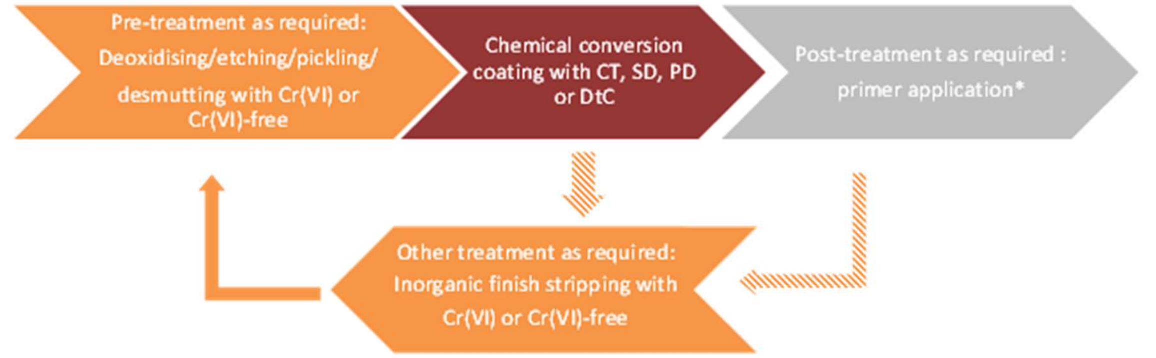
When a specific chromate is not mandated by the design owner (but use of a formulation containing a chromate is), the choice of the chromate by the site is often based on practical reasons, e.g. because a site relies on a formulation based on one of the four chromates for e.g., other processes, due to existing process equipment, experience and knowledge of the workforce, or ease of use.

CCC is usually performed on aluminium or magnesium alloys as a main treatment (> 95% of cases), and more rarely titanium. Aluminium is usually treated by CT aqueous solutions whereas SD and/or PD aqueous solutions are mainly applied on magnesium substrates. DtC is mainly used for touch-ups, using a "ready-to-use" pen for application on aluminium substrates.

Figure 2-1: Chemical conversion coating bath and touch-up using a paint brush

2.3.1.3 Relationship to other uses

Chemical conversion coating with chromium trioxide, sodium dichromate, potassium dichromate, and/or dichromium tris(chromate) may be combined with Cr(VI)-containing or Cr(VI) free pre-treatment(s) like deoxidizing, etching, pickling or desmutting. Usually chemical conversion coating is not combined with any specific Cr(VI) post-treatment, but may be followed by paint or primer application with or without Cr(VI). Inorganic finish stripping can also be required in case of defective finishing or as part of rework processes (see Figure 2-2), as well as mechanical stripping (e.g., blasting, sandpaper stripping). For the combination with deoxidizing, etching, pickling or desmutting pre-treatments with CT or SD, or with inorganic finish stripping with CT, all details on the processes are described in the respective CSR (see ADCR dossiers "Pre-treatments: deoxidising, pickling, etching and/or desmutting" and "Inorganic finish stripping").



* Primer application with Cr(VI) not covered by the current set of combined AoA/SEAs, given their end of review period is in 2026.

Figure 2-2: Schematic presentation of corrosion protection process flow

Please see the other ADCR combined AoA/SEAs for further details of these other processes, the availability of alternatives and the socio-economic impacts of a refused re-authorisation.

It is important to note however, that as these "uses" form part of a process flow, and that the benefits from the continued use of chromate-based chemical conversion coatings may also rely on the ability to continue using the hexavalent chromates in other processes where these are required by OEMs. For example, use of strontium chromate primers can form part of a corrosion protection process (see Figure 2-2), and it may not be possible to substitute a chromate-based CCC if there is not also a technically feasible alternative for the primer. Review reports for the primer uses that work together with chemical conversion coatings to form a corrosion protection system, will be the focus of future submissions.

2.3.2 Temporal scope

Because of the lack of qualified and viable alternatives for the use of the chromates in chemical conversion coating for A&D components, it is anticipated that it will take a further 12 years to develop, qualify, certify and industrialise alternatives across all components across the ADCR membership and the sector as a whole. Over this 12-year period, the temporal boundaries adopted in this assessment take into account:

- When human health, economic and social impacts would be triggered;
- When such impacts would be realised; and
- The period over which the continued use of the chromates would be required by the A&D industry as a minimum.

The impact assessment periods used in this analysis and the key years are presented in **Table 2-2**.

Table 2-2: Temporal boundaries in the analysis			
Present value year		2021	
Start of discounting year		2024	
Impact baseline year		2024	
Scenario	**Impact type**	**Impact temporal boundary**	**Notes**
"Applied for Use"	Adverse impacts on human health	12 years following a 20 year time lag	Based on the length of requested review period
"Non-use"	Loss of profit along the supply chain	12 years	Based on the length of requested review period
	Impacts on growth and GDP	12 years	Based on the length of requested review period
	Disruption to EU society due to impacts on civil, emergency and military aviation, as well as defence equipment	12 years	Based on the length of requested review period
	Loss of employment	1 to over 3 years	Average period of unemployment in the EEA (Dubourg, 2016)

2.3.3 The supply chain and its geographic scope

2.3.3.1 The ADCR Consortium

The ADCR is composed of 67 companies located in the EEA and the UK that act as suppliers to the A&D industry (17 importers, formulators and distributors), are active downstream users (OEMs, DtBs or BtPs); or are MRO providers (civilian or military) within the industry sector. Membership also includes Ministries of Defence (MoDs) due to concerns over the loss of the availability of the chromates for on-going maintenance and repair of military equipment.

Of the downstream user members, 24 comprise the leading OEMs, DtBs and MROs operating in the EEA and UK. These 24 large companies (as per the EC definition) operate across multiple sites in the EEA, as well as in the UK and more globally. It is these leading OEM and DtB companies that act as design owners and establish the detailed performance criteria that must be met by individual components and final products to ensure that airworthiness and military requirements are met. A further 21 small and medium sized companies joined the ADCR in order to ensure the success of the consortium in re-authorising the continued use of the chromates and to share their information and knowledge. These companies are involved in BtP, DtB and MRO activities, sometimes acting as a combination of these.

Most of the larger ADCR members (22 of 24 including OEMs, DtBs, BtPs and MROs) support the use of the four chromates for chemical conversion coating; this may be either for their own use or for use in their supply chains. The larger members in particular may be supporting the use of one or more of the chromates in CCC to ensure it is available to their suppliers (who must use the chromates to meet OEM's and DtB's contractual requirements), as well as for their own use. In addition, a further eleven of the smaller members also identified the need for chromate-based CCC into the future.

The most widely supported substances by the ADCR members chromium trioxide (30 members) and dichromium tris (chromate) (20 members), as indicated in **Table 2-3**.

Table 2-3: Number of ADCR members supporting each substance for use in chemical conversion coating for their own activities or for their supply chain (33 ADCR members in total)			
Chromium trioxide	**Potassium dichromate**	**Sodium dichromate**	**Dichromium tris (chromate)**
30	9	11	20

2.3.3.2 Suppliers of chromate substances and mixtures

Nine generic chromate products are used in chemical conversion coatings, as listed in the table below. In broad terms, three of the chromates (chromium trioxide, sodium dichromate and potassium dichromate) may be sold in solid form (including as a pure substance) or in aqueous solutions of various strengths.

It is important to note that chemical conversion coating is the only use of dichromium tris(chromate) being supported in a combined AoA/SEA by the ADCR members and the quantities involved are very small. DtC is mostly used in touch-up pens (Product G) which contain between 0.1% and 1% DtC within 35g of a dilute aqueous solution of DtC. The touch-up pens are used on treated aluminium and aluminium alloy components. Data from suppliers suggest that many (but infrequent) purchases by downstream users are for a single box of 12 touch-up pens which contain a few grams of DtC per box (based on the equation 12 pens x 35 ml per pen x 1% DtC concentration = < 4.2g DtC per box); expected coverage per touch-up pen is about 4m^2.

Table 2-4: Products used in chemical conversion coating mixtures	
Product Type A	Solid chromium trioxide (flakes or powder), pure substance or mixture (20-100%)
Product Type B	Solid sodium dichromate (flakes or powder), pure substance (100%)
Product Type C	Solid potassium dichromate (flakes or powder), pure substance (100%)
Product Type D	Aqueous solution of chromium trioxide as purchased (0.1-30% chromium trioxide (w/w))
Product Type E	Aqueous solution of sodium dichromate as purchased (10-30% sodium dichromate (w/w))
Product Type F	Aqueous solution of potassium dichromate as purchased (0.1-0.25% potassium dichromate (w/w))
Product Type G	Aqueous solution of dichromium trischromate as purchased (0.1-1% dichromium trischromate (w/w))
Product Type H	Aqueous solution of chromium trioxide and dichromium trischromate as purchased (5-10% chromium trioxide; 1-5% dichromium trischromate (w/w))
Product Type I	Aqueous solution of sodium dichromate and potassium dichromate as purchased (0.25-2.5% sodium dichromate; 0.1-1% potassium dichromate (w/w))

The chromate substances are imported to the EEA and UK by the applicants. The formulations may either be imported or manufactured in the EEA/UK; see the Formulation review report (to be submitted) for further details.

Once the products are within the EEA or UK, they will be delivered to the downstream user either directly or via distributors. Some distributors operate across many EEA countries, and the UK, while others operate nationally.

2.3.3.3 Downstream users of chromates for chemical conversion coating

Chemical conversion coating within the aerospace sector is performed exclusively in industrial settings and is carried out by actors across all levels in the supply chain:

- Original equipment manufacturer (OEM) – generally large companies which design, manufacture, assemble and sell engines, aircraft, space and defence equipment to the final customer;
- Design-to-Build[8] (DtB) manufacturers – companies which design and build components;
- Build-to-Print (BtP) manufacturers – companies that undertake specific processes, dictated by their customers, involving use of chromates on components; and
- Maintenance, Repair and Overhaul (MRO) – companies or military sites that service civilian and military in-service products.

Commercial aircraft, helicopter, spacecraft, satellite and defence manufacturers are involved in the supply chain, and in the use of the chromates for chemical conversion coating of critical components essential to the manufacturing of their final products.

It is also important to note that companies may fit into more than one of the above categories, acting as an OEM, DtB, and MRO[9], where they service the components they designed and manufactured and which are already in use. Similarly, a company may fall into different categories depending on the customer and the component/final product. In addition, downstream users range from sites and repair shops (MROs) who carry out chemical conversion coating only infrequently (e.g. twice a year) as part of "touch-up activities" to sites with a higher throughput using baths to immerse or dip components, as well as carrying out touch-up activities. In some of the latter cases, there is a low level of automation, while in others there is a high level of automation. This variability was also observed in extensive consultation processes during the preparation of this combined AoA/SEA.

The complexity of the supply chain relationships is illustrated in **Figure 2-3** below, with this highlighting the global nature of these relationships and the interlinkages that exist between suppliers in different geographic regions.

[8] Also referred to as "design and make" or "design responsible" suppliers

[9] Also common are companies categorising themselves as a BtP and MRO

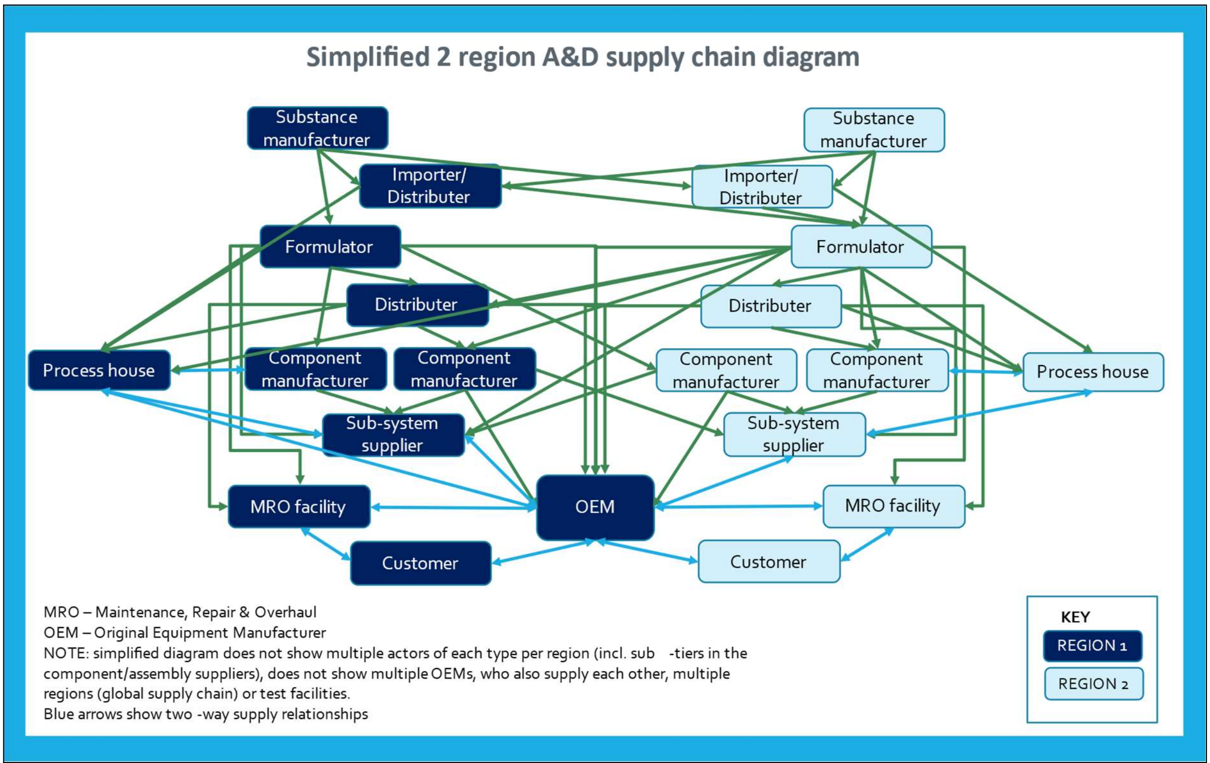


Figure 2-3: Complexity of supply chain roles and relationships within the A&D sector
Two-way supply relationships are indicated by the double-headed arrows

The SEA provided in this combined AoA/SEA document is based on the distribution of companies by role given in **Table 2-5**, where this includes ADCR members and their suppliers involved in chemical conversion coating. It is important to note that these companies operate across multiple sites within the EU and/or UK, with the total number of sites covered by the data provided also reported below. Note that some ADCR members supported CCC in order to cover their value chain (e.g. BtP suppliers or MROs) and did not provide responses themselves to the SEA questionnaire. Instead, they distributed the questionnaires to relevant suppliers. As a result, the number of SEA responses indicated in Table 2-4 below varies from the number of ADCR members supporting CCC.

It is important to note the numbers of BtP and MRO sites for which data was provided. This highlights the large number of actors undertaking CCC and the associated implications for the levels of effort required by design owners (OEMs and DtB companies) in implementing an alternative throughout their value chains.

Table 2-5: Numbers of companies providing SEA information on chemical conversion coating

Role	Number of companies	Number of sites
OEMs	9	50+
Design-to-Build	15	19
Build-to-Print	39	51
MRO mainly (civilian and/or military)	16	46
Total	79	166

2.3.3.4 OEMs, DtB and BtP Manufacturers

While the OEMs do undertake CCC (especially as part of touch-up activities), it is clear that CCC is also carried out by a range of companies within the supply chain. In the case of EEA/UK-based OEMs, these suppliers are often located in the same country (if not the same region) as their main OEM customer.

The OEMs will often act as the design owner and define the performance requirements of the components required for an A&D product, as well as the materials and processes to be used in manufacturing and maintenance. As design owners, OEMs are responsible for the integration and validation of the final product and certification approval. The OEMs may themselves treat components in a similar manner to their suppliers. They operate at the global level, and therefore may have facilities both in the EEA, the UK and located in other regions. They may also be global exporters of final A&D products.

DtB manufacturers develop in-house designs to meet the performance requirements of their customers, and therefore will also act as design owners. These suppliers may have more control over the substances that they use in manufacturing their components but must still ensure that they achieve the strict performance requirements set by OEMs or their customers. They may carry out research into alternatives and act as test facilities for their customers.

BtP manufacturers produce components to the technical drawings provided by their customers, which often mandate directly (on the drawing) or indirectly the specific CCC formulations to be used to meet the requirements set by their customers. The components are then used by DtBs or OEMs in the final production of A&D equipment. These suppliers have no choice in the substances and formulations that they are required to use within their processes. They, therefore, carry out no research into alternatives (although they may act as test facilities for their customers).

Both DtB and BtP suppliers may undertake chemical conversion coating using dip/immersion methods and/or involving brush, swab, wipe, syringe or pens as part of touch-up. Both types of suppliers tend to be located relatively close to their customers, which sometimes results in the development of clusters across the EEA and within the UK.

A BtP supplier may be requested to sign a manual or code of conduct by the OEM, to ensure expectations for work and awareness of requirements is achieved. Once the BtP supplier is qualified, periodic audits are performed to ensure continued compliance with contractual requirements.

2.3.3.5 Maintenance, Repair and Overhaul

Products for the A&D industry are designed, manufactured and maintained for service lives of several decades. In terms of civil aircraft and defence systems, service lives typically comprise 30-40 years. MRO shops (including those servicing MoDs) carry out the maintenance, repair, and overhaul activities involved in ensuring that A&D final products continue to meet airworthiness and safety requirements. This includes chromate-based chemical conversion coating as part of such activities.

A representative life cycle of a typical aerospace product – a commercial aircraft – is illustrated in Figure 2-4. This highlights that: the development of a new aerospace system can take up to 15 years; the production of one type of aerospace system may span more than 50 years; and the lifespan of any individual aircraft is typically 20-30 years.

Figure 2-5 provides an overview of the life cycle of weapon systems, which are usually used much longer than the originally projected lifetime. Such life cycles can be significantly longer than 50 years.

For such systems, it is extremely costly to identify and replace legacy applications of chromates without impacting performance, where performance has been assured for many decades.

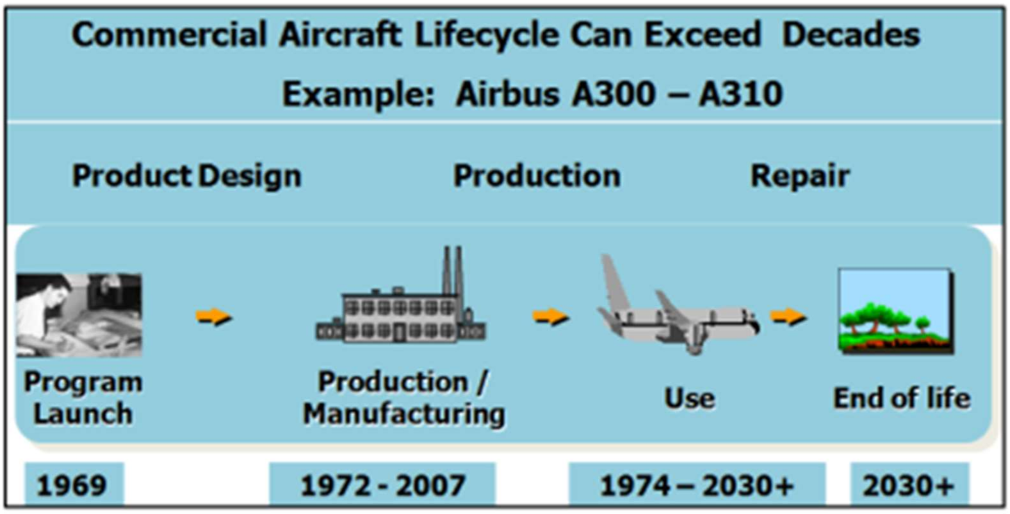


Figure 2-4: Commercial Aircraft Service Life, from ECHA & EASA (2014)[10]

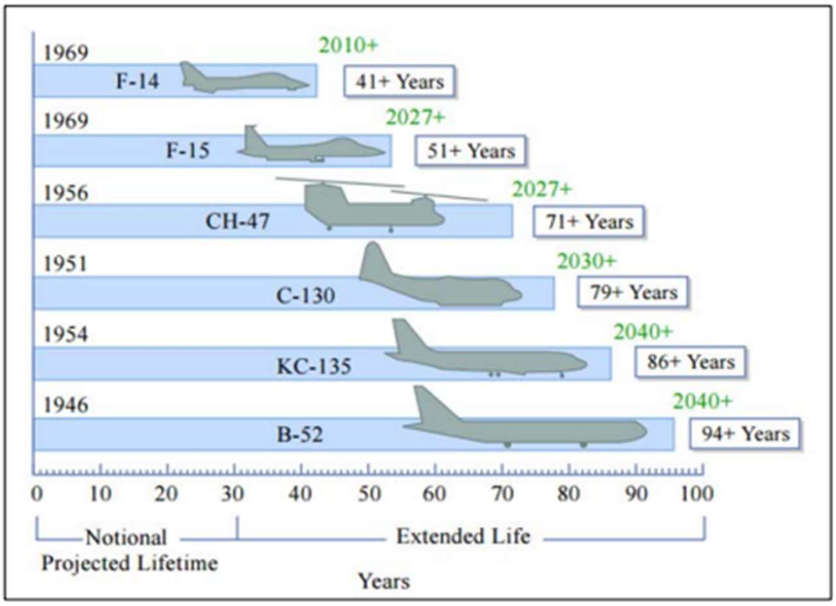


Figure 2-5: Life cycles of defence aircraft, from A Haggerty (2004)[11]

Even if new designs/components – coming onto the market in the short to medium term – might succeed in dispensing with the use of chromate-based CCC formulations, products already placed on the market still need to be maintained and repaired using chromate-based CCC formulations until suitable alternatives are validated & certified for use in MRO for those existing products. Maintenance manuals for such existing products (which the user is legally obliged to comply with) detail, amongst

[10] https://www.easa.europa.eu/en/document-library/general-publications/echa-easa-elaboration-key-aspects-authorisation-process

[11] https://studylib.net/doc/13484803/lifecycle-considerations-aircraft-systems-engineeering-al...

other information, the processes and materials initially qualified (sometimes decades ago) and required to be used, which form a substantial portion of the type certification or defence approval.

As a result, MROs (and MoDs) face on-going requirements to undertake chemical conversion coating, using dip/immersion methods and/or by brush, swab, wipe, syringe or touch-up pen in strict adherence to the requirements of qualified repair and maintenance schemes to ensure continued safe operation of the A&D final products.

It is important to note that there will be an overlap between those companies undertaking work exclusively as MROs and those also involved as DtB suppliers, who also carry out MRO activities. As a result, companies falling into this category will be spread geographically across the EU and UK.

2.3.3.6 Estimated number of downstream user sites

Based on the information provided by the OEMs and DtBs, it appears that each of these companies has on average between 15-30 approved suppliers involved in the provision of conversion coating. Based on this and the number of sites for which data were provided, an estimated 350 sites in the EEA are likely to be involved actively in chemical conversion coating and approximately 80 in the UK.

This takes into account the fact that in some countries, e.g. France and Poland where several OEMs/DtBs have major facilities; there is some overlap in suppliers who will be undertaking chemical conversion coating as a portion of their activities.

Under Article 66 of REACH, downstream users covered by an authorisation up their supply chain must notify ECHA of their use. As of 31 December 2021, ECHA had received 624 notifications relating to the various REACH parent Authorisations listed in Table 2-1, covering 890 sites across the EU-27 (and Norway). The distribution of EEA notifications by substance and authorisation is summarised below. It is important to note that some sites may draw on more than one Authorisation for use of the same substance.

There are more sites than notifications, reflecting the fact that some notifications cover more than one site[12]. However, several of the authorisations cover 'surface treatment' which covers more treatments than just conversion coating. As such, the number of sites undertaking chemical conversion coating will be far fewer than the indicated 890. Furthermore, some sites will be using more than one of the chromates for conversion coating, reducing the figure even further. Indeed, some ADCR members may use two or three of the chromates at an individual site for chemical conversion coating. The figure of around 260 sites using Dichromium tris (chromate) is considered more reliable as conversion coating is the only use of this substance within the aerospace sector.

With these points in mind, the estimated 350 EEA sites to be covered by this review report and by the ADCR applicants is believed to be consistent with the ECHA data on Article 66 downstream user notifications. This number of sites reflect the fact not all of the original CTAC applicants are supporting the ADCR, with this expected to lead to some changes in the number of customers being supplied the chromates by ADCR applicants. In addition, the figure of 350 sites takes into account the fact that some of the A&D sector will be covered by the non-ADCR applicants.

[12] Article 66 reporting is by legal entity, which can have multiple sites using a chromate for CCC. Closer inspection of the (publicly available) data from ECHA suggests that some sites are associated with confidential military activities. These may or may not be relevant to the ADCR given that members include Ministries of Defence (MoDs) and information has been provided by non-member military organisations.

HSE did not provide data on the number of notifications made under UK REACH in time for incorporation into this assessment.

Table 2-6: Number of downstream users using Chromium Trioxide, Potassium Dichromate, Sodium Dichromate and Dichromium Tris (chromate) notified to ECHA as of 31 December 2021				
Substance	**Authorisation**	**Authorised Use**	**Notifications**	**Sites**
Chromium trioxide	20/18/14-20	Surface Treatment for aerospace	263	357
	19/29/0	Conversion Coating & Slurry Coating for aerospace	19	47
Potassium dichromate	20/3/1	Surface Treatment for aerospace	15	18
	20/2/1	Surface Treatment for aerospace	53	61
Sodium dichromate	20/5/3-5	Surface Treatment for aerospace	61	84
	20/4/1	Surface Treatment for aerospace	58	67
Dichromium trischromate	20/1/2-3	Surface Treatment for aerospace	153	254
	20/10/0	Chemical conversion coating by ASD sector	2	2
		Total notifications	**624**	**890**
Source: Number of downstream uses covered by granted authorisations as notified to ECHA by 31 December 2021, data available from https://echa.europa.eu/du-66-notifications				

2.3.3.7 Geographic distribution

The distribution of the 890 sites notified to ECHA is summarised in the table below. This percentage distribution is adopted for the later analysis carried out as part of the SEA. As there is no comparable publicly available data for the UK, no breakdown is provided by country for Great Britain.

Table 2-7: Number of authorised sites using Chromium Trioxide, Potassium Dichromate, Sodium Dichromate and/or Dichromium tris (chromate) notified to ECHA as of 31 December 2021		
Country	**Notified Sites**	**% Total**
France	316	36%
Germany	124	14%
Italy	109	12%
Spain	70	8%
Poland	67	8%
Czech Republic	28	3%
Netherlands	27	3%
Sweden	27	3%
Norway	19	2%
Finland	18	2%
Belgium	14	2%
Romania, Hungary, Ireland, Bulgaria, Malta, Denmark	8-13	c 1%
Portugal, Austria, Greece, Lithuania, Slovakia, Croatia, Cyprus, Estonia, Iceland, Latvia, Luxembourg, Slovenia	0-3	< 0.5%
EU-27 plus Norway	**890**	
Number of sites relates to specific authorisations listed in the previous table.		

2.3.3.8 Customers

The final actors within this value chain are customers of A&D final products treated via chemical conversion coating.

With respect to civil aviation, the global air transport sector employs over 10 million people to deliver in a normal year some 120,000 flights and 12 million passengers a day. In 2017, airlines worldwide carried around 4.1 billion passengers. They transported 56 million tonnes of freight on 37 million commercial flights. Every day, airplanes transport over 10 million passengers and around US$ 18 billion (€16 billion, £14 billion) worth of goods. Across the wider supply chain, subsequent impacts and jobs in tourism made possible by air transport, assessments show that at least 65.5 million jobs and 3.6% of global economic activity are supported by the industry.[13] More specifically to Europe, in 2019 over one billion passengers travelled by air in the European Union, with net profits of over US$ 6.5 billion (€5.8 billion, £5.1 billion).[14] These benefits cannot be realised without the ability to undertake regular maintenance works and to repair and maintain aircraft as needed with replacement components manufactured in line with airworthiness approvals.

In 2020, total government expenditure on defence across the EU equated to 1.3% of GDP, with Norway spending around 2% of GDP[15]. Roughly 38% of this expenditure related to military aviation, with an uncertain but significant proportion also spent on non-aviation defence products that rely on the use of CCC, including naval systems, ground based radars, ground vehicles etc.

Focusing on military aircraft, the dynamics of aircraft development and the market are significantly different than for commercial aircraft. Military aircraft are extremely expensive and specialised projects. As a result, to have an effective military force, Ministries of Defence require equipment that is well-maintained and mission-ready. Although the in-service military fleet is expected to grow rapidly in the future, older aircraft and other equipment will continue to require more frequent scheduled maintenance to replace components that are reaching the end of their "life", which would not have needed replacing on younger aircraft. Upgrades will also be required to extend the service life of aging aircraft given the costs of new military aircraft. Maintenance of aircraft and products is already reported to face difficulties due to material obsolescence issues over the extremely long service lives of such hardware. A major issue is obtaining readily available components for the vast number of aircraft flying beyond their originally expected lifecycles.

2.4 Consultation

2.4.1 Overview

Three types of consultation were undertaken for the purposes of this combined AoA/SEA:

- Consultation with the Applicants (importers and formulators) to gather Article 66 downstream user notifications data, and information on volumes placed on the market and numbers of customers; this has included consultation with the formulators to gather information on their efforts to develop alternatives on their own, in collaboration with the downstream users, and as part of research projects funded by national governments, the EC and more internationally.

- Consultation with ADCR members to gather information on their uses, supply chains, R&D into alternatives, qualification processes and responses under the non-use scenario;

[13] https://www.icao.int/annual-report-2020/Pages/the-world-of-air-transport-in-2020.aspx

[14] https://www.statista.com/statistics/658695/commercial-airlines-net-profit-europe/

[15] *Source:* Eurostat (gov_10a_exp)

- Consultation with component and special process suppliers within the A&D supply chain to gather socio-economic information, ability to move to alternatives and likely responses under the non-use scenario.

Further details of each are provided below.

2.4.2 Consultation with Applicants

Information was gathered from the applicants on their supply chains and on quantities sold per annum. The applicants may act as an importer, a downstream user (e.g. formulator, distributor involved in repackaging) and/or as a distributor for other applicants/formulators of the chromates for use in CCC.

Only a minimal amount of economic data was collected from the applicants, as losses in profits to this group of companies is not what drives the requested re-authorisations by this combined AoA/SEA. Information on alternatives and substitution was, however, collected.

2.4.3 Consultation with Downstream users

2.4.3.1 ADCR Consortium members

Consultation with ADCR members was carried out over a period from 2019 to 2022 to collect a range of data relevant to both the AoA and the SEA. This consultation was carried out with all downstream user members of the ADCR (i.e. members located in both the EEA and UK), and regardless of their role within the supply chain. Consultation took place over different phases:

1) Phase 1 involved collection of information on surface treatment activities that each member undertook. This included:
    a. Supply chains
    b. Substances used in each activity and associated volumes
    c. Key functions provided by the substance
    d. Locations for each activity
    e. Likelihood of substitution before 2024

1) Phase 2 involved collection of data on R&D activities undertaken by each company. This included confidential and non-confidential information on:
    a. Successes and failures
    b. Alternatives tested and for what uses
    c. Reasons for failures, where this was the outcome
    d. Alternatives still subject to R&D and their progression in terms of technical readiness, and if relevant manufacturing readiness

2) Phase 3 then took the form of detailed one-on-one discussions between ADCR members and the AoA technical service team. The focus of these discussions was to ensure:
    a. Additional critical details were collected concerning core aspects of the AoA/SP portions of the dossiers (e.g. clarify R&D and substitution timelines and address outstanding questions regarding alternatives and their comparative performance).

3) Phase 4 collected information for the SEA component of this document, with this including:
    a. Base data on the economic characteristics of different companies

b. Additional information on volumes used of the chromates and for what processes, and trends in this usage over the past seven years and as anticipated into the future
c. The importance of chromate-using processes to the turnover of individual companies
d. Past investments in R&D into alternatives
e. Past investments into capital equipment related to on-going use of the chromates as well as to their substitution; this included investment in new facilities outside the EEA
f. Numbers of employees directly involved in use of the chromates as well as the total number of employees at sites that would also be directly impacted under the non-use scenario
g. Economic and social impacts under the non-use scenario.

It is important to note that as work progressed over these different phases of consultation, members identified reduced needs with respect to the on-going use of chromates for chemical conversion coating. In particular, the use of sodium chromate is no longer required by the original set of members (4 initially) identifying this as needed in 2019.

2.4.3.2 Design-to-Build and Build-to-Print suppliers to ADCR members

SEA questionnaires were also developed for completion by suppliers to the ADCR members. This included separate questionnaires for BtP and DtB suppliers given their different roles within the supply chain and the potentially greater flexibility fort DtB suppliers to move to alternatives certified for the manufacture of their components and products as part of their own design activities.

These questionnaires were distributed to key suppliers by the larger ADCR members and were also made available to any company within the ADCR supply chain requesting they provide information and participate in the re-authorisation work to ensure their conditions of use were covered. The scope of these questionnaires was similar to that described above for the ADCR members.

As a final count, data for 166 sites operated by the OEMs and their BtP and DtB suppliers provided responses to these questionnaires. The information provided by the companies forms the basis for the SEA components of this document.

2.4.3.3 MROs

For consistency purposes, MROs were asked to also complete the BtP questionnaire. Again, these were supplied directly to MROs or were distributed by ADCR members to their key suppliers. MoDs were also asked to participate in the work and a number of military MROs provided data on their activities to ensure that these would also be covered by a renewed Authorisation. Their data is included in the SEA as appropriate to their activities.

3 Analysis of Alternatives

3.1 SVHC use applied for

3.1.1 Overview of the key functions

Chemical conversion coating (CCC) is a chemical process applied to a substrate producing a superficial layer containing a compound of the substrate metal and elements from the processing solution. Conversion coating removes the native oxide and replaces it with an oxide that has predictable and stable properties, formed from the substrate metal and the processing solution.

We define conversion coating as "*a chemical process that introduces a chemical coating or changes the surface of the substrate to improve the substrate properties (e.g. corrosion resistance or to promote adhesion of subsequent coatings)*". Note that the conversion coating layer itself is not corrosion resistant, but it provides improved corrosion resistance to the substrate.

In general, conversion coating forms an adherent, fixed, insoluble, inorganic crystalline or amorphous surface film of complexes from oxides and hydroxides and chromium trioxide as an integral part of the metal surface by means of a chemical reaction between the metal surface and the immersion solution. Typical thickness of coating is 0.05-2.00 µm. The coatings are typically in the lower thickness range (below 0.5 µm). The term "chemical conversion coating" is used for both the process and the resulting coating layer.

Several factors determine the quality of a final conversion coating such as the base alloy composition and phase structure, pre-treatment processes, composition and concentration of bath chemicals, bath temperature and pH, immersion time, degree of agitation and post-treatment conditions (Saji, 2019). For the avoidance of doubt, the hexavalent chromate (Cr(VI)) substances that are of relevance to the Applied for Use are:

• Chromium trioxide (includes "Acids generated from chromium trioxide and their oligomers", when used in aqueous solutions)	EC 215-607-8	CAS 1333-82-0
• Sodium dichromate	EC 234-190-3	CAS 10588-01-9
• Potassium dichromate	EC 231-906-6	CAS 7778-50-9
• Dichromium tris(chromate)	EC 246-356-2	CAS 24613-89-6

The key functions of the four chromates in CCC include: corrosion resistance (self-healing); chemical resistance; adhesion promotion; layer thickness; resistivity; temperature resistance; and pre-treatment compatibility. These functions are relevant to all four chromates, and their use across all applications methods, e.g., immersion versus brush/swab and touch-up.

These are discussed in further detail in Section 3.2.

3.1.1.1 Usage

Parts and assemblies that may be treated with the Annex XIV substance

As detailed above, chemical conversion coating, like all surface treatments, aims to modify the surface of the substrate to improve the substrate properties and adapt it to its specific use conditions. There are many corrosion and wear prone areas on A&D products which require the application of surface treatments. Examples of these are included in Table 3-1 below:

Table 3-1: Examples of corrosion and wear prone areas of A&D products (non-exhaustive)

Structural/flight	Propeller/rotor	Engine/power plant	Additional Space- and Defence-specific
Aileron and flap track area	Blade tulip and hub	Auxiliary Power Units (APUs)	Air-transportable structures
Centre wing box	Gearbox	Carburettor	Fins
Cockpit frames	High bypass fan components	Data recorders	Gun barrels and ancillaries
Differential	Main and tail rotor head assemblies	Engine Booster and Compressors including Fan Containment	Interstage Skirts
Emergency valve landing gear	Propeller speed controller	Engine control unit	Launchers (rocket, satellite, etc.)
Environmental control systems	Propellers	Engine External components	Missile and gun blast control equipment
External fuel tanks	Transmission housing	Fuel pump	Missile launchers
Flight control systems		Gearbox	Pyrotechnic Equipment
Fuselage		Hydraulic intensifier	Radomes
Hydraulic damper		Ram air turbine	Rocket motors
Hydraulic intensifier		Starter	Safe and arm devices
Landing equipment		Vane pump	Sonar
Nacelles			
Pylons			
Rudder and elevator shroud areas			
Transall (lightning tape)			
Undercarriage (main, nose)			
Valve braking circuit			
Window frames			
Wing fold areas			

Source: (GCCA, 2017a)

It is important to note that even with the highly developed Cr(VI)-containing treatments available, corrosion and wear of these components still occurs, however decades of experience relating to the appearance and impacts of corrosion on Cr(VI) systems allows the A&D industry to define inspection, maintenance and repair intervals.

Cr(VI)-free alternatives cannot be introduced where they are known to result in a decreased performance, since some or all of the following consequences may occur (GCCA, 2017):

- Substantial increase in inspections, some of which are very difficult or hazardous to perform;

- Increased overhaul frequency or replacement of life-limited components;
- Possible early retirement of A&D products due to compromised integrity of non-replaceable structural parts;
- Whole fleets may be grounded until a repair/replacement plan is in place for the whole aircraft fleet - This could impact many or all aircraft fleets. Defence systems would be similarly impacted, affecting the continuity of national security.

In addition to the above, there may be limitations set on how far planes could fly.

Despite best efforts, hidden properties or incorrect performance predictions of any Cr(VI)-free systems that are ultimately introduced cannot be excluded, and remaining risks must be mitigated. Ultimately extensive qualification and validation testing (as described in section 3.1.2 below) is not equivalent to 50 years real-life experience with corrosion protection.

Service life and maintenance intervals of parts and assemblies

Wherever possible, A&D hardware is repaired rather than replaced. In addition to both time and cost considerations, this is a much more environmentally friendly approach from a lifecycle perspective, resulting in reduction of hazardous chemical usage, energy usage, carbon footprint, waste generation, etc. In order to maintain operational safety therefore, A&D components and products are subject to intensive MRO activities.

For aircraft, there are different maintenance activities foreseen after defined intervals of flight hours or take-off or landing cycles:

- Prior to each flight a “walk-around” visual check of the aircraft exterior and engines is completed;
- A-checks entail a detailed check of aircraft and engine interior, services and lubrication of moving systems;
- B-checks involve torque tests as well as internal checks and testing of flight controls;
- In C-checks a detailed inspection and repair programme on aircraft engines and systems is undertaken.
- D-checks include major structural inspections with attention to fatigue damage, corrosion, etc. result in the aircraft being dismantled, repaired and rebuilt.

As an example, for commercial aircraft the A-checks occur every 400-600 flight hours, the B-checks are performed every 6-8 months, and the C-checks are completed every 20-24 months. C-checks typically take up to 6,000 man hours to complete. The D-checks are completed every 6-10 years and typically take up to 50,000 man-hours to complete. At Lufthansa, the D-check begins with the stripping of the exterior paintwork. The aircraft is taken apart and each system is checked thoroughly using the most modern methods for non-destructive material testing such as X-rays, eddy current probes and magnetic field checks. After several weeks and thousands of hours of intensive MRO work, the aircraft is overhauled completely. The D-check is the most extensive check foreseen for aircraft. Even at the D-check, certain areas of the aircraft, such as bonded structures and inaccessible regions, cannot typically be disassembled for inspection. Corrosion protection of these regions must therefore be sufficiently robust to last throughout the life of the aircraft.

The aerospace industry has a permanent learning loop of significant events, failure analysis and decisions for safety improvements. Part of this improvement is the introduction of the Maintenance Steering Group 3 Analyse (MSG-3), specifically developed for corrosion. MSG-3 provides a system for OEMs and the regulators to identify the frequency of inspection with respect to the stress corrosion, protection and environmental ratings for any component or system. Without long-term experience the performance of a system cannot be highly rated due to hidden properties which may only be identified when extensive knowledge of in-service behaviour is available. The consequence of this is that the introduction of a Cr-free system would lead to a significant reduction in the maintenance interval, potentially doubling the frequency of the checks described above (GCCA, 2017a).

3.1.2 Overview of the substitution process in Aerospace & Defence (A&D)

3.1.2.1 Introduction

Aerospace and Defence (A&D) products operate in highly challenging, extreme environments over extended timeframes. Due to these challenges, alongside engineering-based solutions, the A&D industry must use numerous high-performance mixtures which have passed through an extensive approval process in order to demonstrate their suitability for use – some of these mixtures will contain substances which are included on Annex XIV of REACH. Whilst substitution of substances of very high concern (SVHC) is a priority for the sector, and there have been extensive efforts to eliminate Cr(VI) and other SVHC wherever technically feasible, changes to A&D components offer unique challenges that are not seen in other industries. These include: the industry's dependence on certain SVHC to meet key safety requirements; the level of qualification and regulatory controls associated with introduction of alternative chemicals or other design changes; and the complexity of supply chains and the number of stakeholders involved in the substitution process.

In the civil aviation sector of the Aerospace industry, large numbers of aircraft **safely carry billions of people every year**[16]**,** whilst defence aircraft and systems are required to operate safely and reliably for 40 to more than 90 years before they are finally taken out of service**.** This requires A&D components to successfully fulfil a wide range of extremely challenging safety-related requirements, including but not limited to:

- High utilisation rate (around 16 hours per day for commercial aircraft, whilst critical defence systems must operate continuously for extended periods);
- Environmental and service temperatures ranging from below minus 55°C at cruising altitude to in excess of plus 200°C (depending on substrate and location of final product);
- Wide ranging and varying humidity and pressure;
- High and varying loads;
- Fatigue resistance under varying modes of stress;
- Corrosive and abrasive environments (e.g., salt water and vapour, sand and grit, and exposure to harsh fluids such as cleaning solutions, de-icer, fuels, lubricants, and hydraulic fluids at in-service temperatures); and
- Maintained performance in the possible case of a lightning, bird, or other foreign object strike.

Successful, reliable, and safe performance against these parameters is the result of decades of experience and research, and a high level of confidence in the systems currently employed to provide corrosion and wear resistance. Years of performance data, as well as thorough reviews following any incidents, have resulted in improvements to the designs, manufacturing or maintenance processes employed in the industry. Such a level of confidence in the performance of Cr(VI) is essential as the treatments on some A&D components cannot be inspected, repaired, or replaced during the life of

[16] 4.5bn passengers carried and 38.3m departures in 2019. https://www.icao.int/annual-report-2019/Pages/the-world-of-air-transport-in-2019.aspx

the A&D system. An inadequately performing surface treatment allows corrosion pits to form. These can turn into fatigue cracks, which potentially endanger the final product.

The civil aviation industry must comply with the airworthiness requirements derived from Regulation (EC)No 2018/1139[17] in the European Economic Area (EAA). Similar airworthiness requirements exist in all countries where aeronautical products are sold. These regulations require a systematic and rigorous framework to be in place to qualify all materials and processes to meet stringent safety requirements that are subject to independent certification and approval through the European Aviation Safety Authority (EASA), and other agencies requirements. Safety critical defence aviation and space systems are subject to similar rigorous performance requirements as seen in the civil aviation sector, while ground and sea-based defence systems are managed more adaptively based on specific system requirements.

Identification and implementation of feasible, suitable, and available alternatives in the A&D industry is a time consuming and complex process that can involve multiple stages of performance testing in laboratory trials, manufacturing trials and during inflight/in operation testing. Once a proposed candidate is identified, it must be shown that implementing it will maintain the stringent safety requirements that govern the sector. Not only this but, due to the potential implications of inadequate corrosion and abrasion protection described above, it must be ensured that the test candidate demonstrates equivalence in performance on all types of components where the original formulation/process is used. This can often be hundreds of different components, each requiring testing to ensure performance of the test candidate is acceptable.

The A&D companies that design and integrate the final product (e.g. aircraft, engines, radar, and other defence systems), are each responsible for their own product qualification, validation, and certification, according to airworthiness regulations or defence/space customer requirements. Even superficially similar components, when used in different systems or under different environmental conditions, may have unique design parameters and performance requirements, driven by the requirements of the final product. Consequently, an alternative that has successfully been implemented for one component in a given subsystem will not necessarily be suitable for use in a different subsystem. Implementation of an alternative in varying scenarios of use must be individually assessed, validated, and certified across the components, subsystems and systems that make up the final product, for example an engine, aeroplane, helicopter, missile, or tank (as illustrated in Figure 3-1).

Defence OEMs have additional challenges because individual defence customers usually assume full design/change authority upon accepting the defence hardware designs. This means that any intent to change the hardware configuration, including coatings and surface treatments, must be approved by the defence agency, who are concerned with the efficacy of the hardware (i.e., mission effectiveness) as well as meeting legislative goals, and are often very fiscally constrained for such hardware configuration updates. Alternatively, an OEM can attempt to persuade their customers of such hardware changes, but typically are not allowed to spend programme budgets on these hardware changes until expressly directed/contracted by the customer, who again are very fiscally constrained. When OEMs sell the same hardware to multiple defence customers, it is often required to obtain permission from each customer prior to hardware changes and these customers rarely agree. The combination of (a) not mission essential, (b) fiscal constraints, and (c) multiple conflicting customer opinions, greatly complicates any defence OEM effort to make hardware changes to existing designs to meet legislated goals such as Cr(VI) elimination.

[17] Repealing Regulation (EC) No 216/2008

The processes described apply to the implementation of any new design, or changes to an existing design whether still in production or not. This means, to ensure and maintain airworthiness and operational safety requirements, they apply to every component produced for use in an aircraft or defence system. In the case of introducing Cr(VI)-free surface treatments, hundreds of individual components in each final product will be affected.

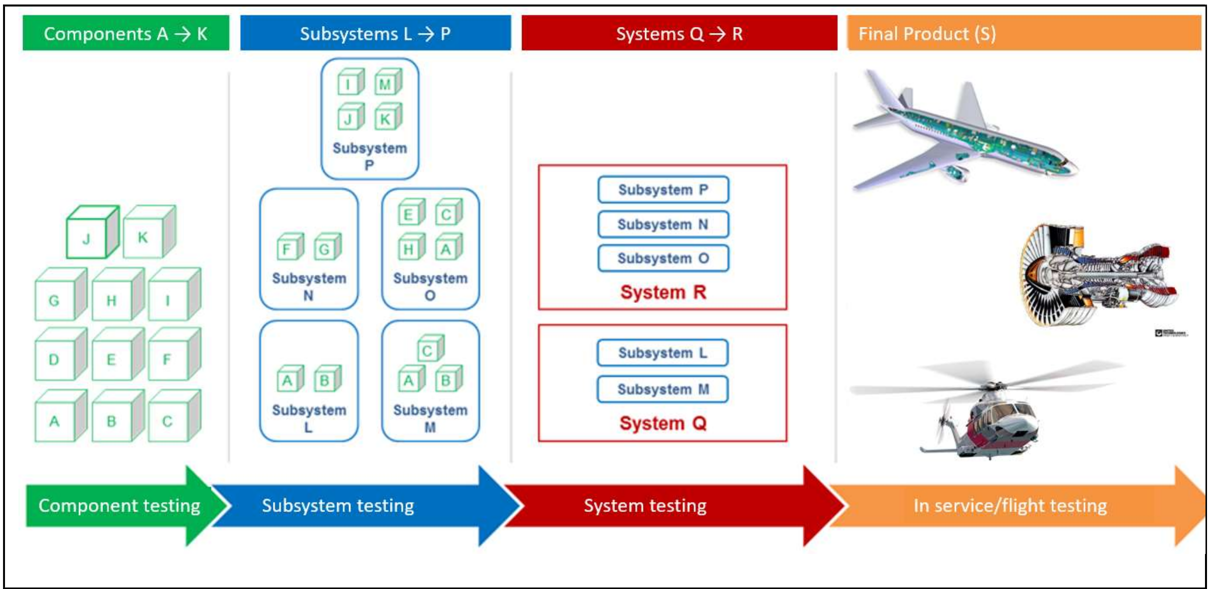


Figure 3-1: Assessment requirements in the implementation of alternatives
Source: Adapted from GCCA white paper

In the substitution process, many ADCR Consortium members use the Technology Readiness Level (TRL) scale as developed by the US National Aeronautics and Space Administration (NASA), and further defined by the US Department of Defence. This scale is used to assess the maturity level of each individual technology, and hence the potential suitability of a test candidate. The scale ranges from TRL 1, basic principles observed, to TRL 9, actual system proven.

Table 3-2: Technology Readiness Levels as defined by US Department of Defence

TRL	Definition	Description
1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.
2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3	Analytical and experimental critical function and/or characteristic proof-of-concept	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4	Component and/or breadboard[a] validation in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.
5	Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated

Table 3-2: Technology Readiness Levels as defined by US Department of Defence		
TRL	**Definition**	**Description**
		environment. Examples include "high-fidelity" laboratory integration of components.
6	System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7	System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space).
8	Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to determine if it meets design specifications.
9	Actual system through successful mission[b] operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.

[a] Breadboard: integrated components, typically configured for laboratory use, that provide a representation of a system/subsystem. Used to determine concept feasibility and to develop technical data.
[b] Mission: the role that an aircraft (or system) is designed to play.
Source: U.S. Department of Defence, April 2011, https://www.ncbi.nlm.nih.gov/books/NBK201356/

The TRL assessment guides engineers and management in deciding when a test candidate (be it a material or process) is ready to advance to the next level. Early in the substitution process, technical experts establish basic criteria and deliverables required to proceed from one level to the next. As the technology matures, additional stakeholders become involved, and the criteria are refined based on the relevant design parameters. A formal gate review process has been established by some companies to control passage between certain levels in the process.

Similarly, the maturity of manufacturing processes is formally tracked using the Manufacturing Readiness Levels (MRL) process. MRLs are used to assess the maturity of a given component, subsystem, or system from a manufacturing process.

Table 3-3: Manufacturing Readiness Levels as defined by US Department of Defence		
MRL	**Definition**	**Description**
1	Basic Manufacturing Implications Identified	Basic research expands scientific principles that may have manufacturing implications. The focus is on a high-level assessment of manufacturing opportunities. The research is unfettered.
2	Manufacturing Concepts Identified	This level is characterized by describing the application of new manufacturing concepts. Applied research translates basic research into solutions for broadly defined military needs.
3	Manufacturing Proof of Concept Developed	This level begins the validation of the manufacturing concepts through analytical or laboratory experiments. Experimental hardware models have been developed in a laboratory environment that may possess limited functionality.
4	Capability to produce the technology in a laboratory environment	This level of readiness acts as an exit criterion for the MSA Phase approaching a Milestone A decision. Technologies should have matured to at least TRL 4. This level indicates that the technologies

Table 3-3: Manufacturing Readiness Levels as defined by US Department of Defence		
MRL	**Definition**	**Description**
		are ready for the Technology Development Phase of acquisition. Producibility assessments of design concepts have been completed. Key design performance parameters have been identified as well as any special tooling, facilities, material handling and skills required.
5	Capability to produce prototype components in a production relevant environment	Mfg. strategy refined and integrated with Risk Management Plan. Identification of enabling/critical technologies and components is complete. Prototype materials, tooling, and test equipment, as well as personnel skills have been demonstrated on components in a production-relevant environment, but many manufacturing processes and procedures are still in development.
6	Capability to produce a prototype system or subsystem in a production relevant environment	This MRL is associated with readiness for a Milestone B decision to initiate an acquisition program by entering into the EMD Phase of acquisition. Technologies should have matured to at least TRL 6. The majority of manufacturing processes have been defined and characterized, but there are still significant engineering and/or design changes in the system itself.
7	Capability to produce systems, subsystems, or components in a production representative environment	System detailed design activity is nearing completion. Material specifications have been approved and materials are available to meet the planned pilot line build schedule. Manufacturing processes and procedures have been demonstrated in a production representative environment. Detailed producibility trade studies are completed and producibility enhancements and risk assessments are underway. Technologies should be on a path to achieve TRL 7.
8	Pilot line capability demonstrated; Ready to begin Low Rate Initial Production	The system, component or item has been previously produced, is in production, or has successfully achieved low rate initial production. Technologies should have matured to TRL 9. This level of readiness is normally associated with readiness for entry into Full Rate Production (FRP). All systems engineering/design requirements should have been met such that there are minimal system changes. Major system design features are stable and have been proven in test and evaluation.
9	Low rate production demonstrated; Capability in place to begin Full Rate Production	The system, component, or item has been previously produced, is in production, or has successfully achieved low-rate initial production (LRIP). Technologies should have matured to TRL 9. This level of readiness is normally associated with readiness for entry into Full-Rate Production (FRP). All systems engineering/design requirements should have been met such that there are minimal system changes.
10	Full Rate Production demonstrated and lean production practices in place	Technologies should have matured to TRL 9. This level of manufacturing is normally associated with the Production or Sustainment phases of the acquisition life cycle. Engineering/design changes are few and generally limited to quality and cost improvements. System, components or items are in full-rate production and meet all engineering, performance, quality and reliability requirements. Manufacturing process capability is at the appropriate quality level.
Source: Manufacturing Readiness Level (MRL) - AcqNotes		

Many companies combine the TRLs and MRLs in their maturity assessment criteria, as issues in either the technology or manufacturing development could affect production readiness and implementation of an alternative material/process. It should be noted that not all affected components in a system will necessarily attain the same TRL or MRL at the same time.

The process described above places limitations on the ability of the design owner, such as an original equipment manufacturer (OEM), to use "generic" commercially qualified components or "generic" commercially qualified formulations without extensive in-house testing. In general, such a component or formulation is unlikely to have been tested in a suitably qualified laboratory. The testing would need to cover all the design owner's specific configurations, involving all relevant substrates, and to consider interactions with all relevant chemicals including, but not limited to, paints, solvents, degreasers, de-icers, hydraulic fluids, and oils. There will also be specific testing required by a design owner in specific configurations which the producer of the component or formulator is not able to test.

The following section summarises the multi-step, multi-party processes that must be completed to develop test candidates and implement a Cr(VI)-free alternative into the supply chain, whilst highlighting the anticipated time necessary to complete these highly regulated processes. It should be noted that many ADCR members have multiple projects with the aim of developing and industrialising Cr(VI)-free alternatives running in parallel, as hexavalent chromates are used in a number of steps in surface treatment processes. Whilst the proposed candidates will be different for each use, taking into account the different requirements of the existing materials, the highly specialised individual experts at both formulator and design owner, and the required testing facilities, will be common. The competing priorities, and the capacity and specialised resource constraints, created by the need to substitute multiple chromates to the same timeframe will therefore also have a negative impact on the timeframes usually associated with the substitution process.

3.1.2.2 Process, requirements, and timeframe

Identification & Assessment of need for substitution

When a substance currently used in the production of A&D components is targeted for regulatory action and needs to be replaced, a component design change may be triggered. Completely removing a substance from one component may impact upon multiple other components and systems, and involve many different processes with varying performance requirements.

The first step is to identify extent to which the substance, or the formulation containing the substance, is used. This must consider the entire life cycle of components containing the substance throughout the supply chain, including maintenance, repair, and overhaul (MRO) activities. After identifying the relevant formulations, processes, and design references, the affected component designs and related systems are identified. This is the first step to assess the impact of substituting the substance and the scale of the design changes which may be needed.

The above work requires contributions from numerous personnel from various departments including Materials & Processes, Research & Development, Design & Definition, Engineering, Customer Service, Procurement, Manufacturing, Supply Chain, and Certification. Assembling this multi-disciplinary team and co-ordinating their activity is itself a complex and time-consuming activity.

Components on which Cr(VI)-based surface treatments are currently used may have been designed 30 to 40 years ago (or more), using design methods and tools that are no longer in use. Attempting to determine the potential interactions/incompatibilities of a Cr(VI)-free formulation or surface treatment process in an old design can take a tremendous amount of work. Failing to adequately identify all interactions creates a significant risk, whilst resolving any incompatibilities between old and new treatment materials and/or techniques is time intensive and has a high chance of failure.

When an existing design specifies a formulation or process utilising Cr(VI), the design change must not only comply with the performance requirements of the newly introduced components, but also be compatible and seamlessly interact with remaining legacy designs. This is because maintenance may require a Cr(VI)-free alternative to be applied proximal to the legacy formulation, containing Cr(VI). If the re-design is going to be integrated with old components treated with Cr(VI), compatibility must be assured.

Definition of requirements

Once a project seeking to develop and industrialise an alternative is launched, materials and process specialists from engineering, manufacturing, procurement, and MRO departments at the design owner, define the requirements that the proposed candidate must fulfil in order to be a suitable test candidate.

Alternatives must satisfy numerous requirements. In many cases those identified introduce competing technical constraints and lead to complex test programmes. This can limit the evaluation of proposed candidates. Categories of technical requirements may include:

- Performance requirements (e.g., corrosion resistance, wear resistance, adhesion strength, and compatibility with other materials);
- Design requirements (e.g., compatibility of the component's geometric complexity with the coating technique);
- Industrial requirements (e.g., robustness, processability, and repeatability); and
- Environment, Health & Safety (EHS) requirements (e.g., is there an equivalent level of concern).

For some materials dozens of individual requirements may exist across these categories.

Definition of requirements itself can be complex and requires a significant timeframe. The complexity can be due to:

- The substitute exhibiting behaviours or interactions which are different to the original product. Where unexpected behaviour is seen, sufficient operational feedback to technically understand the phenomenon and refine the requirements is essential to ensure non-regression;
- Consolidating requirements from multiple customers and suppliers into an existing design;
- Evolution of EHS regulations; and
- Need to substitute multiple chromates to the same timeframe.

Development of initial requirements can take at least six months, although requirements may be added and continue to be refined during the different levels of maturity, based on learnings from the various testing/qualification stages.

Key phases of the substitution process

Once initial technical requirements are defined, test candidates can then be identified and tested by the design owner. Figure 3-2, revised from the Global Chromates Consortium for Aerospace (GCCA) Authorisation applications, shows a schematic of the various stages in the process, which are described further below. These steps are not simply performed one after the other or presented in a chronological order, but rather they represent an iterative process.

Each stage in the process comprises various steps including extensive laboratory testing programmes and, in some situations, in service/flight testing. Each step therefore requires flexibility in the time to be completed, typically taking years overall. It should be noted that there can be **failures at any stage in this process**, and failures may not reveal themselves until a large amount of testing, taking considerable time and incurring significant expense, has already been carried out. Such failures result in the need to return to earlier steps in the process and repeat the extensive testing and associated activities leading to industrialisation. The later in the process these failures occur, the greater the impact will be on schedule and cost.

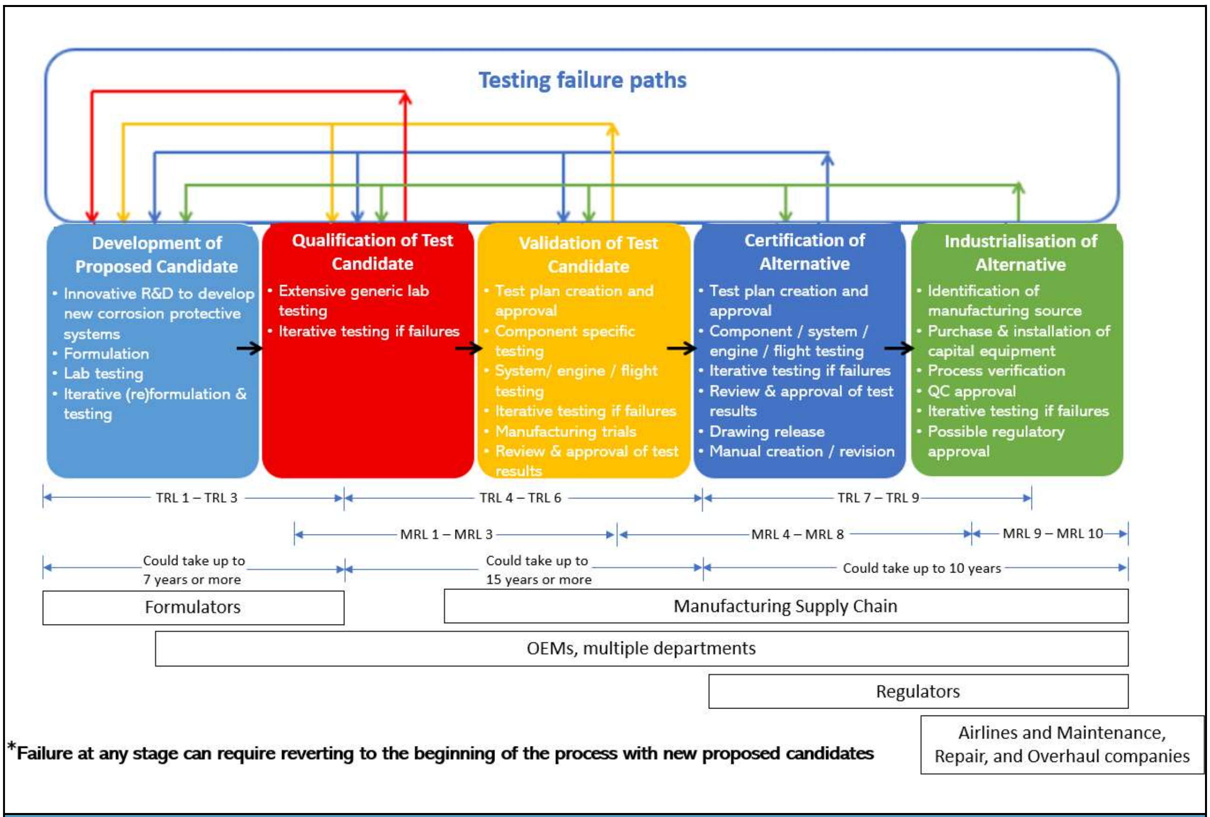


Figure 3-2: Schematic showing the key phases of the substitution process
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note that failures may not become apparent until a late stage in the process.
Source: Adapted from "Use of strontium chromate in primers applied by aerospace and defence companies and their associated supply chains, Application for Authorisation 0117-01, GCCA (2017)

The detailed process involved in each phase of the substitution process is described below, and the associated timeframes are elaborated. Throughout the process it should be remembered that the initial qualification, validation, and certification of a final product is applicable to a single specific configuration of components and materials, assembled by a single set of manufacturing processes. Any change to the components, materials, or manufacturing processes invalidates this initial qualification and certification. The action to approve and industrialise the change can only proceed once a suitable test candidate is developed, qualified, and validated.

Development of proposed candidates

When a need to develop an alternative has been identified (for example, as in this case, because of regulatory action driving the need to make an informed substitution), the first stage comprises innovative R&D, most commonly by the formulator(s), to develop new formulations. Initial activities in the development of proposed candidates stage include:

- Innovative R&D to develop new surface treatments;
- Formulation of proposed candidates;
- Laboratory testing of proposed candidates; and
- Iterative re-formulation and testing.

The development of proposed candidates must take into consideration the complex design parameters identified in the requirements development step discussed above. Once a proposed candidate is developed, testing is carried out in the formulator's laboratory to assess quantitative performance of the new formulation against the critical criteria required by the design owner. Failure against any of these criteria may result in rejection of the proposed candidate, further modification of the formulation, or additional testing. Although it may only be the Cr(VI) compound within a mixture which is subject to regulatory action, the other constituents may also require substantial change to continue to meet the stated performance requirements.

Formulators, or sub-contractors acting on their behalf, perform screening tests on small test pieces of substrate. Such tests provide an indication of whether basic performance criteria have been met, in order to justify more extensive testing by the design owner. The predictive power of laboratory tests performed by the formulators is limited and therefore it is vital to note that a formulation that passes these screening tests is not necessarily one that will be technically suitable to ultimately be fully implemented in the supply chain. **Passing these initial tests is a *necessary, but not sufficient***, pre-requisite for further progression through the process (i.e. a building blocks approach is followed).

Development typically involves an iterative process of re-formulation and re-testing to identify one or more proposed candidate. It is important to note that many iterations of these formulas are rejected in the formulator's laboratory and do not proceed to evaluation by the design owner. Formulators estimate that it typically takes two to five years of testing potential formulations before a proposed candidate is identified for submittal to the design owner[18].

Qualification of test candidate

Qualification is the first step in the process under which a design owner begins to verify that the treatment which may ultimately replace the Cr(VI)-based surface treatment has met or exceeded the specific performance criteria defined at the beginning of the substitution process.

Qualification applies to materials, manufacturing processes, and components, and comprises:

- Extensive generic laboratory testing; and
- Iterative testing if failures occur.

Once proposed candidates are developed by the formulator, the design owner evaluates the formulations by first performing their own screening tests. If the test candidate fails, formulators may choose to reformulate. It is common to iterate multiple times before a test candidate passes the design owners' screening, potentially adding several years to the substitution process (see figure 3-2 above).

[18] GCCA

For those test candidates which pass initial screening, additional testing is performed. Each company has explicit performance requirements, test methods, acceptance testing, and other characteristics for each component that are based upon the results of research, development, and prior product experience. This phase of the substitution process can take multiple years depending upon the performance requirements and only successfully qualified test candidates can progress to the validation stage described below.

Validation of test candidate

After a test candidate is qualified, the performance of each particular aerospace or defence use is validated based on its specific design criteria.

Validation is carried out on each relevant component, followed by system-level testing and engine/flight testing (if relevant). The activities in this stage can overlap with some of those that are carried out in the Certification stage and include:

- Test plan creation and approval;
- Component specific testing;
- Iterative testing if failures occur;
- System/engine/flight testing;
- Manufacturing trials; and
- Review and approval of test results.

The testing criteria are determined on a case-by-case basis with due regard to the design and performance requirements of each component and system. Testing in a relevant environment over an appropriate timescale is necessary, and therefore the validation stage may require full engine and aircraft flight tests, even for very low volumes of product. In the validation of manufacturing processes, the process robustness is also a vital aspect to be demonstrated at this stage.

Validation is carried out by the aerospace and defence companies, sometimes in collaboration with the manufacturing supply chain (in the Certification stage, the Regulator is also involved). Only the original design owner can determine when a test candidate is fully validated.

Some of the components impacted by the substitution of a surface treatment may form part of systems which are no longer in production. In order to conduct the testing required to validate the change on these components, it may therefore be necessary to build bespoke test hardware. Sourcing the relevant hardware and test equipment, and finding test facilities to do this, can add significant time to the process, whilst some of the testing performed at this stage will also be destructive, so failures can result in further schedule slippage. Together the Qualification and Validation processes encompass testing of the test candidate and can take more than 15 years to complete for the most challenging substitutions. At the end of the validation stage the removal of Cr(VI) from the production process is formally approved by the design owner.

Certification of alternative

Certification is the stage under which the component onto which the test candidate will be applied is certified by the Regulator or relevant authority as compliant with safety, performance, environmental (noise and emission) and other identified requirements. OEM's work with the certification authorities to develop a comprehensive plan to demonstrate that the aircraft, engine, propeller, radar system, munitions or any other final product complies with the airworthiness regulation or defence/space customer requirements. This activity begins during the initial design phase and addresses the final product in normal and specific failure conditions. The airworthiness regulations set performance criteria to be met, although they do not specify materials or substances to be used.

Steps in the Certification stage include:

- Test plan creation and approval;
- Component/system/engine/flight testing;
- Iterative testing if failures occur;
- Review and approval of test results;
- Drawing release; and
- Maintenance manual creation/revision.

For the civil aviation industry, the output of the original certification process is a Type Certificate, issued by the airworthiness authority (e.g. EASA) and granted to the engine, propeller, and airframe OEM. This is issued for the original design of the final product, rather than for each individual component, however every component of the final product must be designed, developed, and validated as meeting the requirements of the overall product and system design. The overall compliance demonstration for a new Type Certificate therefore may cover several thousand individual test plans, of which some will require several years to complete. This interconnection is illustrated using the example of an aircraft in Figure 3-3 below.

Certification therefore applies to all components, sub-systems, and systems. A change to one individual component can affect the entire assembly of which it is a part (which may contain hundreds of components), and in turn the sub-system and system. Approval of the impacted components is granted after the airworthiness certification criteria, compliance requirements and methods of compliance have been successfully demonstrated for those components, to the relevant Airworthiness Authority. The same process applies to defence products and systems, with the only distinction being how acceptable means of compliance are defined, and the certification authority (which will usually be a Ministry of Defence (MoD)). In the case of dual use aircraft (A civil and a military version of the same aircraft), or in the case of military specific aircraft, certification may need to be granted by multiple authorities (e.g. certification by the MoD could apply in addition to the EASA certification).

Removing a material or process reliant upon Cr(VI) and implementing an alternative is particularly challenging as it will involve in service or in production components. Re-certification of all components incorporating the new processes and materials is therefore required. As discussed in the description of the certification process in the GCCA AfA for strontium chromate[19], each of these components will need to be approved individually:

[19] Application for Authorisation 0117-01 section 5.3 available at [b61428e5-e0d2-93e7-6740-2600bb3429a3 (europa.eu)] accessed 06 June 2022

"Importantly, even if an alternative is in use in one component in aerospace[20] system A, it cannot be inserted into what appears to be the same part [component] in another aerospace system B (e.g., model B) until it is fully reviewed/validated/certified to ensure that either the design parameters are identical or that the alternative is fully acceptable for the different design parameters. Extensive experience shows that an alternative that is successfully certified in one component in one model cannot necessarily be successfully certified in another. In other words, the circumstances for each component in each model are unique and extrapolation is impossible without validation and certification."

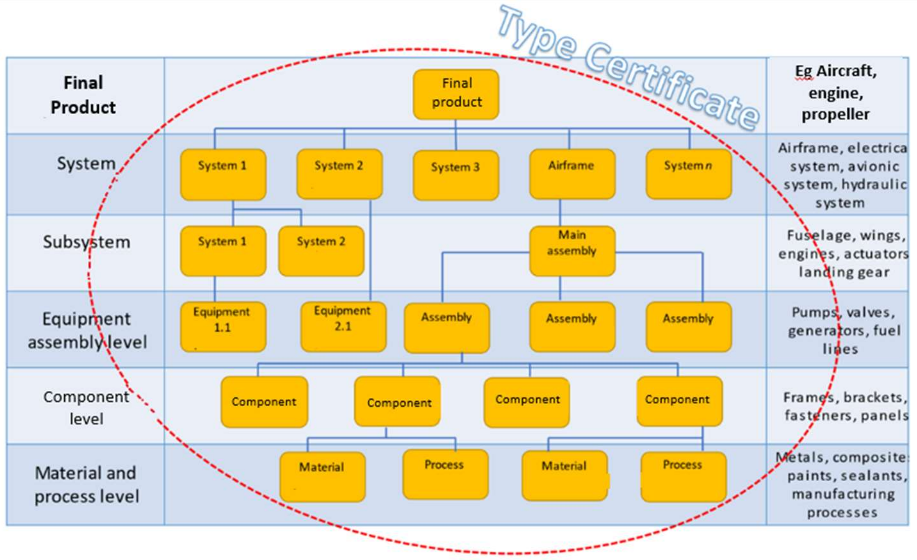


Figure 3-3: System hierarchy of a final product
Diagram shows the interconnection of each level in the system hierarchy, and how changes at a lower level have impacts on higher levels.
Source: ADCR member

After the alternative is certified, design drawings and component lists need to be revised to put the requirements of the Cr(VI)-free material/process as an alternative to the legacy requirements. Thousands of components could be impacted by each process. Only once these revised design drawings have been released can industrialisation of the alternative begin.

Over their operational life A&D components are exposed to extreme mechanical forces and environmental conditions which affect their performance. In order to continue to meet requirements, and ensure operational safety, A&D components and products are therefore subject to intensive MRO activities. The strict schedule of the maintenance program, and method for repair, is stated in the maintenance manual and must be officially approved. For most A&D organisations, repair approval is distinct from design approval, although the processes are analogous and may be undertaken concurrently. Once repair approval is complete the alternative will be included in maintenance manuals.

During initial manufacture, all the components of the system are in a pristine and relatively clean condition, whereas during repair and maintenance, the components are likely to be contaminated and suffering from some degree of (acceptable) degradation. Furthermore, certain cleaning and surface preparation techniques that are readily applicable during initial manufacture may not be available or

[20] In this parent dossier, the term aerospace is defined as comprising the civil aviation, defence/security and space industries.

practical during repair and maintenance. Carrying out MRO activities on in-service products is further complicated due to restricted access to some components, which are much more readily accessible during initial manufacture and assembly. These factors are significant with respect to surface treatments, as their performance is strongly dependent upon the condition of the surfaces to which they are applied. As such, all of these conditions must be addressed in the repair approval process.

The certification and industrialisation stages (see below) encompass progression of the alternative from TRL 7 to TRL 9 and together these stages can take six to ten years to complete. In certain defence applications, certification alone can take more than ten years.

Industrialisation of alternative

Industrialisation follows the certification of the component design incorporating the alternative and is an extensive step-by-step methodology followed to implement the certified material or process throughout manufacturing, supply chain and MRO operations, leading to the manufacturing certification of the final product.

Elements of the Industrialisation of alternative process include:

- Identification of potential manufacturing sources;
- Purchase and installation of manufacturing equipment;
- Process verification (Due to the fact that the industry is working on special processes, the supply chain must be qualified);
- Quality Control (QC) approval; and
- Regulatory approval if needed.

A&D products consist of up to a million components provided by thousands of suppliers or manufactured internally by OEMs, making communication between OEMs and their supply chain regarding what is permissible for use on A&D products key. Suppliers must be vetted through a supplier qualification process prior to being issued a contract. This process typically involves internal approval, contract negotiation, running a specific qualification test program, and undertaking an audit on potential risks of working with a supplier. A supplier may be requested to sign a manual or code of conduct by the OEM, to ensure expectations for work and awareness of required standards is achieved. Once the supplier is qualified, periodic audits are performed to ensure continued compliance with contractual requirements. Significant investment, worker training and manufacturing documentation may be required to adapt the manufacturing processes for new alternatives, which sometimes require changes in existing facilities, the construction of new facilities, or switching to a different facility (including a different supplier's facility).

The industrial implementation is usually scheduled to follow a stepwise approach to minimise the technical risks, and benefit from lessons learned. This implies that the replacement is not implemented simultaneously in all plants and at all suppliers but instead often uses a stepwise approach. Each OEM may operate dozens of manufacturing sites/final assembly lines worldwide.

For components already in products, long-term contractual agreements are often already in place with suppliers. When a change is made to a drawing to incorporate a new alternative, the contract with the supplier needs to be renegotiated, and additional costs are incurred by the supplier when modifying and/or introducing a new production process. These may include purchase and installation of new equipment, training of staff, internal qualification of the new process, OEM qualification of the supplier, manufacturing certification of the supplier, etc. In addition, the supplier may need to retain the ability to use the old surface treatment, or qualify different solutions for different customers/ components, which requires the supplier maintain parallel process lines to accommodate multiple surface treatments/processes. The level of complexity varies by component and process. In some cases, the supplier may be sub-contracting the process. In addition to production organisation approval, the approval of maintenance organisations is also required. This means multiple layers of activity in the industrialisation process.

The industrialisation of alternatives is constrained by many factors including: the complexity of supply chains; extent of process changes required; and the airworthiness regulations or defence/space customer requirements. Even simple changes can take up to five years. When more than one alternative process is introduced simultaneously, up to a decade or more may be necessary for full implementation of the alternative.

The industrialisation process includes the creation and approval of process documents or manufacturing/repair documents. These documents allow detailed implementation of the manufacture and/or repair of each component. Using the example of a commercial aircraft, the process, described above and leading to industrialisation of the alternative, is illustrated in Figure 3-4 below. This is a simplified example. In some cases, there are many different types of components all needing validation test and there are instances where different test candidates are used on different parts (to replace a single original Cr(VI) use).

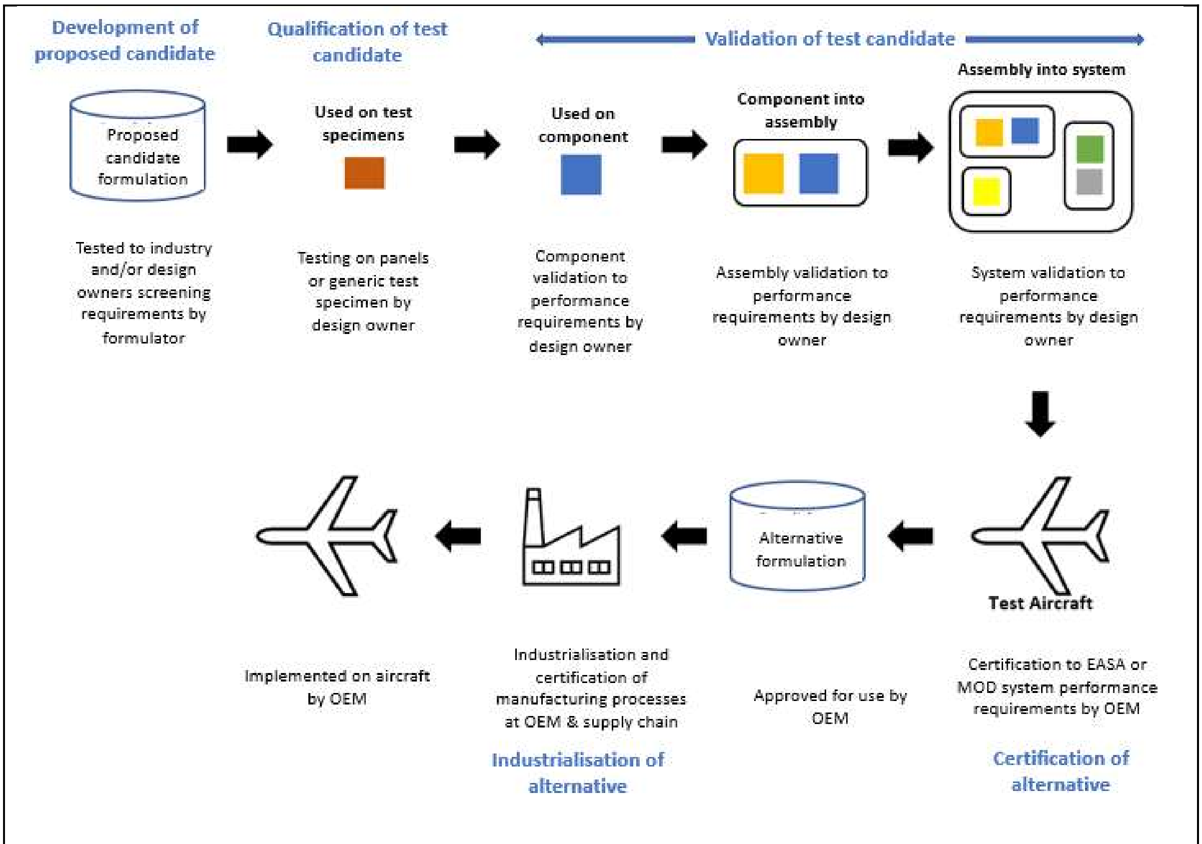


Figure 3-4: Process to Certify a Formulation for use on Aircraft
Formulations used in production have completed this process. New or reformulations must follow same process for use in production.
Source: ADCR member

3.2 Description of the functions of the chromates and performance requirements of associated products

3.2.1 Technical feasibility criteria for the role of the chromates in the applied for use

3.2.1.1 Introduction

The development of technical feasibility criteria for chromates (Cr(VI)) in conversion coating (and proposed/test candidates) has been based on a combination of assessment of the parent AfAs, consultation with ADCR consortium members, and a review of available scientific literature.

Through the use of detailed written questionnaires (disseminated throughout 2021 and 2022) the ADCR consortium members were asked to review the technical feasibility criteria and provide details of the (ideally) measurable, quantifiable technical performance criteria which the chromates meet in this use and that any alternatives (substances and technologies) would also need to meet before they are seriously considered as possible replacements.

In parallel, scientific literature investigating conversion coating and assessing the technical suitability of alternatives to Cr(VI) was collected and analysed (with the assistance of the ADCR consortium members) and has been incorporated into the analysis.

The criteria that are used in the assessment of the technical feasibility and suitability of selected alternatives to Cr(VI) for conversion coating are as follows. These apply to aluminium substrates, and a sub-set of these are relevant for magnesium and titanium substrates:

- Corrosion resistance (and active corrosion inhibition/"self-healing");
- Chemical resistance;
- Adhesion promotion;
- Temperature resistance
- Layer thickness;
- Electrical resistivity; and
- Pre-treatment compatibility.

Impact on fatigue life is also considered when assessing test candidates for Cr(VI) for conversion coating.

In addition to the above, conversion coating is applied without an electrical field. It can therefore be applied to complex geometries such as tubes and pipes. Such components would act as a faraday cage in the presence of an electric field, which would therefore limit or prevent the use of alternative methods such as anodising that use an electric field.

As noted above, this combined AoA/SP and SEA covers the use of multiple chromates in chemical conversion coating (chromium trioxide (includes "acids generated from chromium trioxide and their oligomers", when used in aqueous solutions), sodium dichromate, potassium dichromate and dichromium tris(chromate)). In the context of technical feasibility and the wider AoA it is important to note that the mode of action for corrosion protection clearly describes the benefit as coming from the Cr(VI) species. Therefore, by extension any donor (substance) that delivers Cr(VI) is responsible for also delivering the functions attributed to Cr(VI) within the over-arching 'use'. As such the discussion of technical feasibility discusses the functions imparted by conversion coatings, and the mode of action/mechanism by which Cr(VI) delivers these functions. For example, one function imparted by conversion coatings is corrosion inhibition. The mode of action of Cr(VI) is concerned with the chemical/physical process by which the Cr(VI) and its reduced counterpart Cr(III) contribute to this corrosion protection mechanism. Mode of action is important to consider when analysing alternatives, as there may be something unique about the chemistry of Cr(III)/Cr(VI) in contributing to a particular function that cannot easily or sufficiently be replicated by another substance.

The discussion below explains the relevance and importance of each of the criteria and presents in more detail the threshold values (or ranges) that will be used in Section 3.3 for the comparison of the shortlisted alternatives to Cr(VI).

For reference, substrates identified by the ADCR members as relevant to chemical conversion coatings are:

- Aluminium alloys;
- Magnesium alloys; and
- Titanium alloys.

It should also be noted that, in many instances, technical comparison criteria are strongly interrelated, and it is not possible to consider a criterion independently of several others.

3.2.1.2 Role of standards and specifications in the evaluation of technical feasibility criteria

At the development phase, as described in the substitution process (see Section 3.1.2) proposed candidates are at an early stage of evaluation represented by TRL 1 – 3, and not recognised as credible test candidates at this stage. These proposed candidates are screened against the technical feasibility criteria, or key functions imparted by the use of 'chemical conversion coating'. These functions are measured against performance thresholds using standardised methodologies. The performance thresholds are most often assigned by the design owner of the component subject to the treatment.

As stated, test methodologies are defined within standards and specifications. Standards may be within the public domain originating externally of the A&D sector from professional bodies (e.g. BSI or ISO). Specifications are often internal to the aerospace/defence company, or a Government Defence Department (Ministry of Defence) with access to the documents controlled by the manufacturer and/or design owner of the part. As such, these documents are typically classified as confidential business information.

In the context of AoA, the importance of the performance thresholds and standards are multifold; to ensure reproducibility of the testing methodology, define acceptable performance parameters and determine if the proposed candidate exhibits regression or is comparable in performance compared to the benchmark Cr(VI) substance.

The role of the specification is limited within the substitution process. It provides a reproducible means of screening proposed candidates, however, is typically unsuitable for more mature stages within the substitution process when proposed candidates transition to credible test candidates. These subsequent phases in the substitution process are subject to in depth often bespoke testing as required within steps TRL 4 - 6 and above. Testing regimes to meet the requirements of TRL 4 - 6 often transition from simple specifications intended for quality control purposes, to evaluation of treated components/sub-assemblies via breadboard integrated components either within the laboratory or larger simulated operational environments. These advanced testing regimes rely upon the use of specialised equipment, facilities, and test methodologies such as test rigs or prototype systems, see Figure 3-5. Attempts to replicate environmental in-service conditions are built upon bespoke testing regimes developed over decades of Cr(VI) experience from laboratory scale test panels to test rigs housed in purpose-built facilities. However, they cannot always reproduce natural environmental variations therefore there can be differences between what is observed in the laboratory and experienced in the field.

Figure 3-5: Multi-climate chamber for simulated environment testing (Airbus SAS, 2022)

Examples of standards used for screening proposed candidates within the development phase of the substitution process are presented in Table A-8-1. As stated above, standards serve to provide a means of reproducible testing within the development phase of the substitution process. Both standards and specifications are tools used to evaluate proposed candidates to identify suitable test candidates.

3.2.1.3 Interrelationship of technical feasibility criteria and impact on the surface treatment 'system'

When considering technical feasibility criteria in many instances these are strongly interrelated in the delivery of the 'use', and it is not possible to consider one criterion independently of the others when assessing proposed candidates. The individual criterion collectively constitute part of a 'system' delivering the 'use' with a degree of dependency on one another.

For example, achieving corrosion resistance should not impact the adhesion of any subsequent layer, or at least be comparable to the benchmark Cr(VI) solution. It may be necessary to modify the treated surface to achieve satisfactory adhesion of subsequent layers applied after conversion coating. Therefore, the selection of the surface treatment may be influenced by its compatibility with subsequent processes such as adhesion promoters, not only corrosion and chemical resistance. Additional consideration should be given to the influence and compatibility of any pre-treatments; how they interact with the conversion coating process and how they impact the key technical criteria of the 'use'. Pre-treatments may include chemical alkaline cleaning to remove grease and oily residues, or mechanical cleaning such as grit blasting for example. The selection of pre-treatments and the alternative chosen to deliver the conversion coating 'use' need to take into account the design parameters of each affected part. How the parts interact with each other, and with the treatment 'system' to deliver the technical feasibility criteria should be considered. Interactions between the different elements of the surface treatment system may not be anticipated. These may only manifest themselves when more advanced testing of parts in simulated service environments is conducted or when used in multi-part assemblies with the potential to generate further operational environments that may affect the performance of the treatment system.

The GCCA Application for Authorisation 0116-01 (GCCA, 2017b) considers variables that could impact essentially the same component design which can influence behaviour and compatibility with a treatment system, and therefore delivery of technical feasibility criteria. These variables are listed below[21]:

- Hardware[22] base alloys;
- Contact or mating surfaces with other parts;
- Exposure to fluids;
- Structural stress and strain; and
- External environment.

External environmental variables affecting in-service conditions for different assemblies of parts include:

- Exposure to chemicals e.g., de-icers, lubricants, salts, sea water/moisture;
- Temperature;
- Galvanic influences from different metals in contact with one another; and
- Mechanical effects; galling[23], vibration, erosion.

These can all affect the corrosion behaviour of a part and the performance requirements of the alternative delivering the conversion coating 'system'. Due to the complexity of these assemblies and variety of environments encountered in service, a single test candidate may not provide a universal solution to delivery of all technical criteria under all scenarios of use for a given part.

3.2.1.4 Technical feasibility criterion 1: Corrosion resistance (and active corrosion resistance ("self-healing"))

Aluminium substrates

Corrosion resistance is important to provide safe and reliable performance and assure the life of the component in service. This is especially important in situations where the component is relatively inaccessible and cannot be easily or frequently inspected. Corrosion resistance is also important to prevent corrosion of the component during intermediate steps in the manufacturing process.

In chemical conversion coating of aluminium (Al), Al is oxidised to Al^{3+} and Cr(VI) is simultaneously reduced to Cr(III) as follows (CTAC consortium, 2015):

(1) $2\ Al \rightarrow 2\ Al^{3+} + 6e^-$
(2) $2\ Al^{3+} + 3\ H_2O \rightarrow Al_2O_3 + 6\ H^+$
(3) $2(CrO_4)^{2-} + 10\ H^+ + 6e^- \rightarrow 2\ Cr(OH)_3 + 2\ H_2O$

[21] GCCA Response to Pre and post Trialogue SEAC Questions on DtC and SrC AoA, p.15

[22] 'Component an aerospace system', GCCA Response to Pre and post Trialogue SEAC Questions on DtC and SrC AoA, p.15

[23] Wear caused by adhesion between sliding surfaces (Wikipedia, 2021)

Following reduction of Cr(VI) to Cr(III), the mechanism of chemical conversion coating occurs with the formed protective coating containing a balance Cr(VI) and Cr(III) (Jiang et al., 2016a). As residual chromium trioxide is retained in the outermost layer of the coating, upon exposure to water or salt solution, Cr(VI) species are released from the coating, particularly when they are scratched to refresh the coating area. This released Cr(VI) then diffuses to a defect to passivate the surface and thus provides active corrosion inhibition to the surface (Jiang et al., 2016a), (CTAC, 2015).

The mechanisms for the inhibition of metal alloy dissolution are that the chromium trioxide is a very soluble, higher-valent, oxidizing ion (CrO_4^{2-} or $Cr_2O_7^{2-}$) with a lower valent form that is insoluble and creates an extremely protective film (Cr_2O_3 or $Cr(OH)_3$). The degree of corrosion resistance provided by conversion coatings is generally proportional to the coating thickness (CTAC, 2015).

An appropriate pre-treatment step to prepare the substrate is typically used prior to the chemical conversion coating surface treatment. Cr(VI)-containing pre-treatment solutions permit the removal of surface oxides and exposed intermetallic particles with minimal loss of the alloy matrix and avoidance of intergranular attack.

Active, or self-healing, corrosion protection is possible due to the presence of residual Cr(VI) retained in the conversion coating layer. If the substrate is damaged locally, this residual Cr(VI) reacts with the exposed substrate, reducing to Cr(III), and renewing the passive chromium oxy-hydroxide protective barrier (CCST Consortium, 2015).

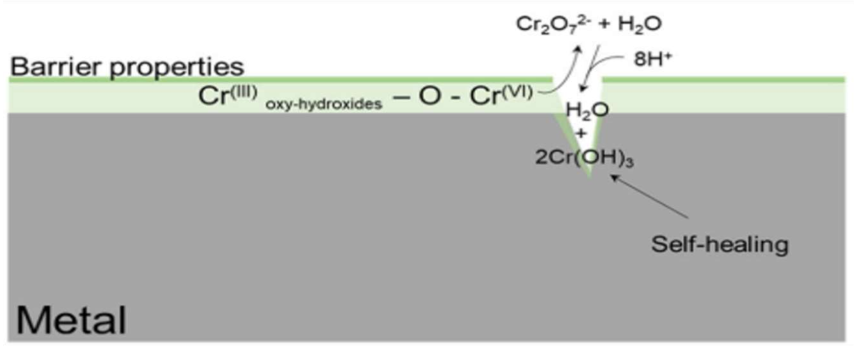


Figure 3-6: Self-healing mechanism afforded by Cr(VI) on metal substrates
(Gharbi et al., 2018)

The 'active' layer is typically composed of both Cr(VI) and Cr(III). The interior of the layer is composed of the Cr(III) oxy-hydroxide, which forms a covalent bond, $Cr^{(III)}$ – O –$Cr^{(VI)}$, with residual Cr(VI) species. This promotes a Cr(VI) enriched outermost region of the protective layer. Should the passive coating be damaged, exposing the underlying substrate to corrosive agents, the Cr(VI) is released, or diffuses, from this region of high Cr(VI) concentration, thereby renewing the passive barrier (Jiang, Guo and Jiang, 2016a).

Unlike most corrosion inhibiting compounds, chromates are both anodic and cathodic inhibitors, meaning that they can restrict the rate of metal dissolution, and simultaneously lower the rate of reduction reactions (oxygen and water reduction) in many environments and over a broad range of pH. This makes the Cr(VI) compounds uniquely capable of providing/ensuring the corrosion protection required for the safety critical operations of A&D products over the wide range of use environments in which they operate.

The presence of residual Cr(VI) in chemical conversion coatings limits base metal attack and blistering of a subsequent coating from the hydrogen evolution that accompanies aluminium corrosion. This is accomplished by the dissolution and electrophoretically-enhanced[24] transport of chromate or dichromate anions to corroding sites to counterbalance the outward ionic diffusion of aluminium cations, and the reduction of soluble hexavalent chromium compounds on exposed metallic surfaces to produce insoluble and protective Cr_2O_3-rich deposits.

Magnesium substrates

The mechanism of corrosion resistance of magnesium is analogous to that described for aluminium above.

Magnesium is much more reactive than aluminium and does not have the same self-passivation property exhibited by aluminium. The Pilling-Bedworth ratio is a measure of the extent to which an oxide film covers the bare metal from which it derives. Magnesium corrosion products have a smaller molar volume than the magnesium metal, so the corrosion products do not cover the surface of the magnesium (the Pilling Bedworth ratio is less than 1), and therefore do not provide corrosion protection as bare metal remains exposed. In comparison, the Pilling Bedworth ratio for aluminium is 1.28 and the aluminium oxide completely covers the aluminium substrate.

A conversion coating on magnesium, although essential for providing improved adhesion of subsequently applied sealing resins or paints, has a relatively low corrosion protective value in its own right. Conversion coatings on magnesium are typically tested in a relatively mild corrosion test environment, such as a humidity chamber as an alternative to a salt spray chamber. Cr(VI)-free test candidates for conversion coatings for magnesium are tested by comparison with the Cr(VI)-based process, to assess the corrosion resistance behaviour.

Given these corrosion characteristics of magnesium, conversion coating is primarily applied to magnesium for the purpose of achieving a good surface onto which to apply subsequent coatings. Although it is more difficult to achieve corrosion resistance for magnesium compared to aluminium, conversion coating is nevertheless applied to magnesium to provide improved corrosion resistance, for example until a paint/coating is applied.

Titanium substrates

Titanium alloys do not have a significant requirement for additional corrosion resistance. Finishing may be required to meet colour requirements, to prevent fretting corrosion, or to insulate between dissimilar metals in structural applications.

3.2.1.5 Technical feasibility criterion 2: Chemical resistance

Chemical resistance refers to the ability of the component to withstand contact with fluids encountered in the service life of the part, such as lubricants, hydraulic fluids, greases, fuels, solvents, de-greasers, cleaning fluids, and de-icing fluids. Due to its inorganic nature, the chemical conversion coating resists many organic substances, such as solvents, lubricants, and greases.

[24] Electrophoresis is the motion of dispersed particles under a uniform electric field, relative to the fluid in which the particles are present.

The principal mechanism for chemical resistance of chemical conversion coatings is the insolubility of their primary constituent, chromium oxide (Cr_2O_3). Inspection of the potential/pH (Pourbaix[25]) diagram for the chromium/chlorine/water system, shows that insoluble Cr_2O_3 is stable and prevails over the potential/pH environmental conditions experienced by aerospace components in most conditions. It is also apparent that Cr_2O_3 is immune to attack by chloride ions at pH values above 2. A similar chemical resistance holds for other corrosive species.

3.2.1.6 Technical feasibility criterion 3: Adhesion promotion

Adhesion promotion refers to the ability of the coating to improve the adhesion of subsequent layers such as paints, primers, adhesives, and sealants. It also includes the adhesion of the coating to the substrate, and the cohesion of the coating (how strongly the coating adheres to itself). Adhesion promotion is an important function of conversion coatings for aluminium, magnesium, and titanium alloys.

Untreated aluminium, magnesium and titanium alloys provide very little adhesion promotion. One reason for this is that aluminium alloys instantaneously oxidize on contact with air or water but do so in an uncontrolled manner. One uncontrolled factor is that the first corrosion product of aluminium oxidation is amorphous aluminium hydroxide, $Al(OH)_3$, which has low cohesive and adhesive strength. Over a period of days to weeks, aluminium hydroxide will slowly convert and crystallize to the energetically preferred tri-hydrated aluminium oxide $Al_2O_3 \cdot 3H_2O$. If this transformation takes place under a coating film, as a consequence adhesion will be poor.

Chromate conversion coatings provide a stable and repeatable surface for adhesion by forming a mixed oxide film of stable cohesive and adhesive strength. Chromate conversion coatings are initially amorphous when freshly applied but undergo dehydration to a stable crystalline form over a few hours. Chromate conversion coatings provide acceptable adhesion for a wide range of adherents.

The presence of residual hexavalent chromium (Cr(VI) in chemical conversion coatings serves to prevent the corrosion-induced loss of adhesion by limiting base metal attack and blistering of a subsequent coating from the hydrogen evolution that accompanies aluminium corrosion. This is accomplished by the dissolution and electrophoretically-enhanced[26] transport of chromate or dichromate anions to corroding sites to counterbalance the outward ionic diffusion of aluminium cations, and the reduction of soluble hexavalent chromium compounds on exposed metallic surfaces to produce insoluble and protective Cr_2O_3-rich deposits.

Chromate conversion coatings form strong adhesion to the substrate due to the superficial dissolution of the substrate and the precipitation of a mixed material of dissolved metal ions and treatment solution. The superficial dissolution removes oxides to produce a clean, high-energy surface[27], then deposits an oxide film that minimised this surface energy, causing a high strength of adhesion between the oxide layer and the metal.

[25] Pourbaix, M. (1974), Atlas of Electrochemical Equilibria in Aqueous Solutions, National Association of Corrosion Engineers p262

[26] Electrophoresis is the motion of dispersed particles under a uniform electric field, relative to the fluid in which the particles are present.

[27] Surface energy may be defined as the work required to create an area of surface from a bulk material. A surface has excess energy compared to the bulk, and a surface will therefore try to minimise its energy, e.g. by absorbing a material with a lower energy onto its surface.

3.2.1.7 Technical feasibility criterion 4: Layer thickness

Layer thickness is important as it affects component dimensions and tolerances, which affect the performance of the component when it is integrated into assemblies and sub-systems. For example, if layer thickness increases it can cause reduced fit of fasteners that require close compliance to the specified tolerances, and increased wear when the component is integrated with other components and where the component moves in relation to those components. Any alternative to Cr(VI) must not adversely affect layer thickness, or adversely affect the ability to control them through the normal process operating conditions (such as time, temperature, pH, and degree of agitation).

Layer thickness is not directly influenced by Cr(VI) but are associated with process conditions and must be carefully controlled.

Layer thickness is also important as it affects fatigue. For conversion coatings the usual thicknesses lie below 1 µm as so has little impact on fatigue life. Proposed candidates to Cr(VI) for conversion coating may be thicker and therefore may introduce a fatigue concern. For example, this is why anodise cannot replace conversion coating in some applications.

It should be noted that the propensity for a surface to form small cracks also plays an important role in fatigue life. Pre-treatments that etch the surface, especially those that introduce inter-granular attack, can introduce fatigue debit, irrespective of coating thickness or composition. Anodised coatings are brittle and therefore more liable to form small cracks than is a conversion coated surface.

3.2.1.8 Technical feasibility criterion 5: Resistivity

Aluminium substrates

Conductivity is the reciprocal of resistivity. Chromate conversion coatings have been shown to be electrical insulators through mercury drop contact experiments. Resistivity is not directly influenced by Cr(VI) but by the thickness and morphology of the conversion coating layer, which is influenced by process conditions and must be carefully controlled. Apparent surface electrical conductivity (contact resistance) is achieved by the fracture of the thin, brittle chemical conversion coating under load between metal faces to allow for direct metallic contact. Consequently, for applications requiring apparent surface electrical conductivity (low resistivity/low contact resistance), the maximum coating weight is 100 mg/m^2, as opposed to 2,000-5,000 mg/m^2 for other classes of chemical conversion coating (note that it is not typical to actually measure conversion coating weight).

Examples of where low resistivity (high conductivity) is needed include applications where electrical grounding is needed across a metal interface, and when electromagnetic interference (EMI) shielding is needed at a metal interface, sometimes with a conductive gasket between. A main requirement for low resistivity is for the mitigation of lightning strikes. This mitigation damps the effect of lightning strike by allowing the high electrical current to flow through the super-structure. Any insulation (high resistivity) at a structural interface will cause a high voltage drop at the interface and once overcome, an arc will be produced resulting in localized melting of the structures and significant fire risk.

The actual thickness requirements for achieving apparent surface electrical conductivity depend on the load, ductility, and geometry of the opposing mechanical faces to be brought into metallic contact. Since thin layers of chemical conversion coating provide conductivity in many applications through localized fracture of the coating, the self-healing properties of the Cr(VI) is particularly important.

Magnesium substrates

Resistivity is a requirement of conversion coatings on magnesium.

Magnesium structures usually do not have flow of electrons across coatings (e.g., between structures separated by coatings) because corrosion will occur if there is any allowance for electron flow. Magnesium structures are almost always painted fully between structure interfaces.
A low resistivity requirement applies to magnesium parts that provide electrical grounding of equipment connected to the electrical system. For example, a Cr(VI) conversion coating is typically used on the machined areas of magnesium sleeve seats, and this coating is conductive.

3.2.1.9 Technical feasibility criterion 6: Temperature resistance

Conversion coating films have to withstand the in-service temperature envelopes relevant for the aerospace and defence products, which ranges between -55 °C and over 200 °C, depending on the environment and substrate material.

3.2.1.10 Technical feasibility criterion 7: Pre-treatment and post-treatment compatibility

Conversion coating must be viewed as part of an overall treatment 'system'. The performance of chemical conversion coating is highly dependent upon the performance of and interaction with a pre- or subsequent 'uses' for example deoxidising, pickling/etching in a pre-treatment step or application of a primer in a subsequent step. As such, it is possible that changes to any of these other steps in the overall treatment system will need to be implemented in the manufacturing process to accommodate a non-Cr(VI) alternative for the 'use' conversion coating.

Potential test candidate substances to Cr(VI) for conversion coating must remain compatible with relevant pre-treatments, or pre-treatments may also need to be modified for compatibility with the non-Cr(VI) proposed candidate. While it may be possible to get a Cr(VI)-free conversion coating treatment to work with an existing or modified Cr(VI) pre-treatment, the overall objective is to remove Cr(VI) from the entire process. This is a much higher technical challenge.

Conversion coating is frequently used as a touch-up for other surface treatments (not just conversion coating) and its compatibility for these situations needs to be maintained when considering test candidates to replace Cr(VI).

3.3 Efforts made to identify alternatives

3.3.1 Research and Development

3.3.1.1 Past Research

As noted by Naden, 2019, "*hexavalent chromium remains the benchmark for corrosion inhibition, providing protection over a wide pH range and electrolyte concentration*". Chromates are both anodic and cathodic inhibitors, restricting the rate of metal dissolution whilst simultaneously reducing the rate of reduction reactions. The author recognised that, during corrosive attack a "self-healing" character to the coating is imparted by hexavalent chromium. Self-healing occurs via the reduction of Cr(VI) in the coating to an insoluble Cr(III) compound. Excellent anti-corrosive properties are offered by chromate-based compounds and their use has been extensive in environmental degradation protection.

With regard to the replacement of chromates, despite the fact that the aerospace sector is widely seen as the instigator of technology change in multiple essential engineering disciplines (including the use of new metals, composites and plastics) (Royal Academy of Engineering, 2014) there has been a lack of viable chromates substitutes that promise engineering quality whilst also ensuring user safety; this is despite extensive research into alternative corrosion inhibitors which has been underway since the 1980s (Naden, 2019).

The significant nature of substitution efforts in the aerospace sector is also noted by (Hughes *et al.*, 2016), who highlights the substantial effort that has been made to develop a suitable alternative to the chromated chemical conversion coatings, which have a robust performance in processing, corrosion protection and adhesion performance.

As highlighted throughout this AoA-SEA, the substitution of chromates in the aerospace and defence sector is met by particularly strong challenges. (Rowbotham and Fielding, 2016) highlight the nature of such challenges, noting that there are an estimated three million components in each of the 20,000+ aircraft currently flying. The demanding nature of applications in the aerospace sector, and potentially serious consequences if just one of these should fail, means that great care is being taken to develop and qualify chromate alternatives.

To further highlight the significant efforts being made by the aerospace and defence sector to substitute chromates, a range of recent and ongoing 'R&D collaborations' are identified below. It is noted that many of these collaborations were mentioned within parent AfAs associated with the ADCR consortium combined AoA/SEAs, including AfAs developed by the Global Chromates Consortium for Aerospace (GCCA), Chromium trioxide Authorisation Consortium (CTAC) and Chromium VI Compounds for Surface Treatment (CCST). However, efforts have also been made to expand upon the recognised collaborations, as well as to identify and describe additional relevant collaborations.

A short summary of the global collaborations relevant to chemical conversion coating is provided below.

Please note that for many projects only limited information is publicly available due in part to issues of intellectual property and potentially patentable technologies.
Relevant collaborations/projects include:

- Multiple sub-projects under the **Highly Innovative Technology Enablers for Aerospace (HITEA)** project with partners including Innovate UK (part of UK Research and Innovation) and the Engineering and Physical Sciences Research Council (EPSRC). HITEA was initiated in 2012, with phase one ending in 2015 and two subsequent phases running. Amongst others, the first and third HITEA projects considered alternatives to conversion coating;

  International Aerospace Environmental Group (IAEG) Replacement Technologies Working Group (WG2) provides a global framework for aerospace and defence manufacturers to collaborate on widely applicable, non-competitive alternative technologies. Interlaboratory comparison testing (across several companies) of chromated conversion coating alternatives is an ongoing project in this group. Additionally, interested member companies have worked on information exchange/survey projects on Anodise seal, Functional Chrome Plate, and Corrosion inhibiting primers

- **Advanced Surface Engineering Technologies for a Sustainable Defense (ASETSDefense)** consists of SERDP (Strategic Environmental Research and Development Program) and ESTCP (Environmental Security Technology Certification Program) and is a US Department of Defense initiative. ASETSDefense aim to provide information on environmentally friendly surface engineering technologies, including chromate free alternatives. ASETSDefense's mandate is to be a promulgator/aggregator of research and although participants are engaged in active research, the primary goal and benefit of the ASETSDefense database is that it will not make a claim without a written report summarizing the experimental data. Cr(VI)-free test candidates to Cr(VI) conversion coating that have been reported on include trivalent chromium, molybdenum-based compounds, rare earths and adhesion promoters, sol-gels, and silanes;

- **The Aerospace Chrome Elimination Team (ACE)** were established in the US in 1988, with members including all major A&D OEMs and US Department of Defence divisions While this team does not conduct joint projects, members meet regularly to report on their progress/difficulties on common aerospace and defence chromate uses such as chemical conversion coating.

- **Scientific Understanding of Non-chromated Corrosion Inhibitors Function:** Collaboration between the United Technologies Research Center (UTRC) and Department of Defence Strategic Environmental Research and Development Program (SERDP), running between 2008 and 2012. A trivalent chromium process (TCP) Cr(III) as an alternative to conversion coating (on aluminium alloys) was assessed;

- **The Clean Sky Joint Technology Initiative** was launched in 2008 as a collaboration between the European Aerospace and Defence Industry and the European Commission. The project was established beforehand by industry members in 2006. Since the launch of Clean Sky, two Clean Sky Joint Undertakings have taken place, known as Clean Sky 1 and Clean Sky 2. Since December 2021, Clean Aviation began, running alongside Clean Sky 2 which will end in 2024 (Clean Aviation, 2022). Under the Clean Sky initiative, projects assessing conversion coating alternatives have included 'MAGNOLYA' and 'ALMAGIC';

- **Hexavalent Chrome Free Coatings for Electronics Applications**: reports a NASA based consortium as operating from 2010 to 2015. Within the project trivalent chromium passivation proprietary mixtures Metalast TCP and SurTec 650 were evaluated as alternatives for the use conversion coating alternatives on the alloys 5052-H32 and 6061-T6;

- **U.S. National Centre for Manufacturing Sciences (NSMS)** consortia: United Technologies Corporation has participated in two industrial consortiums with NCMS in 1995 and 2002 as reported in GCCA 0096-01 analysis of alternatives. In 2002, "Recent Alternatives to Chromate for Aluminium Conversion Coating" was published, noting contributions from UTRC, Raytheon, CCAD (Corpus Christi Army Dept), NAVAIR, Pratt & Whitney, and Hamilton Sundstrand. The study concluded that the chromate free alternatives tested were unsuitable for universal substitution across all existing applications of chromates. Specific applications were stated to require specific alternatives that must be tested for each application, there was not a 'one size fits all' alternative (National Center for Manufacturing Sciences, 2002); and

- **Noblis Cadmium and Hexavalent Chromium Alternatives 5-Year Strategy and Roadmap**: Noblis is a not-for-profit independent organisation, based in Virginia USA. In May 2016 it published the review "Cadmium and Hexavalent Chromium Alternatives 5-Year Strategy and Roadmap" summarising the current status of research and implementation of Cr(VI) alternatives, primarily in US DoD applications. The review was commissioned by the Strategic Environmental Research and Development Program (SERDP) and Environmental Security

Technology Certification Program (ESTCP) supporting the US Department of Defense (DoD), Environmental Protection Agency (EPA) and Department of Energy (DoE). Multiple potential conversion coating alternatives were considered within the scope of this strategy and roadmap.

- **Project NAPOLET** Replacement of surface anticorrosive materials used in aerospace with more environmentally friendly technologies, reference number FW01010017. This project is within the TREND Programme. Conversion coatings is captured with sub-project reference WP4 investigating the use of Cr(III) plus zirconium, and titanium-based conversion coatings[28]**;**

- **TREND programme.** The TREND programme supports industrial research and development projects financed from the state budget by the Technology Agency of the Czech Republic and Ministry of Industry and Trade under 'CzechInvest'. Projects encompass advanced production technologies, advanced materials, nanotechnology, industrial biotechnology), digital technologies (micro & nanoelectronics, photonics, artificial intelligence), and cyber technologies (security, connectivity) (*TREND Programme - Research & Development in the Czech Republic*, no date)

3.3.2 Consultations with customers and suppliers of alternatives

Details on consultation activities associated with the development of this AoA-SEA are provided in Section 2.4.

3.3.3 Data Searches

3.3.3.1 High level patent review

A patent search was performed with the aim to identify patents related to conversion coating. The search was performed using Espacenet, the European Patent Office (EPO) open access search portal. Espacenet contains over 120 million patent documents held by patent offices around the world, including North America and Asia (EPO, 2020). Using Espacenet, a search for "Conversion coating" returned more than 650,000 results.

Modifying the search to "conversion coating non-chromate" and applying classification filters C23[29] and C23C2 returned 348 results. Further modifying the search to limit the publication date to post 1st January 2000 returned 273 results. At this point the decision was taken not to introduce additional search terms to restrict the list further, due to the possibility of missing potentially relevant patents. From the long list of 273 patents, the abstracts and broad types of chemistries were extracted into an Excel spreadsheet, from which a final list of 159 patents were identified as broadly relevant. The following table summarises the broad types of chemistries identified in the patent search, with the approximate number of patents in each broad group identified in brackets, suggesting the types of chemistries that have undergone the most research.

As with all patents, they introduce concepts and developments that may be advantageous within a given field in the fulness of time. However, it should be remembered that patents are granted for

[28] ADCR member

[29] C23: Coating metallic material; coating material with metallic material; chemical surface treatment; diffusion treatment of metallic material; coating by vacuum evaporation, by sputtering, by ion implantation or by chemical vapour deposition, in general; inhibiting corrosion of metallic material or incrustation in general

their novelty. Novelty does not necessarily translate to feasibility or applicability. Patented technologies are still bound to the requirements of the substitution process which will determine if a novel concept can be transformed into a feasible test candidate. Patents can also introduce limitations on the availability of a particular technology for example through the requirements for licencing. Where this is the case, a third party may obtain access to the technology if a licensing or some other commercial arrangement is available and meets the requirements of both parties.

Table 3-4: Broad types of chemistries identified in patent search		
Cr(III)-based systems (13)	Ferrate(VI) (2)	Niobium oxide (2)
Phosphate/phosphoric acid (6)	Organic (3)	Permanganate-containing (3)
Resin-based systems with a variety of additives (27)	Polymer or PVA (3)	Vanadium-containing systems (7)
Silane, silica, or sol-gel as a major component (26)	Physical vapour deposition using Ni/Cr	Zirconium and titanium-based systems (24)
Magnesium nitrate-based system (1)	Azole-containing systems (4)	Layers of poly(dimethyldiallylammonium chloride) and montmorillonite clay (1)
Molybdates (2)	Electrophoretically deposited coating (1)	Amine-containing (2)
Fluoroacid-containing systems (4)	Zirconium-based systems (7)	Other (21)
Note: Chemistries listed in the same column does not imply a link between them.		

3.3.3.2 High-level literature review

A review of scientific journal articles was carried out using Science Direct[30]. The purpose of this search was to identify any alternatives to chemical conversion coating that have been investigated in the academic field and was intended to augment the patent search. It is acknowledged that technical requirements for conversion coating in another sector may not be relevant within A&D, this non-exhaustive review demonstrates any potential sources of cross-fertilisation from other industries or academic research. This exercise is an example of initial screening for candidates from industry and academia.

The search strategy and its evolution are summarised below.

Table 3-5: Search strategy for chemical conversion coating in Science Direct			
Search terms in field "Title, abstract or keyword"	**Hits**	**Review articles**	**Open access**
Conversion coating	4,706	92	169
"Conversion coating"	930	13	30
Conversion coating non-chromate	41		1
Conversion coating AND chromate	282		4
Conversion coating AND (non-chromate OR "chromate-free" OR "chromate free")	55		1
Notes: Underlined numbers represent those articles that were analysed in detail "Open access" documents are ones with unrestricted access, that are available in full without payment of a licence fee			

[30] https://www.sciencedirect.com/, a search tool for scientific publications

A brief summary of the papers identified in the above search are summarised in this section. Because the type of alloy was not included in the search terms (i.e., it was not restricted to a particular type of alloy), several of the identified articles are by coincidence focussed on magnesium alloys and these have been discussed separately in the section "*Research on magnesium substrates*" below. Similarly, no papers discussing titanium alloys were identified using the search terms discussed above.

(Gharbi *et al.*, 2018) in the study 'Chromate replacement: what does the future hold?', provided a critical review of conversion coating and primer systems and their potential as alternatives to chromium technology (see following table).

Table 3-6: Summary of primer and conversion coating systems and their viability as alternatives to chromium technology according to Gharbi et al (2018)

Coating	Substrate	Characteristics	Viability
Trivalent chromium	AA2024-T3 Zinc	Good barrier properties provided by the coprecipitation of chromium hydroxide and hydrated zirconia in TCC3	The presence of Cr(VI) is still required to obtain self-healing properties Several studies demonstrated the presence of Cr(VI) within the conversion coating Suspected to be carcinogenic
RE-based (Ce or La)	AA2024-T3 Galvanized steel	Mainly works as cathodic inhibitors, precipitation of Ce-oxide on cathodic sites, induced by the local pH increase	Vulnerability of RE market as mainly dominated by Chinese production Only minor improvement in pitting potential and corrosion current was noted
Vanadate-based	AA2024-T3 zinc carbon steel6	Adsorption of inhibitor on cathodic sites (intermetallic particles in the case of AA2024-T3) and stabilization of passive film. Inhibition of oxygen reduction reaction	Do not meet environmental and health restrictions as Vanadium and its compounds were proven to be carcinogenic
Li-containing (Conversion coatings and primers)	Only tested on AA2024-T3	Barrier and self-healing properties noted in the Li containing primer Local pH increase induced by the presence of carbonate species triggers the precipitation of an Al-Li-based hydroxide	Based on the results presented by Visser et al. only 1.09 g/m2 of Li2CO3 is needed for good inhibition. According to Henckens et al. the predicted price of Li2CO3 should not exceed USD$22 by 2100;126 thereby rending Li2CO3 alternative cost effective (AUD$ 0.03/m2) relative to SrCrO4 primers (see note a)
Organic (including epoxy, sol-gel, polyurethane, silane and nanocomposites)	Al alloys galvanized steel	Good barrier properties provided by both systems Nanocomposites: higher density of inhibitor can be loaded into the system	Organic: effective inhibitor is still needed to achieve good corrosion resistance (see note b) Nanocomposites: cost towards implementation could be too important
Phosphate-based	Steel carbon steel Al alloys zinc	Good barrier properties provided by the precipitation of metal-phosphate compounds	pH stability of phosphate-based coatings inferior to chromium oxide No self-healing properties
Mg-rich primers	AA2024-T3	Act as sacrificial anode and maintain the substrate below its pitting potential	Additional topcoat is needed to ensure durability of the coating (see note c)

Table 3-6: Summary of primer and conversion coating systems and their viability as alternatives to chromium technology according to Gharbi et al (2018)			
Coating	**Substrate**	**Characteristics**	**Viability**
			Cannot be used on Mg alloys or galvanized steel
Notes: a – Lithium salts are proposed to be classified as reprotoxic b - Organic coatings usually feature thickness > 5 µm in order to form a continuous film. Hence, layer thickness might be an issue here c - Mg-rich primers feature thicknesses > 50 µm in order to completely embed the Mg particles. Hence, layer thickness might be an issue here Source: (Gharbi et al., 2018), notes a-c provided by ADCR members			

Rare earth conversion coatings e.g., cerium

The papers summarised in this section predominantly discuss aluminium alloys, with some discussion of magnesium alloys.

Literature review suggests that rare earth conversion coatings are attractive as an environmentally friendly alternative to Cr(VI) conversion coatings that can provide excellent corrosion resistance, as well as modest price, acceptable eco-friendliness, , and synergism and compatibility with inorganic and organic co-additives. The majority of rare earth-based conversion coatings that have been extensively investigated for aluminium and magnesium alloys are cerium-based (Saji, 2019). In recent years, researchers have reported that introduction of cerium species in coatings can offer the important self-healing property to the coating system, which improves the corrosion resistance for long term exposure in salt solution (Jiang, Guo and Jiang, 2016a).

Cerium-based conversion coatings can be applied with spontaneous spray or immersion processes as well as an electrolytic process. As reported by O'Keefe *et al* in 2007 they were able to meet military standards by providing corrosion protection for aluminium alloys for up to 14 days in ASTM B117 salt spray (a test method and quality control specification). The performance is a function of the parameters used in the deposition, but the process is reproducible and robust (O'Keefe, Geng and Joshi, 2007). However, a subsequent study published by some of the same authors[31] showed that the cerium-based process did not perform well during corrosion testing. These coatings have not been commercialized or successfully demonstrated in the twelve years since the final SERDP report was published.

A process for surface modification of aluminium-based materials was described which involves immersion in boiling $Ce(NO_3)_3$ and $CeCl_3$ followed by anodic polarization in a deaerated molybdate solution (Mansfeld, Wang and Shih, 1992). Aluminium alloy 6061-T6 treated in this manner did not show any signs of corrosion after immersion for 60 days in 0.5 N NaCl, and a sample with a scratch in the modified surface did not show any corrosion after 25 days in NaCl. The authors concluded that given the corrosion resistance results, this process should be considered as a candidate for the replacement of Cr(VI) conversion coatings.

A chrome-free samarium-based conversion coating on magnesium alloy was investigated, revealing a crack-mud morphology. Electrochemical measurements showed that it could improve the corrosion resistance of magnesium alloys (Hou *et al.*, 2013). The influence of cerium nitrate in vanadate

[31] Corrosion Finishing/Coating Systems For DoD Metallic Substrates Based on Non-Chromate Inhibitors and UV Curable, Zero VOC Materials, SERDP Project WP-1519 (2010)

solutions on the properties of Ce–V conversion coatings on magnesium alloy AZ31 revealed a self-healing effect of the Ce–V conversion coating, which was provided by the release and migration of vanadium compounds (Jiang, Guo and Jiang, 2016b)

A review by Bethencourt *et al* concluded that lanthanide compounds fulfil the low toxicity and protective capacity requirements for consideration as components of more environmentally-friendly formulations for aluminium alloys, but that further research efforts were necessary to develop feasible treatments for industry (Bethencourt *et al.*, 1998)

Silane and sol-gel

The papers resulting from the literature review summarised in this section predominantly discuss aluminium alloys, with some discussion of magnesium alloys.

A study by Nezamdoust *et al* reported two novel sol–gel/conversion coating composites deposited on AM60B magnesium alloy to provide sufficient corrosion protection. The first composite (Ti–Zr/hybrid) was obtained via combination of a hybrid sol–gel film (synthesized by mixing tetraethoxysilane (TEOS), and 3-glycidyloxypropyl-trimethoxysilane (GPTMS)) as outer layer and Ti–Zr conversion coating as primer. The second composite (Ti–Zr/PTMS) was applied in a similar manner by combination of phenyl-trimethoxysilane (PTMS) sol–gel film with a Ti–Zr conversion coating. The Ti–Zr conversion coating pre-treatment was required to achieve uniform and defect-free deposits (Nezamdoust, Seifzadeh and Rajabalizadeh, 2019).

A silane 3-mercapto-propyl-trimethoxysilane (PropS-SH) formed a porous conversion coating on magnesium alloy, which allowed a rapid electrolyte uptake. $Ce(NO_3)_3$ addition to the pre-treatment bath improved the coating performance, and Ce^{3+} ions provided a self-healing feature to the coating (Zanotto *et al.*, 2011).

Sol-gel is used as a post-treatment to improve the corrosion resistance provided by Plasma electrolytic oxidation (PEO) conversion coatings on magnesium (Yeganeh and Mohammadi, 2018).

"Super-primers", primers for metals with the conversion coating built in, are discussed by Seth *et al*. They have a high concentration of organofunctional silanes, with excellent adhesion to the substrate and to overcoats. The corrosion resistance can further be improved by adding corrosion-inhibiting pigments such as micronized zinc phosphate. It was shown that 2000h of salt spray resistance was obtained on AA2024-T3 and HDG steel (Seth *et al.*, 2007).

A chromate-free approach to protective hybrid coatings on aluminium alloy AA2024-T3 using photoinduced sol–gel and cationic polymerizations has been described. Beginning with a film of n-alkyltrimethoxysilane and diepoxy monomer, photogenerated superacids[3] induce the single step formation of two inorganic and organic barrier networks. This technique avoids chemical conversion coating and some films have passed 2000h of salt spray testing (Ni *et al.*, 2014)

Plasma electrolytic oxidation (PEO)

Plasma electrolytic oxidation (PEO) is a type of anodising which uses much higher electrical potentials resulting in localised generation of plasma which modifies the surface. PEO can provide strong adhesion of organic coatings, but the pores and microcracks in the coating structure reduce its provision of corrosion resistance to the substrate. PEO coatings have been used for the surface preparation of top layers such as organic coatings, sol–gel and silane layers, conversion coatings, electrophoretic and electroplating coatings (Toorani and Aliofkhazraei, 2019)

Other

The following examples have been investigated as proposed or test candidates in the scientific literature. These examples have not been shortlisted for further research by members, and some are not available at scale for industrial uses.

A novel hybrid conversion coating derived from water extracts of *hibiscus sabdariffa calyx* in conjunction with ammonium molybdate was shown by potentiodynamic measurements to provide more corrosion resistance on 6061 aluminium alloy than both chromate and molybdate conversion coatings (Oki *et al.*, 2020).
Other alternatives to Cr(VI) conversion coatings that have been identified include electro-active polymer coatings (Zarras and Stenger-Smith, 2014), hydrotalcite conversion coatings (Leggat, Taylor and Taylor, 2002), cobalt conversion coating with cerium (Grolig, Froitzheim and Svensson, 2015), copper-iron conversion coating (Grolig *et al.*, 2015), and a titanium/zirconium salts and aminotrimethylene phosphonic acid (ATMP) with an epoxy primer coated on top (Liu *et al.*, 2018).

Research on magnesium substrates

The literature search using the search terms discussed above in Section 3.3.3.2 (Table 3-5) revealed a number of papers that focussed on magnesium substrates. A number of corrosion prevention strategies have been considered for magnesium and its alloys including methods such as surface modifications (ion implantation, laser annealing etc.) and protective films and coatings such as electroplating, chemical conversion coatings, electrochemical conversion coatings, vapor phase coatings, polymer coatings, physical vapor deposition, electroless plating, plasma electrolytic oxidation (PEO), chemical conversion treatments, sol–gel coatings, calcium phosphate coatings, hydroxyapatite coatings, and polymer coatings (Saji, 2019), (Yeganeh and Mohammadi, 2018). The main alternatives to Cr(VI)-based conversion coatings used on magnesium alloys are Cr(III), phosphates, permanganates, molybdates, and rare earth-based systems (Saji, 2019).

Several studies of environmentally friendly chemical conversion film treatments have been focused on magnesium alloys. These include phytic acid conversion film, oxalate films, cerium conversion films, stannate conversion films, silane films, phosphate films and Cr(III), phosphate-permanganate, hydrotalcite, rare earth, vanadium, zirconium, and titanate conversion coatings (Cui *et al.*, 2012), (Liao *et al.*, 2020), (Pommiers *et al.*, 2014). Liao *et al* report that the corrosion resistance provided by chromate-free phosphate, stannate, phosphate-permanganate, hydrotalcite, rare earth, vanadium, zirconium, titanate and phytic acid conversion coatings is still significantly inferior to that of CR(VI) conversion coatings. Unlike the excellent self-healing property of Cr(VI) conversion coatings, the ubiquitous cracks within Chromate Free Conversion Coating (CFCCs) act as pathways for Cl− penetration, leading to a serious localized corrosion on the Mg substrate (Liao *et al.*, 2020). Zirconate combined with trivalent chromium which gained prominence from the 1990s till the present day have been found to contain hexavalent chromium species (Oki et al., 2020). Permanganate/phosphate-based coating provides a corrosion resistance equivalent to CCC, and Rare Earth Elements (REEs) have self-healing properties, but no coating presents all the properties of CCCs and the development of new non-toxic conversion coatings remains a priority (Pommiers *et al.*, 2014).

Phosphate

Phosphate films are widely applied because they provide good corrosion resistance and contact between paint and metal surface. However, the conventional phosphate solutions contain many hazardous substances such as fluorides, nitrites and heavy metal elements (Cui *et al.*, 2012).

Say *et al* discuss a chemical conversion treatment on AZ80 magnesium alloy using a phosphate and hydrofluoric acid coating, followed by anodising (Say, Chen and Hsieh, 2008).

A chromium-free conversion coating using a phosphate–permanganate solution applied to AZ91D magnesium alloy was developed. Corrosion resistance matched that of the traditional chromate conversion method, and corrosion resistance after painting out-performed the chromate method (Zhao *et al.*, 2006).

Phosphate-permanganate conversion coating on as-cast AZ91D magnesium alloys show that the corrosion protection is due to the presence of stable manganese oxides in basic pH. Phosphoric and soda pickling associated with phosphate–permanganate conversion treatment are ecologically efficient alternatives to fluoride-based pickling and the chromating treatment (Rocca, Juers and Steinmetz, 2010).

3.3.4 Shortlist of alternatives

Potential test candidates for alternatives to Cr(VI) in conversion coatings are shown below. This list comprises all the alternatives that were reported in the parent AfAs, and others that have been investigated by members. Note that only a small sub-set of these test candidates have been the focus of research and progression by the members, based on an assessment of their technical feasibility and potential to be viable alternatives to Cr(VI), and these have been identified accordingly in the following list.

Test candidates that have been the subject of a greater amount of focus and progression by the ADCR members are:

- Acidic (sulphuric, tartaric/sulphuric, and phosphoric) anodising + organic coating;
- Cr(III) based surface treatments (TCP, Trivalent Chromium Process); and
- Silane/Siloxane and Sol-gel coating.

Test candidates that are also discussed in this section that are either considered in general to be less promising or not viable, or have not been a key development focus by the members or have not been further investigated since the parent Applications are:

- Molybdates- and Molybdenum-based processes (MoCC);
- Plasma electrolytic oxidation (PEO anodising) for magnesium substrates;
- Organometallics (zirconium and titanium- based products);
- Benzotriazoles-based processes, e.g. 5-methyl-1H-benzotriazol;
- Manganese-based processes;
- Magnesium rich primers;
- Electrolytic paint technology; and
- Chromate-free etch primers.

These are discussed in more detail from Section 3.5.

3.3.5 Performance requirements and testing

Performance of test candidates needs to be equal to or better than the incumbent Cr(VI) treatment and this is driven by safety and performance requirements.

It should be noted that members' experience has shown that there can be difficulty in transferring good laboratory test results to an industrial environment. Decades of experience with Cr(VI) has contributed to the design and development of testing methods and protocols by the industry. Nevertheless, it is impossible to exactly reproduce in the laboratory environment the conditions that hardware will experience in its operating environment over its lifetime, or to correlate an accelerated test to actual in-service behaviour. The laboratory tests have been designed to give the best and most realistic information possible, but because of these unavoidable limitations it is necessary, as a minimum, to ensure that results in the laboratory of test candidates are at least as good as Cr(VI). Additionally, service life of equipment can be extended beyond its designed service life, requiring a high amount of effort and approval from stakeholders. This increases the importance that test candidates' performance needs to be at least as good as Cr(VI).

There are different application methods for conversion coating. Dip/immersion is carried out in baths/tanks. For maintenance/repair/touch-up, application methods are pen, brush, swab, and wipe. The different application methods need to work together, and Cr(VI)-free test candidates need to work for all of these application methods.

The functionalities required of conversion coatings are:

- Corrosion resistance;
- Active corrosion inhibition;
- Adhesion to subsequent layer;
- Chemical resistance;
- Temperature resistance;
- Layer thickness; and
- Electrical resistivity.

Corrosion resistance also applies to the provision of temporary corrosion resistance during manufacturing stages.

Note that not all of these functionalities are relevant to all substrates for conversion coating, and this distinction is discussed further in Section 3.2.1 above.

Critical to quality tests that are carried out to assess performance of the alternatives in the laboratory environment include corrosion resistance (salt spray test chamber), coating weight test/analysis, electrical contact resistance (possibly after thermal cycle is applied to simulate the conditions of the actual parts in the field), and wet/dry paint adhesion.

Corrosion resistance is assessed in a neutral salt spray chamber. ASTM B117, ISO 9227, and ISO7253 are examples of test method specifications against which corrosion is assessed. MIL-DTL-81706 and MIL-DTL-5541 are examples of quality control specifications for aluminium conversion coatings. AMS 2475 is a quality control specification for conversion coating of magnesium.

For these quality control specifications, a minimum of 168 hours must be achieved in the salt spray chamber with acceptably low appearance of pitting or corrosion in the test samples as a minimum requirement at the laboratory testing scale and members use more stringent internal performance requirements when validating test candidates. The 168 hours timeframe was instituted as a *quality control measure of the production process*, not as a life or performance test of the treated part. Conversion coating processes that are running outside of statistical process control limits, i.e. that are not running within acceptable process variance, will produce treated parts that will likely show corrosion by 168 hours, so such batches can be screened out.

In addition, passing tests on coupons/panels at the laboratory scale does not mean that the alternative will perform as intended when applied to a component and tested in its operating environment. Failures at this testing stage can still occur.
Adhesion is measured according to for example ISO 2409:2013 GT0 dry, GT1[32] wet after 336 hours water immersion. This specifies a test method for assessing the resistance of paint coatings to separation from substrates when a right-angle lattice pattern is cut into the coating, penetrating through to the substrate.

Resistivity is measured according to MIL-STD-5541 which requires ≤ 5 mΩ-in² for aluminium substrates as applied and ≤ 10 mΩ-in² after exposure to neutral salt fog for 168 hours. Resistivity is measured when clamped between copper anvils under a specified load. Resistivity/conductivity are also needed for magnesium parts.

Examples of standards used in the evaluation of the above technical feasibility criteria are provided in Annex 1. Test methods and requirements contained therein do not define success criteria for alternatives validation.

The ability to visually determine that the conversion coating has been appropriately and uniformly applied (inspectability) is also an important factor in the manufacturing and quality control process. This is important for bath/immersion treatment, but particularly important for manual application/touch-up for treatment of a component that has been damaged. Cr(VI) conversion coatings are coloured but many test candidates are not easily visible and this is a significant impediment to their adoption. This is challenging to overcome. For example, in trialogue discussions with the GCCA consortium, SEAC asked whether X-ray based methods could be used in place of visual inspection. GCCA responded that X-ray photoelectron spectroscopy (XPS) and X-ray fluorescence (XRF) are not suitable. For example, XPS has too small a field of view and is impractical due to size of the equipment, whilst XRF cannot distinguish between chromium in the coating and chromium in the base alloy, amongst other issues. GCCA also responded that some work based on the inclusion of inorganic colorants has been done to improve residual colour, however this impaired the coating adhesion performance.

3.4 Progression reported by ADCR members

3.4.1 Introduction

To achieve certification or approval by the relevant authority and/or design owner, each component must meet the required performance and safety requirements provided by the incumbent Cr(VI) based treatment. A complete suite of tests should include evaluation of all alloys subject to conversion coating, thereby highlighting impacts on niche alloys to be addressed prior to adoption of the test candidate.

Approval of the test candidate must include a complete understanding of the influence of the adjacent treatments to conversion coating within the process flow. This is to understand the influence of all processes representing the surface treatment 'system' including pre-treatments and post-treatments. Evaluation of the technical feasibility of the test candidate for conversion coating should consider its behaviour in contact with different alloy substrates, as well as in combination with other supporting

[32] GT0 and GT1 are classifications of the cross-cut test for adhesion. GT0 is achieved if none of the squares of the cross-cut lattice are detached; GT1 is achieved if up to 5% of the cross-cut area is detached.

treatments within the 'system'. Any change in these system variables may lead to irregular or unacceptable performance of the test candidate delivering conversion coating, and consequently impact or delay approval of the test candidate for different component designs. This scenario is a leading reason for the graduated implementation of test candidates in combination with different component/design families. Different designs exhibiting varying degrees of complexity have the potential to interact with elements of the treatment system differently and thus effect the performance of the test candidate.

Progression of the test candidates is assessed against the following criteria:

- Technical feasibility/Technical Readiness;
- Economic feasibility;
- Health and safety considerations;
- Availability; and
- Suitability.

3.4.1.1 Suitability of a test candidate

When assessing the suitability of a test candidate reference is made to the European Commission note dated 27 May 2020 which clearly defines the criteria by which a test candidate may be judged as suitable[33]. In order to be considered as suitable in the European Union (EU) the alternative should demonstrate the following:

- Risk reduction: the test candidate should be safer;
- The test candidate should not be theoretical or only available in the laboratory or conditions that are of an exceptional nature;
- Technically and economically feasible in the EU;
- Available in sufficient quantities, for substances, or feasible as an alternative technology, and in light of the "legal" and factual requirements of placing them on the market; and
- Feasibility for the applicant: Are alternatives established during the authorisation procedure technically and economically feasible for the applicant?

To be available, a test candidate should meet the regulatory requirements of placing it on the market. Until the technical feasibility criteria and associated performance requirements of the use and wider treatment system are fulfilled, including all certification obligations as stipulated in the Airworthiness Directives[34], the test candidate cannot be deemed 'available'.

All civil aircraft operating in the EU are subject to Airworthiness Directives issued by the EASA on behalf of the EU and its Member States, and European third countries participating in the activities of EASA. Changes to design of a product are subject to certification (EU, 2018), and can only be made following approval from the Regulator and compliance with the requirements of the appropriate Airworthiness

[33] EC (2020): Available at https://echa.europa.eu/documents/10162/13637/ec_note_suitable_alternative_in_general.pdf/5d0f551b-92b5-3157-8fdf-f2507cf071c1 accessed 25 August 2022

[34] EASA (2022), available at Airworthiness Directives - Safety Publications | EASA (europa.eu) accessed 18 October 2022

Regulation, such as (EU) 2018/1139[35]. To reinforce this point, a civil aircraft's Certificate of Airworthiness is not valid until the Type Certificate has been approved by the Regulator (EASA, 2012) Defence equipment is subject to standalone change protocols including approval by the relevant Member State Ministries of Defence. Therefore, a test candidate not deemed available from a regulatory standpoint would not meet all required criteria within the above definition of 'suitable'.

3.4.2 Status reported in original applications

The following sections discuss the progress of the development of test candidates by the ADCR members for use in conversion coating. For context, a short summary of the status reported in the parent Applications[36] in 2015-16 is presented for each of the test candidates, followed by a description of progress by the ADCR members to date.

3.4.3 Conclusions on suitability of shortlisted alternatives

As discussed in Section 3.4.4, a number of test candidates are considered more promising based on the current level of development and progress achieved in substitution plans, these are:

- Cr(III) based surface treatments (TCP, Trivalent Chromium Process);
- Acidic (sulphuric, tartaric/sulphuric, and phosphoric) anodising + organic coating;
- Plasma electrolytic oxidation (PEO anodising) for magnesium substrates; and
- Silane/Siloxane and Sol-gel coating.

Some of these test candidates are in use by some ADCR members for some components on some alloys, however significant technical challenges remain before any of these test candidates can be used in all situations. The main limiting factors are failure to meet technical performance requirements, the specifics of which are discussed in detail in the following sections.

Consequently, none of these test candidates can be considered a generally available and suitable alternative to all applications of Cr(VI)-based conversion coating.

3.5 Cr(III)-based treatments

3.5.1 Status reported in original Applications in 2015-16

This sub-section summarises the development status of candidate alternatives to Cr(VI) for conversion coating *that were reported in the parent Applications in 2015-16*. This is to provide context to the progress that is reported by members in this combined AoA/SEA (see subsequent Section 3.5.2).

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[35] REGULATION (EU) 2018/ 1139 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL - of 4 July 2018 - on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency, and amending Regulations (EC) No 2111 / 2005, (EC) No 1008 / 2008, (EU) No 996 / 2010, (EU) No 376 / 2014 and Directives 2014/ 30/ EU and 2014/ 53/ EU of the European Parliament and of the Council, and repealing Regulations (EC) No 552 / 2004 and (EC) No 216 / 2008 of the European Parliament and of the Council and Council Regulation (EEC) No 3922 / 91 (europa.eu)

[36] CCST consortium. (2015). *Potassium dichromate AoA, use 2 (0044-02)*; CTAC consortium. (2015). *Chromium trioxide AoA, use 4 (0032-04);* GCCA consortium. (2016a). *Chromium trioxide AoA, use 1 (0096-01);* GCCA consortium. (2016b). *Sodium chromate AoA, use 2 (0099-02*

In the parent AfAs, Cr(III)-based alternative treatments were reported as applicable to aluminium and its alloys, and magnesium and its alloys.

Cr(III)-based treatments were considered as the best alternative to conventional Cr(VI)-based conversion coating at the time of the previous applications. It was reported this alternative had been implemented at various aerospace companies on selective aluminium alloys although it was not robust enough to meet the requirements for all alloys, although fatigue and conductivity were acceptable. It was reported corrosion resistance was inferior for most applications with inconsistent adhesion performance, (which also applied to local repair applications), although it had been qualified at some suppliers for some alloys according to MIL-DTL-81706. It was a promising alternative for some applications but overall, it was reported as not yet technically feasible; mostly as the corrosion resistance requirements were not met, but also because there was no active corrosion inhibition. Additionally, unlike Cr(VI) it was reported this alternative may come in a neutral colour making visual inspection difficult (although some coloured formulations were available, e.g., for touch up purposes). In the parent Applications it was reported that one of the main challenges for the reproducibility of Cr(III) based alternatives was to identify and specify the optimum process window, which includes the influence of the pre-treatment steps on layer formation.

For some applications on specific alloys, some companies reported in the previous applications that first implementations may be expected in 2017. Some companies reported that TRL 6 could be reached “within the next years” for specific applications. Note that in the period since the publication of the previous applications, some ADCR companies appear to be closer to TRL 8 and a few have been able to qualify and operationalise this alternative for some uses.

For aluminium alloys 5000 and 6000 series, it was reported in the parent Applications the corrosion resistance was inferior compared to Cr(VI) conversion coating.

It was stated by several companies that for 2000 series alloys (commonly used in the aerospace industry) and for 7000 series alloys, corrosion performance was insufficient for most applications when tested at an industrial scale. Depending on the Cr(III)-based formulation used, first signs of corrosion appeared after 48-100 hours in salt spray tests compared to a comparative reference at 168 hours (ISO 9227 test method). These surface characteristics were dependent on the surface preparation. In addition, Cr(III)-based solutions did not exhibit the same active corrosion inhibiting properties as Cr(VI)-based solutions.

Some aerospace companies stated that their Cr(III)-based solutions were in line with their requirements for various alloys including on the 2000 and 7000 series aluminium under narrow and thoroughly controlled process conditions. Cr(III)-based solutions were reported as qualified according to MIL-DTL-81706[37], meaning that 168 hours in salt spray testing (used for screening purposes only) could be achieved on alloy AA2024, although it was noted that the Cr(III)-based solutions were only applicable under very narrow and controlled process conditions and included Cr(VI)-based pre-treatment. For MIL-DTL-81706, polished specimens are used. This is not representative for the industrial application. In general, results on the corrosion resistance provided by Cr(III)-based conversion coating were inconsistent within the aerospace sector and further R&D and industrial testing was reported to be necessary to obtain reproducible results and high-quality coating.

[37] Note that MIL-DTL-81706 only specifies the coating solution. Even if a coating solution is qualified to MIL-DTL-81706, this does not mean that it is possible to perform a reproducible process

Results from the industry reported at the time demonstrated that the adhesion performance was inconsistent. Depending on the Cr(III)-based formulation used, adhesion promotion to subsequent corrosion resistant paints was not in line with the cross-cut requirement of <GT1 after water immersion. With regard to adhesion of the conversion coating to the substrate, Cr(III) conversion coating was hardly visible on an aluminium surface while Cr(VI) conversion coating was characterized by its yellow colour. This made the control of the adhesion of the conversion coating to the substrate by visual inspection or wipe test very challenging, especially on large surfaces.

Implementation was expected to be after 2030 for structural parts.

3.5.2 Progression reported by ADCR members

3.5.2.1 Introduction

Cr(III) remains the most promising and by far the most investigated test candidate to hexavalent chromate for conversion coating. ADCR members have reported its use for aluminium, magnesium and titanium alloys in aerospace and defence applications, for bath/immersion and touch-up via brush, wipe, or applicator pen.

Multiple types of Cr(III)-based proprietary formulations, incorporating a range of different additives, are available on the market and have been variously investigated by ADCR member companies. Several of these formulations contain Zr(IV), and various other additives are used across the different products. Typically, individual ADCR members have included several of these Cr(III)-based formulations in their testing programme, with these testing programmes still ongoing.

Although these formulations are all based on Cr(III) chemistry, in general these different Cr(III)-based formulations perform differently to each other, even when tested on the same alloy. Each formulation being tested must be assessed on each relevant alloy and part. The same Cr(III) formulation has been seen to behave differently on different alloys, giving different performance results. Results have shown that each Cr(III) formulation may also require different surface preparation and pre-treatment steps (which may be different to the Cr(VI) incumbent), different processing conditions, and may have to be supplemented by an additional post-treatment step (in addition to what is needed for the Cr(VI) process) in order to perform adequately. Compatibility with primers can also be an issue. One of the products is a two-step process requiring two tanks, compared to the Cr(VI) one tank process. A number of the ADCR companies have ruled out some of these Cr(III)-based formulations due to inadequate performance, while continuing to develop others for which they have seen good results. Thus, even within the range of Cr(III)-based chemistries, very different performance results have been seen.

ADCR members have progressed the development of Cr(III)-based alternatives since the parent Applications in 2015-16, and some Cr(III)-based treatments are in use in production for some parts and some alloys. Cr(III)-based alternatives are by no means fully implemented and further significant testing is ongoing which must extend beyond the current review period. Key technical performance issues that remain to be solved are inadequate corrosion protection, inconsistent performance, and suitability for all types of alloys. Barriers to achieve higher TRL levels include the need for acceptance by OEMs or the airlines/Ministries of Defence by demonstration of acceptable performance, lack of vendors to apply the coating, and the necessity to complete the relevant qualification and certification requirements.

3.5.2.2 Technical feasibility of Cr(III)-based alternatives

A number of technical results from the ongoing development of Cr(III)-based alternatives for conversion coating have been reported by ADCR members. These are discussed in the following sections.

Of the relevant performance requirements discussed in Section 3.2.1, corrosion resistance and adhesion promotion were reported by members as key reasons for failure of the Cr(III) coatings.

Corrosion resistance and performance with various grades of alloys

Key failure modes for the Cr(III)-based alternatives are inadequate levels of corrosion protection, and different corrosion performance on different alloys.

Considering the conversion coating step in conjunction with the primer, which together result in the overall corrosion protection package, compatibility issues between the Cr(III) conversion coating and the primer have been reported by members. This results in the overall corrosion performance being compromised.

Achieving robust corrosion protection for bare metals (corrosion sensitive aluminium alloys) in an industrial setting, as well as resolving compatibility with the primer, remains a challenge.
The degree of protection of Cr(III)-based treatments does not have such a close dependence on the thickness of the coating layer deposited onto the substrate compared to Cr(VI).

Ongoing corrosion performance testing has shown that the Cr(III) products generally achieve 168 hours in a neutral salt spray chamber with no observed pitting (a screening test), for selected aluminium alloys in the 5000 and 6000 series (these alloys have higher inherent corrosion resistance), but do not meet these requirements for alloys in the 2000 and 7000 series. This is attributed to the presence of alloying elements such as copper and zinc in these alloys. Inadequate corrosion protection for some alloys means that Cr(III)-based alternatives are not a drop-in replacement for the incumbent Cr(VI)-based treatments. Suppliers typically treat parts from several different customers and for practical reasons it is not always possible to define the precise alloy being treated (this is particularly the case in touch-up/MRO operations). For many companies it is therefore impractical to consider operating both a Cr(VI) and alternative Cr(III) conversion coating line, not only because of restrictions on having additional tanks, but because it would not be practical to ensure the correct parts were being treated with the right process, leading to unacceptable quality control risks. A Cr(III) test candidate is required which provides adequate corrosion protection on all relevant alloys. However, in some cases substitution has begun in product lines where corrosion performance requirements are not as stringent. Targeted applications may be transitioned to tri-chrome processes before others, for example 5000 and 6000 series aluminium alloys first due to higher inherent corrosion resistance of the alloy.

Insufficient corrosion resistance performance provided by the conversion coating has a serious impact that can lead to failure of parts. In the aviation context this can directly lead to the safety of the aircraft being compromised. The severity of this impact is greater for parts that cannot be easily inspected.

Adhesion promotion

Adhesion promotion performance for painted parts measured according to ISO 2409 using cross-cut tests has produced various findings across the ADCR membership. Adhesion to the subsequent layer (paint/primer) has failed to meet the requirements in some cases, even if corrosion resistance and resistivity requirements were achieved. Adhesion appears among other aspects to be related to the crystallinity of surfaces; many Cr(III) alternatives form significantly different crystalline structures compared to the incumbent Cr(VI).

In other cases, the Cr(III) candidates provided good adhesion performance, which was equal to the incumbent Cr(VI) coating.

Insufficient adhesion performance for the conversion coating has serious consequences as it can lead to subsequent protective layers such as primers being damaged or scratched off. These protective layers provide additional corrosion resistance and if they are compromised the resulting exposed area can suffer higher corrosion.

Visibility and detection of coating for quality control

Cr(VI) conversion coatings are an iridescent yellow/golden brown colour and therefore easy to visually detect and distinguish from the bare substrate. This is important for quality control inspection, to ensure the presence and uniformity of the coating. Cr(III) products are not clearly coloured and are similar in appearance to the substrate. There can be significant quality control risks/issues given this difficulty in detecting the Cr(III) coating and detecting damage to the coating, resulting in risk of manufacturing delays and rework. This limitation has prevented the use of Cr(III) for some customers, even where it has met qualification requirements.

Options which may be considered to attempt to address this issue include:

- Adding a dye to the Cr(III) formulation (some dyed treatments are now available, with varied performance);
- Operators inspecting the applied coating against a photographic standard;
- Treating with an agent that causes a colour change (testing would be required to ensure such an agent that is applied to parts meets performance requirements);
- Testing coupons[38] treated with CCC to determine if they are coated (this could be a quality check for immersion, but not for touch-up).

Spot testing is an option but is considered destructive and therefore can only be applied to a small proportion of the production. Other optical or electrical testing options are also being considered.
For all the above potential options, effectiveness, practicality, and impact on the performance of the coating need to be acceptable.

Any potential solutions for detecting the coating that are not based on visible light will present technical or practical limitations and greater difficulty to implement or interpret the results compared to a visible coating.

3.5.2.3 Economic feasibility of Cr(III)-based alternatives

Process considerations

In some cases, additional post-treatment steps are required to provide the required performance. One of the Cr(III)-based treatments for bath/immersion applications requires an additional post

[38] A testing coupon is a small panel of alloy used in performance testing of coatings

treatment step using a polymer film deposition. Another Cr(III)-based treatment requires an additional post treatment step using hydrogen peroxide. For use of these Cr(III)-based treatments, this two-step process therefore needs an additional tank in the plant, which will need to be changed more frequently, leading to knock-on impacts for costs. Monitoring and adjusting the process tanks will take more time, using different and possibly more complicated chemical analysis techniques. The installation of improved tank controllers and process line monitoring will also be needed; this is in addition to the existing controllers and monitoring that are already used with the Cr(VI)-based formulations.

The requirement to use hydrogen peroxide in one of the treatments brings handling and safety concerns which will need to be managed.
There are also differences in temperature requirements in the tanks in the two-step process, one needs to be maintained at a higher temperature than the other. The energy consumption of this alternative process is marginally higher.

Process consistency

Achieving consistent corrosion performance using the Cr(III)-based alternatives has been found to be an issue. When adequate corrosion results can be obtained, it can be difficult to maintain this performance consistently over time. Manufacturing delays, rework, and potential failures in the field can result from an inconsistent process. Process controls to overcome this issue continue to be evaluated and optimized.

Influence of pre-treatment

Performance of the Cr(III)-based treatment is very sensitive to the type of pre-treatment, which may be mechanical, Cr(VI)-based, or Cr(VI)-free. Surface preparation in the pre-treatment step varies according to the application method used for the Cr(III) conversion coating (whether it is dip/immersion or touch-up via pen or applicator).

Considering the overall corrosion protection package of pre-treatment in conjunction with main treatment, Cr(III)-based alternatives are not always a drop-in replacement for the current hexavalent chromate products as each Cr(III)-based conversion coating has unique pre-treatment requirements. This is a particular challenge if the pre-treatments required for Cr(III)-based conversion coating need to be different to the pre-treatments required for anodising (as suppliers tend to use the same pre-treatment baths for Cr(VI)-based conversion coating and anodising processes). In some cases, pre-treatment products used for Cr(VI) conversion coating or anodising can be used as pre-treatments for Cr(III) conversion coating. Surface preparation strongly influences corrosion resistance. Cr(VI)-based conversion coatings can accommodate inconsistent/incomplete cleaning and surface activation on a wide variety of aluminium alloys, and still produce reliable coatings with acceptable performance. This is not the case with Cr(III)-based alternatives.

3.5.2.4 Health and safety considerations related to using Cr(III)-based treatments

As discussed in Section 3.5.2.1, several types of Cr(III)-based proprietary formulations, incorporating a range of different additives, are available. A summary of the key identifiers and hazard properties for Chromium(III) oxide, and the substances identified as additives across the range of Cr(III)-based formulations, is shown below in Table 3-8.

Note that the nature and concentration of substances present varies across different Cr(III)-based formulations. For example, dipotassium hexafluorozirconate (CAS number 16923-95-8) is not present in all Cr(III)-based formulations. For those formulations where it is present, its concentration varies between less than 1% to around 50%, depending on the formulation.

Table 3-7 below summarises the hazard properties of a selection of proprietary Cr(III)-based formulations, derived from the identity and concentration of substances in the formulation, as reported in the relevant safety data sheet. The proprietary formulations include those for dip/immersion and touch-up pen.

Table 3-7: Summary of hazard properties of selected Cr(III)-based proprietary formulations based on SDS data

Proprietary Cr(III)-based formulation	Hazard information including GHS hazard statements
A	GHS signal word – Warning. GHS Hazard Statements - H315 - Cause skin irritation, H319 - Causes serious eye irritation
B	GHS signal word – Warning. GHS Hazard Statements - H315 - Cause skin irritation, H319 - Causes serious eye irritation
C	Not hazardous
D	Skin sensitiser H317; GHS 07 pictogram – Harmful
E	Warning, Eye Irrit. 2A, Causes serious eye irritation. GHS Hazard statements - H319 Causes serious eye irritation
F	Not hazardous
G	GHS 07 pictogram – Harmful, skin corrosion/irritation Cat 3, causes eye irritation Cat 2A
Source: Safety data sheets	

The overall consensus of members is that the use of Cr(III)-based formulations will result in an overall risk reduction compared to Cr(VI). The Cr(III)-based formulations, although some of them have hazard warnings, are less hazardous than Cr(VI). None are carcinogenic, mutagenic, or reproductive toxicants (CMRs).

Table 3-8: Substances in Cr(III)-based formulations - key identifiers and hazard properties

Substance	EC number	CAS number	Hazards (REACH)[a]	Hazards (CLP)[b]
Chromium(III) oxide	215-160-9	1308-38-9	None	May damage fertility or the unborn child, causes serious eye irritation, is harmful if swallowed and may cause an allergic skin reaction
Chromium (III) fluoride	232-137-9	7788-97-8	Toxic if swallowed, causes severe skin burns and eye damage, is very toxic to aquatic life, is toxic to aquatic life with long lasting effects, causes serious eye damage and may cause an allergic skin reaction	Causes damage to organs through prolonged or repeated exposure, is harmful in contact with skin and is harmful if inhaled
Zinc sulphate, heptahydrate	616-097-3	7446-20-0	None	Very toxic to aquatic life with long lasting effects, is very toxic to aquatic life, causes serious eye damage, is harmful if swallowed, causes skin

Table 3-8: Substances in Cr(III)-based formulations - key identifiers and hazard properties				
Substance	**EC number**	**CAS number**	**Hazards (REACH)[(a)]**	**Hazards (CLP)[(b)]**
				irritation, and may cause respiratory irritation
Dipotassium hexafluorozirconate	240-985-6	16923-95-8	Toxic if swallowed and causes serious eye damage	Toxic in contact with skin, is toxic if inhaled, causes severe skin burns and eye damage, is harmful to aquatic life with long lasting effects, causes skin irritation and may cause respiratory irritation
Ammonium hexafluorozirconate	240-970-4	16919-31-6		
Chromium hydroxide sulphate	235-595-8	12336-95-7	Causes serious eye irritation, is harmful to aquatic life with long lasting effects, causes skin irritation and may cause an allergic skin reaction	Harmful if inhaled, causes serious eye damage and may cause respiratory irritation
Sulphuric acid	231-639-5	7664-93-9	Toxic if inhaled[(c)]	Causes serious eye damage and may be corrosive to metals
Lanthanum nitrate hexahydrate	600-351-5	10277-43-7		Causes serious eye damage, may intensify fire (oxidiser), causes skin irritation, and may cause respiratory irritation
Hydrogen peroxide	231-765-0	7722-84-1	Causes serious eye damage, is harmful to aquatic life with long lasting effects and may cause respiratory irritation(d)	

Notes:
(a) – Hazard classification according to the notifications provided by companies to ECHA in REACH registrations
(b) – Hazard classification provided by companies to ECHA in CLP notifications
(c) - According to the harmonised classification and labelling (CLP00) approved by the European Union, this substance causes severe skin burns and eye damage
(d) According to the harmonised classification and labelling (CLP00) approved by the European Union. this substance causes severe skin burns and eye damage, may cause fire or explosion (strong oxidiser), is harmful if swallowed and is harmful if inhaled
Source: ECHA – Search for chemicals (https://echa.europa.eu/home)

Chromium(III) oxide, which as discussed in Section 3.5.2.1 is the most promising and most investigated test candidate to Cr(VI) for conversion coating, is included in the Community Rolling Action Plan (CoRAP). It was added to the CoRAP in 2019 for being suspected of being both reprotoxic and a sensitiser, as well as its high (aggregated) tonnage. In January 2022, ECHA published a substance evaluation conclusion document. The evaluating Member State (France) concluded that:

- Identification as Substance of Very High Concern (SVHC, and first step towards Authorisation) deemed not applicable;
- Restriction deemed not applicable;

- Harmonised Classification and Labelling – a group assessment is currently under development for chromium(III) compounds, it has been considered that chromium(III) compounds whole group should be classified for their skin sensitisation properties and that a CLH dossier on the group should be initiated.

3.5.2.5 Availability of Cr(III)-based alternatives

Partly due to the factors discussed above, Cr(III)-based treatments have been progressed to a wide range of Technology Readiness Levels, both across the ADCR membership, and sometimes within individual ADCR member companies that have multiple substitution plans for Cr(VI) conversion coating. In the latter case, a company may have developed the Cr(III)-based test candidate to different TRLs according to the alloy being treated, for bath or touch-up application, or the type of component or the environment in which the component is used, where different levels of corrosion protection levels are needed. With these factors in mind, TRLs that have been achieved by the ADCR members for Cr(III)-based conversion coatings today range from TRL 3 to TRL 9.

The various Cr(III)-based formulations are expected to be accessible on the EU market in the required quantities, although some member companies reported that an adequate supply chain is not currently in place.

Considering the factors above it is concluded that availability of Cr(III)-based test candidates for conversion coating is limited.

3.5.2.6 Suitability of Cr(III)-based alternatives

The use of Cr(III) does constitute a reduction in hazard profile compared to Cr(VI), the requirement to use hydrogen peroxide in one of the treatments brings handling and safety concerns which will need to be managed.

Cr(III) is sensitive to process parameters. It has been seen that additional analytical equipment may be required for maintaining tight control of the chemistry of the treatment bath. For some Cr(III) processes it has proved very difficult to maintain bath stability and optimum process parameters.

A limited number of Cr(III) based treatments are in use by some ADCR members for some components for some alloys, and for these situations the Cr(III) treatment can be considered technically and economically feasible and available. However, Cr(III)-based alternatives are by no means fully implemented, with significant technical feasibility failures relating to corrosion performance for many components/alloys. Overall Cr(III)-based treatments cannot be considered a generally available and suitable alternative to Cr(VI)-based conversion coating.

3.5.2.7 Conclusions

Cr(III) remains the most promising and by far the most investigated test candidate to hexavalent chromate for conversion coating. A range of Cr(III)-based proprietary formulations are available on the market and are being investigated by ADCR members. The different formulations perform differently to each other, even when tested on the same alloy.

As discussed above, a limited number of Cr(III)-based conversion coating treatments are in use for some parts and some alloys by some ADCR members, and as such these companies have reduced the number of parts that are treated with Cr(VI) conversion coating.

Cr(III)-based alternatives are by no means fully implemented due to corrosion performance failures for some parts/alloys and further significant testing is ongoing which must extend beyond the current review period.

3.6 Acidic anodising + organic coating

This class of proposed candidates include the use of either sulphuric, tartaric-sulphuric, or phosphoric acid, in addition to an organic coating /sealant. Boric-sulphuric acid is also an option however boric acid is an SVHC and is on the Candidate List of substances of very high concern for Authorisation.

3.6.1 Status reported in original applications

This sub-section summarises the development status of candidate alternatives to Cr(VI) for conversion coating *that were reported in the parent Applications in 2015-16*. This is to provide context to the progress that is reported by members in this combined AoA/SEA and discussed in Section 3.6.2. These alternatives were reported as applicable for aluminium and its alloys.

It was reported that acidic anodising (comprising sulphuric acid anodising (SAA), tartaric-sulphuric acid anodising (TSA), phosphoric acid anodising (PAA) and phosphoric sulphuric acid anodising (PSA)) could be used instead of chromate conversion coating when used in conjunction with paint but only for specific aluminium parts on certain aerospace alloys (such as AA2024 or AA7075), as a final corrosion protection layer, and only in cases where no conductive coating was required. A Cr(VI) primer had to be applied on top to achieve adequate corrosion performance. Acidic anodising was not a stand-alone alternative, because a Cr(VI) primer had to be applied on top to achieve adequate corrosion performance.

Fatigue properties were affected by anodising, which was not the case with chromate conversion coating.

Layer thickness (including the topcoat) was higher resulting in issues with the mechanical dimensions of the treated parts. In addition, due to the anodising process requiring an electrical field there are certain limitations to geometries that could be anodised (e.g. pipes).

Anodising processes were only an alternative for conversion coatings prior to paint applications, where conductivity was not a requirement. In general, only the electrical contact area was treated using a chemical conversion coating. As conductivity is a broad requirement[39] of the aerospace and defence sector on conversion coated substrates, the test candidate did not fulfil these requirements technically. It was assessed by the CTAC and CCST consortia as not technically feasible and unlikely to be pursued.

One company reported TRL 4 for a sulphuric acid anodising followed by a Cr(III) sealing, which also involved a Cr(VI)-free pre-treatment. TRL 9 was estimated as not before 2022.

For non-structural applications, more than 6-8 years was thought to be required for qualification at the time of the past AfAs (2015), i.e., qualification was estimated as 2021-2023.

[39] Aeronautic structural parts require to have electrical contact zones to evacuate the current in the event of a lightning strike.

The use of phosphoric acid based anodising processes as treatment *prior to structural metal bonding* was reported as either already implemented, or ready for qualification within the aerospace sector. In this case the corrosion resistance limitations of PAA were less important as the treatment is immediately covered by another layer.

PSA was reported as having shorter process times and lower process temperatures, leading to a more efficient process and an increased capacity. One company within the aerospace and defence sector planned testing on the component level for 2015. The process was stated to be at TRL 3 stage. Industrial qualification was not expected to be reached before 2020.

3.6.2 Progression reported by ADCR members

3.6.2.1 Introduction

Development is highly application dependent and is reported to be between TRL levels 3-9 (implemented). Cr(VI)-free acidic anodising can replace Cr(VI) conversion coating prior to paint application in some cases, however it cannot replace all applications of Cr(VI) conversion coating. The HITEA 1 and 2 research collaboration projects concluded that trivalent chrome in conjunction with thin film sulphuric acid anodising reached TRL 7 in June 2019. Other developments expect TRL 4-6 to be achieved in the next 6-8 years, and other developments expecting TRL 9 during 2020-25. There are limitations to direct substitution due to issues with parameters such as layer thickness, electrical conductivity, and the difficulty in performing as a localized repair. In cases where individual companies are able to achieve acceptable performance testing results for specific components and substrates, validation and certification steps still need to be carried out by each company. This impacts the time required for these alternatives to be put into production.

3.6.2.2 Technical feasibility of acidic anodising alternatives

All anodising variants can create a hard surface, but the surface will no longer be electrically conductive. This means that the test candidate cannot be used for all applications. Challenges include dimensional differences, lack of electrical conductivity, negative impact on fatigue, and the need for subsequent paint layers. Acidic anodising processes are difficult to perform for localised repairs.

One key reason for the lack of success in replacing Cr(VI) conversion coating with Cr(VI)-free acidic anodise is the fatigue debit associated with other anodise candidates, so fatigue debit presents a technical limitation on using acidic anodising alternatives as a Cr(VI)-free test candidate for conversion coating.

Additionally, the most common sulphuric acid anodise includes a seal in 5% dichromate (Cr(VI) which arguably contains more hexavalent chromium than chromic acid anodise. This is especially relevant for unpainted parts.

Some members in the defence sector have expressed concern about using sulphuric acid anodising where the treated surface may be in contact with munitions, in case of undesirable or unexpected reactions.

Some types of anodise phosphoric anodise do not provide corrosion resistance and need to be used with primer and sealant.

There are some Cr(VI)-free anodising processes designed specifically for magnesium substrates. The HAE process involves the use of a highly alkaline permanganate solution (pH 14). Its use was discontinued in at least one situation as major quality issues were caused due to the inability to adequately rinse off the highly alkaline solution from parts with complex shapes. This resulted in major paint adhesion problems. Tagnite, a formulation containing hydroxide, fluoride, and silicate, has been found to be suitable for very limited types of components. The majority of magnesium components cannot be anodised. One technical limitation of replacing magnesium alloy conversion coatings with any type of anodising is that other metals incorporated into the assembly are generally not compatible with the electrochemical anodising process and must either be masked (very difficult) or removed prior to anodising and then replaced (very costly and time consuming).

3.6.2.3 Economic feasibility of acidic anodising alternatives

Anodising can be more expensive than CCC due to the application of electrical current during the application process, which requires additional equipment.

For unpainted parts, some types of anodising such as phosphoric acid anodising do not provide corrosion resistance and need to be used together with primer and sealant. This makes the process more complex and expensive compared to conversion coating, and is typically not appropriate to use in place of conversion coating for unpainted parts.

The Tagnite formulation for magnesium alloys must be used under licence and was ruled out as cost prohibitive as a licence would be needed for each site.

3.6.2.4 Hazard considerations related to using acidic anodising alternatives

A summary of the key identifiers and hazard properties of substances used in acidic acid anodising are shown below in Table 3-9.

Table 3-9: Substances used in acidic anodising - key identifiers and hazard properties

Substance	EC number	CAS number	Hazards (REACH)1	Hazards (CLP)[2]
Sulphuric acid	231-639-5	7664-93-9	Toxic if inhaled[3]	Causes serious eye damage and may be corrosive to metals
Tartaric acid[4]	205-105-7	133-37-9	n/a	Causes serious eye damage, causes skin irritation and may cause respiratory irritation
Phosphoric acid	231-633-2	7664-38-2	Harmful if swallowed, causes serious eye damage and may be corrosive to metals[3]	n/a
Boric acid	233-139-2	10043-35-3	May damage fertility or the unborn child[5]	n/a

Notes:
1 – Hazard classification according to the notifications provided by companies to ECHA in REACH registrations
2 – Hazard classification provided by companies to ECHA in CLP notifications
3 - According to the harmonised classification and labelling (CLP00) approved by the European Union, this substance causes severe skin burns and eye damage
4 – (±)-tartaric acid (mixed enantiomer) is reported here
5 – Harmonized classification reprotoxic 1B
Source: ECHA – Search for chemicals (https://echa.europa.eu/home)

With the exception of boric acid, the overall consensus of members is that the use of acidic anodising alternatives will result in an overall risk reduction compared to Cr(VI). The acidic anodising alternatives, although some of them have hazard warnings, are less hazardous than Cr(VI). Apart from boric acid, none are carcinogenic, mutagenic, or reproductive toxicants (CMRs). However, the technical feasibility limitations of anodising alternatives discussed above should be noted.

Boric acid is an SVHC and has a harmonised classification as reprotoxic 1B. Most members have ruled out boric sulphuric acid anodising as a regrettable substitution although it remains an option for some and is written into specifications.

3.6.2.5 Availability of acidic anodising alternatives

Progression of acidic anodising alternatives has been developed to TRL 4-9 between 2020-2025. For some members of the ADCR, chromate-free acid anodising processes are already industrially implemented but restricted to specific cases, while for others progression of acidic anodising alternatives is at an early stage of development and technical feasibility issues still need to be solved (e.g., fatigue debit). Therefore, while acidic anodising alternatives are expected to be accessible on the EU market in the required quantities, availability of acidic anodising test candidates for conversion coating is limited.

3.6.2.6 Suitability of acidic anodising alternatives

The use of acidic anodising does constitute a reduction in hazard profile compared to Cr(VI). Anodising is not a suitable replacement for all applications of conversion coating where the brittle nature could be detrimental. They resulting layer is also thicker than conversion coating, causing issues on fatigue sensitive components. It is valid for painted parts that are not fatigue sensitive and do not have a complex geometry (e.g., tubes). Typically, it cannot replace Cr(VI) conversion coating for unpainted parts or partially painted parts, as anodising does not provide sufficient corrosion protection by itself, and it has a high electrical resistance and higher thickness than Cr(VI) conversion coating. Overall therefore, acidic anodising cannot be considered a generally available and suitable alternative to Cr(VI)-based conversion coating. Acidic anodising is valid for some production applications (painted parts that are not fatigue sensitive) but not a full replacement for Cr(VI) based conversion coating.

3.6.2.7 Conclusions

Acidic anodising plus organic coating alternative treatments for conversion coating do not meet all of the requirements such as for electrical conductivity and fatigue, with the application method deemed impracticable for many applications where localised repairs or complex geometries are concerned. It is also deemed unsuitable for fatigue and dimensional tolerance sensitive components, particularly due to the thickness of the coating produced, which is thicker than the chromated conversion coating. There are also concerns that phosphoric acid anodising in particular does not provide corrosion resistance, and therefore must be used in tandem with a primer and sealant, resulting in a more complex and expensive procedure.

Therefore anodising, as a Cr(VI)-free test candidate for conversion coating, is very dependent on the type of component and its specific requirements in its operating environment.

By replacing chromate conversion coating prior painting by acid anodising where possible, the number of parts still needing a suitable replacement for CCC can be reduced and this approach is followed by some of the members of the consortium.

3.7 Silane/siloxane and sol-gel coating

3.7.1 Status reported in original applications

This sub-section summarises the development status of candidate alternatives to Cr(VI) for conversion coating *that were reported in the parent Applications in 2015-16*. This is to provide context to the progress that is reported by members in this combined AoA/SEA and discussed in Section 3.7.2.

This alternative was reported as applicable for aluminium and its alloys.
Sol-gel technology was reported to be expanding rapidly, with extensive R&D effort being made and many new products appearing on the market, especially since the advent of hybrid and nanocomposite materials.

Sol-gel did not provide standalone corrosion protection; additives and additional coating were needed such as a Cr(VI)-containing corrosion inhibiting primer. It was understood that silane/siloxane sol-gel coatings were also used after acidic anodising in impregnation. It was reported acidic anodising provides anti-corrosion protection and sol-gel provides the finish.

Adhesion and corrosion performance were strongly dependent on the properties of the pickling solution and/or the surface pre-treatment and conditions. Fatigue performance depended on the silane chemistry and was reported as adequate for some specific applications, but not all sol-gel chemistries had been assessed. Specific organo-silanes on aluminium had found adequate/improved adhesion for specific paint systems and applications. Inadequate corrosion protection means they were limited to parts that were primed with specific primers. Sol-gel had been used for parts with low corrosion risk.

Adhesion performance was found to be acceptable and, in some cases, superior.
Other limitations reported were:

- Layer thickness was too high, leading to electrical insulation and failure to meet conductivity requirements;
- Short tank life hence usually applied by spraying;
- Limited reproducibility of the process;
- Curing temperature was >100°C, which means that it could only be applied during the manufacturing of parts but would not provide a feasible alternative during touch-up or MRO activities; and
- The application method (e.g. spraying) can limit their use in complex geometries.

R&D for magnesium substrates was stopped as no corrosion protection could be achieved.

Given the relatively nascent state of technical development of this alternative, no detailed analysis of economic feasibility had been carried out although it was thought to be economically feasible.

3.7.2 Progression reported by ADCR members

3.7.2.1 Introduction

Development varies widely, with TRL 7-9 reported in 2021-22 by a small minority of members on certain alloys and parts, in some cases with measures to increase visibility of the coating.

Issues including poor corrosion resistance and surface conductivity have led other projects remaining at TRL 2-3, with TRL 6 expected in 10-15 years.

3.7.2.2 Technical feasibility of silane/siloxane and sol-gel coating alternatives

One company found that silane/siloxane and sol-gel coating alternatives failed at corrosion protection, and mixed results were found for paint adhesion, depending on the paint/primer used. Some good results were found for resistance to filiform corrosion with an alkaline primer, however mixed results were found for antimony and WR (water resistant) primers, but with no fatal failure. The company reported that a homogeneous layer thickness could not be achieved, but electrical resistance tests have not been completed. The company reported TRL 2-3 for this alternative.

Another company developed a sol-gel from a licenced technology comprised of an aqueous solution of zirconium salts, activated by an organo-silicon compound. A dye is added to facilitate the inspection of the sol-gel application, with the ability to inspect the applied coating increasing the ability to implement the sol-gel as an alternative to chromate coatings. The substrates tested are aluminium alloys from the 2000 series and 7000 series, and some titanium alloys, with an expected TRL 7 by the end of 2021.

A company investigating sol-gel on aluminium 2000 series alloys using dip/immersion found that corrosion and adhesion results were not always equivalent to chemical conversion coating or anodise performance, however this does not always preclude implementation when local performance requirements are met. Specific adhesion and corrosion resistance properties were noted by the company and incorporated into internal civil design guidance. A recommendation was made to use only when the substrate is to be completely painted and specific adhesion and corrosion requirements are met. The company reported that implementation has been carried out for some exterior fuselage surfaces.

A company developing a specification for low-risk corrosion applications of a sol-gel with a combined chromated paint system on a 7000 series bare aluminium alloy found equivalent general corrosion resistance to other traditional Cr(VI) finishes. Results indicated that sol-gel is an excellent adhesion promoter for aluminium alloys finished with epoxy-based and polyurethane-based organic coatings. Sol-gel conversion coatings on targeted parts provides the opportunity to gather service data/history on sol-gel in a low-risk, relatively non-corrosive environment. The data presented also suggested that sol-gel could be used on 5000/6000 series aluminium alloys, which are less susceptible to corrosion. However, the introduction of sol-gel into other applications will be considered on a case-by-case basis as the data supports. Some limited implementation is reported to have taken place.

Another company reported that silane/siloxane and sol-gel coatings produced no inherent corrosion resistance and apparently surface conductivity properties were unknown and thought to be unacceptable.

One company reported that it does not use silane/siloxane, although they reported that it works similar to a topcoat, it is not conductive and is difficult to strip in cases where the surface needs to be repaired or maintained.

3.7.2.3 Economic feasibility silane/siloxane and sol-gel coating alternatives

No detailed analysis of economic feasibility has been reported by ADCR members for this test candidate but in general is not thought to be significantly different from Cr(VI).

3.7.2.4 Health and safety considerations related to using silane/siloxane and sol-gel coatings

Table 3-10 below summarises the hazard properties of a selection of proprietary sol-gel formulations, as reported in the relevant safety data sheet. Sol-gel alternatives can consist of multi-part, independent components.

Table 3-10: Summary of hazard properties of selected sol-gel formulations based on SDS data	
Proprietary sol-gel formulation	**Hazard information including GHS hazard statements**
A	H315 Causes skin irritation; H319 Causes serious eye irritation
B	Mild skin and eye irritation
C	H318 causes serious eye damage; H412 harmful to aquatic life with long lasting effects
Source: Safety data sheets	

3.7.2.5 Availability of silane/siloxane and sol-gel coating alternatives

Silane/siloxane and sol-gel treatments have been progressed to TRL 2 to TRL 9. In some cases this treatment has been implemented in certain alloys and certain parts, in a limited number of cases. While suppliers of sol-gel are available, and the equipment is relatively simple and readily available, the technical feasibility issues discussed in the section above mean that availability in general of this test candidate is limited.

3.7.2.6 Suitability of silane/siloxane and sol-gel coating alternatives

The use of silane/siloxane and sol-gel coating does constitute a reduction in hazard profile compared to Cr(VI). In general silane/siloxane and sol-gel coatings do not provide adequate corrosion resistance and a subsequent primer/paint coating needs to be applied. Adhesion promotion results are mixed, and resistivity is unacceptably high. Consequently, not all companies are developing this alternative, and of those that are, development varies widely, with one company implementing sol-gel in limited cases, and others still in development at TRL 2-3. Consequently, while silane/siloxane and sol-gel coatings can be used by some members in limited cases, it cannot be considered as a generally available and suitable alternative to Cr(VI) for conversion coatings.

3.7.2.7 Conclusions

In general silane/siloxane and sol-gel coatings do not provide stand-alone corrosion resistance and applications may be limited to situations where a subsequent primer/paint coating is applied. Adhesion promotion results are mixed. High resistivity of the sol-gel coating may limit application to situations where low resistivity is not a requirement. Consequently, not all companies are developing this alternative, and of those that are, development varies widely, with one company implementing sol-gel in limited cases, and others still in development at TRL 2-3.

3.8 Molybdates and molybdate based processes

3.8.1 Status reported in original applications

This sub-section summarises the development status of candidate alternatives to Cr(VI) for conversion coating *that were reported in the parent Applications in 2015-16*. This is to provide context to the progress that is reported by members in this combined AoA/SEA and discussed in Section 3.8.2.

It was reported that MoCC-based processes must be carefully controlled, as the final corrosion resistance from the treated surface is highly dependent on the substrate, its pre-treatment, and the process conditions. It was reported MoCC did not meet the requirements for corrosion resistance on Al alloys, did not provide self-healing characteristics of conventional Cr(VI) conversion coating, and the MoCC coatings were non-conductive therefore failing to meet the resistivity requirements of the industry.

There was no detailed data in the previous applications on economic feasibility, although it was noted that while chemical costs can double that of conventional treatment, there was no indication that it was not economically feasible

3.8.2 Progression reported by ADCR members

3.8.2.1 Introduction

Development is at TRL level 1-2 or otherwise has been considered unsuitable.

3.8.2.2 Technical feasibility of molybdates and molybdate-based alternatives

A company reported that a collaboration project investigating a zirconium/molybdenum treatment process found mixed results for paint adhesion. Polymer additives were found to have an important impact. Testing with second generation of additives is ongoing, with promising results reported with an antimony primer. Tests have been extended in painted conditions with first generation additives for salt spray testing. Bare corrosion protected and electrical conductivity have not yet been tested. TRL 1-2 has been achieved, with testing progressing to TRL 3.

Other companies have found that Zr/Mo with adhesion promotors are unsuitable as an alternative for conversion coating due to lack of uniform coverage and adhesion/cohesion of deposits, thus no planning for progression of TRL has taken place. Lower intrinsic corrosion inhibition on aluminium alloys has also been reported.

3.8.2.3 Economic feasibility of molybdates and molybdate-based alternatives

No detailed analysis of economic feasibility has been reported by ADCR members for this alternative.

3.8.2.4 Health and safety considerations related to using molybdates

A summary of the key identifiers and hazard properties of selected molybdate-based alternatives is shown below in Table 3-11.

Table 3-11: Summary of hazard properties of selected molybdates				
Molybdate	EC number	CAS number	Hazard (REACH)[a]	Hazard (CLP)[b]
Disodium molybdate	231-551-7	7631-95-0	None	Causes serious eye irritation, is harmful if inhaled, is harmful to aquatic life with long lasting effects, causes skin irritation and may cause respiratory irritation
(a) – Hazard classification according to the notifications provided by companies to ECHA in REACH registrations (b) – Hazard classification provided by companies to ECHA in CLP notifications *Source: ECHA – Search for chemicals (https://echa.europa.eu/home)*				

3.8.2.5 Availability of molybdates and molybdate-based alternatives

This test candidate is not currently available as the TRLs that have been achieved by the ADCR members that have investigated this test candidate range from only TRL 1 to TRL 2. No comments have been provided regarding the expected accessibility on the EU market in the required quantities but given the limited technical progress of this test candidate, molybdate-based processes for conversion coating are not considered to be available.

3.8.2.6 Suitability of molybdates and molybdate-based alternatives

The use of molybdate does constitute a reduction in hazard profile compared to Cr(VI), however given the low technical maturity of this test candidate and the technical feasibility issues that have been encountered, molybdate-based processes cannot be considered a generally available and suitable alternative for Cr(VI) conversion coating.

3.9 Organometallics (zirconium and titanium-based products)

3.9.1 Status reported in original applications

This sub-section summarises the development status of candidate alternatives to Cr(VI) for conversion coating *that were reported in the parent Applications in 2015-16*. This is to provide context to the progress that is reported by members in this combined AoA/SEA.

It was reported this test candidate is applicable for aluminium and its alloys, and magnesium and its alloys.

Conversion coatings based on Zr and Ti were determined to be not technically suitable as an alternative for conventional chemical conversion coating in the previous applications. While products based on Zr were qualified according to military standard MIL-DTL-81706, they were determined to be generally not suitable due to inadequate and mixed corrosion resistance results on copper-containing aluminium alloys, the most commonly used alloys in the A&D sector (e.g., aluminium grade 2024).

3.9.2 Progression reported by ADCR members

3.9.2.1 Introduction

Development of this test candidate is generally low, pursued by few members. One company has reported its use in a specific touch-up application but otherwise it is at TRL 3 and has been considered unsuitable.

3.9.2.2 Technical feasibility of organometallics (zirconium and titanium-based) alternatives

A company taking part in a collaboration project investigating a titanium/zirconium/vanadium formulation as an alternative to chromate conversion coating is currently moving to TRL 3. They found limited bare corrosion protection performance (onset of corrosion at 96 hours in salt spray testing). Electrical conductivity is still to be tested. Paint adhesion tests were passed for antimony and water resistant (WR) chromate-free primers. Mixed paint adhesion results were reported with alkaline model primer at the initial stage and after water immersion. Extended filiform corrosion testing (FFT) in painted conditions is ongoing.

One company commented that, although they had no in-house experience of this alternative, they were aware that it is rarely used, and it is difficult to find suppliers for these types of products.

Another company reported that no corrosion resistance was obtained from testing this alternative, and apparent surface conductivity properties were unknown and thought to be insufficient. They estimated an implementation time of 15 years.

One company reported using titanium-zirconium-based wipes for a specific touch-up application.

3.9.2.3 Economic feasibility of organometallics (zirconium and titanium-based) alternatives

No detailed analysis of economic feasibility has been reported by ADCR members for this alternative.

3.9.2.4 Health and safety considerations related to using organometallics (zirconium and titanium-based) alternatives

A summary of the key identifiers and hazard properties of selected organometallic alternatives is shown below in Table 3-12.

Table 3-12: Summary of hazard properties of an organometallic alternative				
Substance	EC number	CAS number	Hazard (REACH)[(a)]	Hazard (CLP)[(b)]
Hexafluorotitanic acid	241-460-4	17439-11-1	Toxic if swallowed, is toxic in contact with skin, causes severe skin burns and eye damage, is toxic if inhaled and may be corrosive to metals	Fatal if swallowed and is fatal if inhaled
Zirconium dioxide	215-227-2	1314-23-4	None	Causes serious eye irritation and causes skin irritation
(a) – According to the classification provided by companies to ECHA in REACH registrations (b) – Hazard classification provided by companies to ECHA in CLP notifications *Source: ECHA – Search for chemicals (https://echa.europa.eu/home)*				

Members have not reported on the expected impact on hazards associated with using organometallics as an alternative to Cr(VI) for conversion coating.

3.9.2.5 Availability of organometallics (zirconium and titanium-based) alternatives

This test candidate is not currently available as the TRLs that have been achieved by the ADCR members that have investigated this test candidate range from only TRL 1 to TRL 2. One company noted that it is difficult to find suppliers for these types of products.

3.9.2.6 Suitability of organometallics (zirconium and titanium-based) alternatives

The use of zirconium and titanium-based organometallics does constitute a reduction in hazard profile compared to Cr(VI), however given the low technical maturity of this test candidate and the technical feasibility issues that have been encountered, zirconium and titanium-based organometallic processes cannot be considered a generally available and suitable alternative for Cr(VI) conversion coating.

3.10 Benzotriazoles-based processes, e.g. 5-methyl-1H-benzotriazol

3.10.1 Status reported in original applications

This sub-section summarises the development status of candidate alternatives to Cr(VI) for conversion coating *that were reported in the parent Applications in 2015-16*. This is to provide context to the progress that is reported by members in this combined AoA/SEA.

It was reported this test candidate is applicable for aluminium and its alloys.

Laboratory tests on corrosion inhibition revealed this test candidate was not suitable as standalone system. When mixed with other stabilizers, such as phosphates (Sr-Mg polyphosphates or Na_2HPO_4), the laboratory results were better.

Economic assessment of this test candidate revealed that investments would be needed for collecting waste containing the 5-methyl-1H-benzotriazol, as it cannot be discharged to the on-site sewage treatment plant due to its complexing properties. Therefore, it was reported the existing one-step process would have to be adapted to a two-step process.

3.10.2 Progression reported by ADCR members

3.10.2.1 Introduction

No members reported pursuing this alternative. Every company's research and development programme necessarily has a finite budget and scope, and proposed candidates need to be selected and prioritised for testing based on their expected chance of success. Additionally, selection of test candidates depends on availability of commercial products for testing. If formulators do not propose a test candidate, it cannot be tested by OEMs. OEMs are dependent upon the formulators to come forward with potential test candidate formulations. If they are not developing any, because their own in-house work suggests that a test candidate will not be technically feasible, then there will be no follow-up work by the design owners.

3.10.2.2 Technical feasibility of benzotriazole-based alternatives

No members reported pursuing this alternative.

3.10.2.3 Economic feasibility of benzotriazole-based alternatives

No members reported pursuing this alternative.

3.10.2.4 Health and safety considerations related to using benzotriazoles

A summary of the key identifiers and hazard properties of benzotriazole-based alternatives is shown below in Table 3-13.

Table 3-13: Summary of hazard properties of a benzotriazole

Substance	EC number	CAS number	Hazard (REACH)[(a)]	Hazard (CLP)[(b)]
6-methylbenzotriazole	205-265-8	136-85-6	Causes severe skin burns and eye damage and causes serious eye damage	Harmful if swallowed, causes serious eye irritation, may cause respiratory irritation and causes skin irritation

(a) – According to the classification provided by companies to ECHA in REACH registrations
(b) – Hazard classification provided by companies to ECHA in CLP notifications
Source: ECHA – Search for chemicals (https://echa.europa.eu/home)

3.10.2.5 Availability of benzotriazole-based alternatives

No members reported pursuing this test candidate and therefore no comments were provided on the expected accessibility on the EU market in the required quantities of this potential test candidate.

3.10.2.6 Suitability of benzotriazole-based alternatives

As the technical feasibility of benzotriazole-based test candidates has not been assessed, these cannot be considered as a generally available and suitable alternative to Cr(VI) conversion coating.

3.11 Manganese based processes

3.11.1 Status reported in original applications

This sub-section summarises the development status of candidate alternatives to Cr(VI) for conversion coating *that were reported in the parent Applications in 2015-16*. This is to provide context to the progress that is reported by members in this combined AoA/SEA.

It was reported this test candidate is applicable for aluminium and its alloys, and magnesium and its alloys.

Some positive results for corrosion resistance were obtained when permanganate conversion coatings were tested on zinc, but on aluminium and its alloys it was found to be insufficient and inferior to Cr(III) processes. Additionally, process times were longer.

This test candidate was not suitable for high copper-containing aluminium alloys (e.g. aluminium grade 2024), which are the most important substrates in the aerospace sector.

For magnesium and its alloys, potassium permanganate conversion coatings were reported to be at a very early R&D stage in the previous applications, and not all key functionalities had yet been evaluated. Corrosion resistance requirements could only be met for one kind of magnesium substrate without varnish.

Layer adhesion and layer thickness were reported to be adequate.

3.11.2 Progression reported by ADCR members

3.11.2.1 Introduction

Few members have reported pursuing this alternative.

3.11.2.2 Technical feasibility of manganese-based alternatives

One company reported that testing of manganese and cerium-based solutions failed at TRL 2. The solutions did not fulfil any of the required performance, including corrosion resistance, paint adhesion and electrical conductivity.

Another company estimated an implementation time of 12-15 years.

One member is developing a permanganate-based process for magnesium alloys. This is presently at TRL 6 and is discussed in Section 3.6 (anodising alternatives).

One member is developing a permanganate chemical process for magnesium-based alloys which is present close to TRL 6.

3.11.2.3 Economic feasibility of manganese-based alternatives

No information was provided on the economic feasibility of this test candidate.

3.11.2.4 Health and safety considerations related to using manganese-based alternatives

A summary of the key identifiers and hazard properties of manganese-based alternatives is shown below in Table 3-14.

Table 3-14: Summary of hazard properties of potassium permanganate				
Substance	**EC number**	**CAS number**	**Hazard (CLH)[(a)]**	**REACH[(b)]**
Potassium permanganate	231-760-3	7722-64-7	Very toxic to aquatic life (H400), is very toxic to aquatic life with long lasting effects (H410), may intensify fire (oxidiser) (H272), is harmful if swallowed and is suspected of damaging the unborn child (H361d)	Causes severe skin burns and eye damage, causes serious eye damage, is suspected of damaging fertility or the unborn child and may cause damage to organs through prolonged or repeated exposure
(a) – According to the harmonised classification and labelling (b) – Hazard classification provided by companies to ECHA in REACH Registrations *Source: ECHA – Search for chemicals (https://echa.europa.eu/home)*				

3.11.2.5 Availability of manganese-based alternatives

No members reported pursuing this test candidate and therefore no comments were provided on the expected accessibility on the EU market in the required quantities.

3.11.2.6 Suitability of manganese-based alternatives

The use of manganese-based processes does constitute a reduction in hazard profile compared to Cr(VI), however given the low technical maturity of this test candidate and the technical feasibility issues that have been encountered, manganese-based processes cannot be considered a generally available and suitable alternative for Cr(VI) conversion coating.

3.12 Magnesium-rich primers

3.12.1 Status reported in original applications

This sub-section summarises the development status of candidate alternatives to Cr(VI) for conversion coating *that were reported in the parent Applications in 2015-16*. This is to provide context to the progress that is reported by members in this combined AoA/SEA and discussed in Section.

This test candidate was reported as applicable for aluminium and its alloys.

Ongoing R&D at the time of the previous applications showed that results from standard filiform corrosion tests and salt spray tests were satisfactory, but that more studies, especially on the long-term stability needed to be performed.

3.12.2 Progression reported by ADCR members

3.12.2.1 Introduction

No members have reported pursuing this alternative. A company's research and development programme necessarily has a finite budget and scope, and proposed candidates need to be selected and prioritised for testing based on their expected chance of success. Additionally, selection of test candidates depends on availability of commercial products for testing. If formulators do not propose a test candidate, it cannot be tested by OEMs.

3.12.2.2 Technical feasibility of magnesium-rich primers

No members have reported pursuing this alternative.

3.12.2.3 Economic feasibility of magnesium-rich primers

No members have reported pursuing this alternative.

3.12.2.4 Health and safety considerations related to using magnesium-rich primer

As we do not have any information on the specific substance, no hazard properties are provided.

3.12.2.5 Availability of magnesium-rich primers

No members have reported pursuing this test candidate, and therefore no comments were provided on the expected accessibility on the EU market in the required quantities.

3.12.2.6 Suitability of magnesium-rich primers

No members have reported pursuing this test candidate and as the technical feasibility of magnesium-rich primers has not been assessed, these cannot be considered as generally available and suitable alternatives to Cr(VI) conversion coating.

3.13 Electrolytic paint technology

3.13.1 Status reported in original applications

This sub-section summarises the development status of candidate alternatives to Cr(VI) for conversion coating *that were reported in the parent Applications in 2015-16*. This is to provide context to the progress that is reported by members in this combined AoA/SEA.

Mixed results were obtained on corrosion protection from laboratory and military research. Results from the aerospace sector showed performance was inferior to conventional conversion coating followed by Cr(VI) primer. A Cr(VI)-free electrocoat system was available on the market and was qualified according to AMS 3144. Problems also included heat and humidity sensitivity. It was understood it was qualified and operationalised for specific applications in the military sector however it was noted that it was not suitable or qualified for civil aviation.

3.13.2 Progression reported by ADCR members

3.13.2.1 Introduction

Although it was stated in the previous Applications that this has been qualified for specific applications in the military sector electrolytic paint for specific applications, few members have reported pursuing this alternative. Where it has been investigated, multiple issues were found with performance e.g., conductivity and adhesion.

3.13.2.2 Technical feasibility of electrolytic paint technology

One company observed that use of electrophoretically deposited paint is limited to fully painted parts/areas. A low electrical contact resistance was not provided, and the deposition was based on the application of an electric field. The paint therefore cannot be used for complex shaped parts such as tubes (faradaic effect).

One company reported that wet ageing performance is not sufficient. Additionally, this formulation is not suitable for touch-up, as this technology requires the whole component to be treated and it cannot be applied to only the damages area which is mandatory for aircraft and service life.

3.13.2.3 Economic feasibility of electrolytic paint technology

No information was provided on the economic feasibility of this technology.

3.13.2.4 Health and safety considerations related to using electrolytic paint

No comments were provided on the expected hazard properties of electrolytic paint.

3.13.2.5 Availability of electrolytic paint technology

Electrolytic paint is at a low level of technical maturity. No comments have been provided on its expected accessibility on the EU market in the required quantities. The present availability of this technology is considered as low.

3.13.2.6 Suitability of electrolytic paint technology

Given the low technical maturity of this test candidate and the technical feasibility issues that have been encountered, electrolytic paint cannot be considered a generally available and suitable alternative for Cr(VI) conversion coating.

3.14 Chromate-free etch primers

3.14.1 Status reported in original applications

This sub-section summarises the development status of candidate alternatives to Cr(VI) for conversion coating *that were reported in the parent Applications in 2015-16*. This is to provide context to the progress that is reported by members in this combined AoA/SEA.

As a Cr(VI)-free test candidate for chromate conversion coating, chromate-free etch primers were reported as only qualified for external applications and are therefore not suitable for all over protection as required. Surfaces treated with etch primers did not meet the corrosion requirements of the aerospace sector and showed insufficient active corrosion inhibition and poor chemical resistance. Nevertheless, chromate free etch primers were reported as used when repainting aircrafts under specific conditions.

3.14.2 Progression reported by ADCR members

3.14.2.1 Introduction

This is generally not being pursued, although one member reported that it has been implemented for limited applications.

3.14.2.2 Technical feasibility of chromate-free etch primers

One member reported corrosion protection level is not achieved, and there is insufficient adhesion for further layers (like coatings). However, they reported the advantages are that it requires fewer process steps.

A member reported that it has been implemented for limited applications.

3.14.2.3 Economic feasibility of chromate-free etch primers

No detailed analysis of economic feasibility has been reported by ADCR members for this test candidate.

3.14.2.4 Health and safety considerations of chromate-free etch primers

As we do not have any information on the specific substance, no hazard properties are provided.

3.14.2.5 Availability of chromate-free etch primers

No comments were provided on the expected accessibility on the EU market in the required quantities of this test candidate. Given the low level of technical maturity and the fact that it is being investigated by few members, it is concluded that availability of chromate-free etch primers for conversion coating is limited

3.14.2.6 Suitability of chromate-free etch primers

Given the low technical maturity of this test candidate and the technical feasibility issues that have been encountered, chromate-free etch primers cannot be considered a generally available and suitable alternative for Cr(VI) conversion coating.

3.15 Summary of Cr(VI) alternatives for conversion coating

The table below summarises the current development status of Cr(VI)-free test candidates for conversion coating. A qualitative assessment (low, moderate, or high) has been provided for each of the criteria technical feasibility, economic feasibility, availability and suitability. This qualitative assessment is provided as a high-level summary and is based on the detailed discussions in the preceding sections.

Table 3-15: Current development status of alternatives to Cr(III) for conversion coating				
Alternative	Technical feasibility	Economic Feasibility	Availability	Suitability
Cr(III)-based	High	Moderate	Moderate	Moderate
Acidic anodising + organic coating	Low/Moderate	Low/moderate	Low	Low
Silane/siloxane and sol-gel	Moderate	n/a	Moderate	Moderate
Molybdate-based	Low	n/a	Low	Low
Organometallics (zirconium and titanium-based products)	Low	n/a	Low	n/a
Benzotriazoles-based processes, e.g. 5-methyl-1H-benzotriazol	n/a	n/a	n/a	n/a
Manganese based processes	Low	n/a	n/a	n/a
Magnesium-rich primers	n/a	n/a	n/a	n/a
Electrolytic paint technology and etch primers	Low	n/a	n/a	n/a
Chromate-free etch primers	Low	n/a	n/a	n/a
Notes n/a = insufficient data or not pursued as an alternative				

3.16 The substitution plan

3.16.1 Introduction

3.16.1.1 Factors affecting the substitution plan

The substitution plan is impacted by a combination of factors affecting the implementation of the alternative, these include:

- Functionality and ability to meet performance requirements (technical feasibility);
- Availability, and suitability of the alternative;
- Process changes such as equipment, training, health and safety (*Technical challenges and economic feasibility*);
- A substitution process which is subject to regulatory controls, legal constraints, and customer requirements;
- Economic feasibility, including the capital and operational costs of moving to an alternative and the costs of implementing the alternative across the supply chain; and
- Progress and alignment with other REACH substitution workstreams.

Each factor will contribute to the achievement of milestones that must be met to realise delivery of the substitute(s) to Cr(VI) for conversion coating, and its relevant pre-treatments. They require continuous review and monitoring to ensure that the substitution plan progresses through its phases and all changes are clearly documented. Monitoring of progress markers associated with the substitution plan includes a timetable of steps and targeted completion dates, assessment of the highest risks to progression, and how these risks can be reduced (if possible), which may not always be the case.

3.16.1.2 Substitution plans within individual members

Each ADCR member has at least one substitution plan to remove Cr(VI) in conversion coating that is uniquely reflective of their individual situation. Additionally, an individual member often has multiple substitution plans for conversion coating, running in parallel work streams. The reason for different substitution plans within one member is that they are segmented by factors such as type of substrate, type of alternative, and whether the substitution plan is related to bath/immersion or local/touch-up applications. These different substitution plans are progressed simultaneously although they typically have differences in timing of milestones and anticipated achievement of each TRL level, based on various factors such as the technical difficulty of introducing the alternative and prioritisation of certain types of components or substrate. The test candidates of most focus and progression by ADCR members are Cr(III)-based, anodising, and sol-gel.

3.16.1.3 Interplay with pre-treatments

Development of substitution plans for alternatives to Cr(VI) for conversion coating are fundamentally related to and impacted by the pre-treatment. In the case where members are using Cr(VI) in the pre-treatment, they develop the Cr(VI)-free pre-treatments in parallel with the Cr(VI)-free conversion coating. The progression and success of the development of alternatives to Cr(VI) in conversion coating depends on the successful development of pre-treatment alternatives. Any unexpected technical failures in the development of the pre-treatment will impact the planned timing of the substitution plan for the conversion coating.

In some cases, a member will target substitution of Cr(VI) from both the pre-treatment and the conversion coating at the same time.

3.16.2 Substitution plan for ADCR in conversion coating

The expected progression of ADCR members' substitution plans to replace Cr(VI) in conversion coating is shown in Figure 3-7 below. The progressive stages of the substitution plan (development, qualification, validation etc.) as shown in the diagram are described in detail in section 3.1.2. Implementation and progression of substitution plans ultimately leads to reduced Cr(VI) usage. MRL 10 is the stage at which manufacturing is in full rate production/deployment and is therefore where significant reduction in Cr(VI) use due to replacement with an alternative is expected.

Recognising the SEAC's need for information which reflects the position of individual companies and their value chains, the substitution plans have been developed based on a granular analysis of the progression made by each OEM and DtB company supporting conversion coating in achieving substitution. As design owners, the substitution plans of these companies impact on their suppliers (other DtBs, BtPs) and MROs, who are unable to also substitute until the design owners have fully implemented the alternatives (i.e. progress to TRL9 and MRL10).

The data in the figure show the expected progress of 78 distinct substitution plans for Cr(VI) in conversion coating, covering different plans across different members, and also multiple plans within individual members. These data have been aggregated to present the expected progress of the substitution of Cr(VI) from conversion coating for the ADCR consortium as a whole.

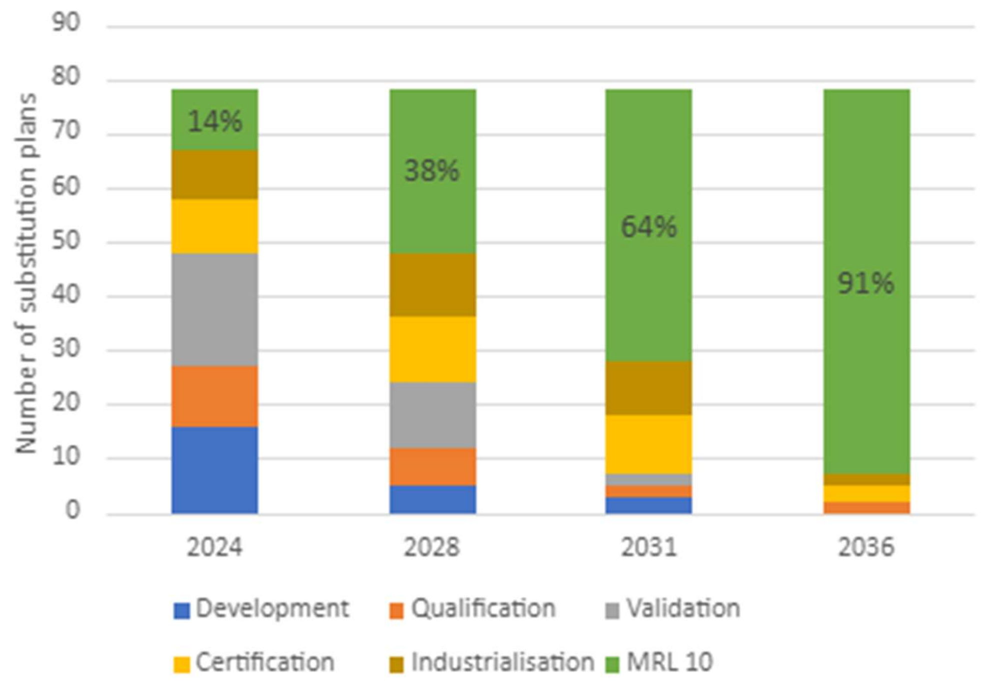

Figure 3-7: Expected progression of substitution plans for the use of Cr(VI) in conversion coating, by year. The vertical axis refers to number of substitution plans (some members have multiple substitution plans for conversion coating). The percentage value shown on each of the green bars indicates the proportion of substitution plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which there is expected to be a significant reduction in Cr(VI) usage.
Source: **RPA analysis, ADCR members**

The above summary shows:

- Variation in the status of different substitution plans in each of the years (this variation is due to issues such as technical difficulty (including consequential compatibility issues), types of substrates, types of parts); and
- Expected progression in future years as an increasing proportion of the substitution plans reach MRL 10.

The dates at which each substitution plan is expected to achieve each stage are estimates provided by the members based on each members' substitution plans, and there are uncertainties due to, for example, unexpected technical failures which may only reveal themselves at more advanced stages of testing (see description of TRL stages in Section 3.1.2). Consequently, the expected progress of substitution plans, especially in the outer years 2031 and 2036 where there is more uncertainty, may be slower (or faster) than estimated today, as presented in figure 3-6. The actual status of the substitution plans 12 years from now could be different to our expectations today.

Because many members have multiple substitution plans for conversion coating, it is the case that for those substitution plans that are not expected to have achieved MRL 10 by a given date, other substitution plans from the same member will have progressed to this level. This highlights the complexity of multiple substitution plans within members resulting from differences in, for example, type of substrate, types of components and type of test candidate being developed.

There are many issues that limit members' progression of the substitution plans beyond the stages indicated in fig. 3-6. Technical issues include for example failure to meet performance requirements on some types of components or types of substrates. Manufacturing issues include poor visibility of the test candidates compared to the Cr(VI) process (for the test candidates, it is much less easy to visually check that they have been properly applied to the substrate), which impacts inspectability and quality control. New inspection methods will need to be developed and this has a high level of uncertainty. Process issues include for example the requirement for approval from a large and diverse range of customers in a wide range of component uses (which requires extensive and time-consuming testing), and the need for a phased transition by product line. There are also interlinked and interdependent workstreams where for example substitution plans for conversion coating cannot be implemented until those for anodising have also been implemented. Some of the test candidates for conversion coating require additional treatment stages requiring additional tanks compared to the Cr(VI) process. Running both the old and new process in parallel is not practicable due to, for example, limitations on floor space and in these cases switch over to the Cr(VI)-free process will need to wait until all relevant substitution plans have reached the appropriate stage.

The timeframes associated with the activities presented in Figure 3-7 result from the requirements of the substitution process which are presented in Section 3.1.2. To be noted is that approval of suppliers cannot always occur in unison; qualification may need to cascade down the supply chain depending upon the number of tiers and actors involved. As resources are not available to action this simultaneously across all suppliers, the timescale for supplier qualification may be extended. Modifications may be required to the supply chain to allow for the installation of new equipment in some cases, although this can be mitigated by sourcing from existing established suppliers familiar with the requirements of qualification protocols.

3.16.2.1 Requested review period

It can be seen in Fig. 3-6 that despite ongoing and concerted efforts of the members to develop alternatives to Cr(VI) in conversion coating, it has not proved possible to replace Cr(VI) by the end of the review periods granted in the parent Authorisations (which end in September 2024/September 2026). It is clear from the chart that in 2031 (equivalent to seven years beyond the expiry date for the existing applications), while many substitution plans are expected to have successfully progressed to MRL 10 and the consortium is expected to have reduced its Cr(VI) use, an equally significant proportion of the substitution plans are not expected to have achieved MRL 10 and are expected to be predominantly at the certification or industrialisation stages, with some substitution plans at earlier stages. For these substitution plans (which are from several member companies), there is still expected to be a need for the use of Cr(VI).

As a result of the individual members' substitution plans summarised above, **the ADCR requests a review period of 12 years for the use of Cr(VI) in conversion coating.**

4 Continued Use Scenario

4.1 Introduction

Section 3 provided an analysis of the alternatives with respect to the technical feasibility, economic feasibility, availability and suitability of alternatives. The assessment highlights the importance of Cr(VI) to the mode of action for corrosion resistance and the other key functions delivered by chemical conversion coatings, in its application to aluminium (and it alloys), magnesium (and its alloys) and titanium substrates. Although some of the companies supporting this use have implemented alternatives at the industrial level (e.g. Cr(III) alternatives or acidic anodising) for some components, this is not across all components or products given varying geometries, operational performance requirements and substrates.

Until alternatives which are also compatible with pre- and post-treatment steps as relevant, and which deliver an equivalent level of functionality (as required) on all three substrates are tested, qualified, validated and certified for the production of components and products, use of the chromates in CCC formulations will continue to be required; their use is essential to meeting airworthiness and other safety and reliability requirements. Even then, issues may remain with legacy spare parts and maintenance where certification of components using alternatives is not technically feasible or available due to design control being held by MoDs, who will not revisit older designs in the near future.

In some cases, alternatives are technically qualified and certified, but time is needed to industrialise and implement them across all industrial sites in the value chain. Given the large numbers of BtP suppliers and MROs involved in the use of CCC, implementation itself may take several years (e.g. up to four years within the larger value chains).

As a result, as demonstrated by the substitution plan, the OEMs and DtBs as a whole (and as design owners) require between 7 and 12 years to complete substitution across all components and final products.

The continued use scenario can be summarised in Figure 4-1:

Continued use of Cr(VI) CCC while substitution plans progress	Continued use for production, repair and maintenance of parts and components
-> R&D on substitutes and progression through TRL 2/3 to 9 and to MRL10 continues	-> A&D sector retains and expands its EEA / UK manufacturing base
-> Downstream use continues in A&D supply chain as alternatives are certified and implemented	-> Industrialisation of substitutes and their adoption across supply chains
-> Modification of designs as substitutes are certified and industrialised	-> R&D into the adoption of more sustainable technologies continues
-> Update of Maintenance Manuals to enable substitution in MRO activities	-> Employment in the sector is retained while worker exposures and risks decline over time
-> Continued production, repair and maintenance of aircraft and other final products ensured	-> Impacts on civil aviation, emergency services and military mission readiness is minimised

Figure 4-1: Continued use scenario

The remainder of this section provides the following supporting information to describe the Continued Use Scenario:

- The market analysis of downstream uses in the A&D markets;
- Annual tonnages of the chromates used in CCC, including projected tonnages over the requested review period based on design owners' substitution plans; and
- The risks associated with the continued use of the chromates.

4.2 Market analysis of downstream uses

4.2.1 Introduction

The A&D industry has separately and jointly assessed, and continues to review, its needs to ensure:

- the ability to carry out the specific processes required to manufacture, maintain and repair A&D components and products in the EEA/UK; and
- continuity of supply of critical products containing hexavalent chromium.

The requirements of the ADCR members – as downstream users - supporting this application have been carefully identified and analysed, taking as the starting point the parent authorisations and the substance-use combinations covered by these. Over the lifetime of the ADCR consortium, the number of uses identified as requiring authorisation and the number of OEMs and downstream users supporting each use has decreased (including the individual chromate substances involved in a use), to ensure that authorisation is only sought for those cases where there is no substitute that is fully qualified as per stringent airworthiness requirements and industrialised by all members and their supply chains. The continual re-visiting of supply chain requirements fed into the narrowing of the substance-use combinations requiring re-authorisation compared to the original applications for authorisation. This has led, for example, to sodium chromate no longer being supported for authorisation in chemical conversion coating because members and their supply chains have been able to eliminate its use in the EEA and UK.

Furthermore, the scope of this combined AoA/SEA is driven by A&D qualification, validation and certification requirements, which can only be met by use of the substances/formulations that provide the required performance as mandated by airworthiness authorities. This constrains OEMs DtBs, and hence their suppliers and MRO facilities (civilian and military), to the use of the chromates in chemical conversion coating until alternatives can be qualified and certified across all the relevant components. In many cases, the choice of substances and mixtures to be used is further affected by the fact that they form part of a process flow (see Figure 2-2), which has been developed over time to meet specific performance requirements as part of ensuring airworthiness.

4.2.2 Overview of the European aerospace and defence sector

In 2020, the European A&D industry comprised over 3,000 companies of all sizes and employed over 880,000 highly skilled employees (with these figures including the UK[40]). As noted by the European Commission, the industry is "characterised by an extended supply chain and a fabric of dynamic small-

[40] Further information on the UK is provided in Annex 1.

and medium- sized enterprises throughout the EU, some of them world leaders in their domain"[41]. **Figure 4-2** provides details of turnover and employment for the industry in 2020, based on the AeroSpace and Defence Industries Association of Europe (ASD) publication "2021 Facts & Figures".[42]

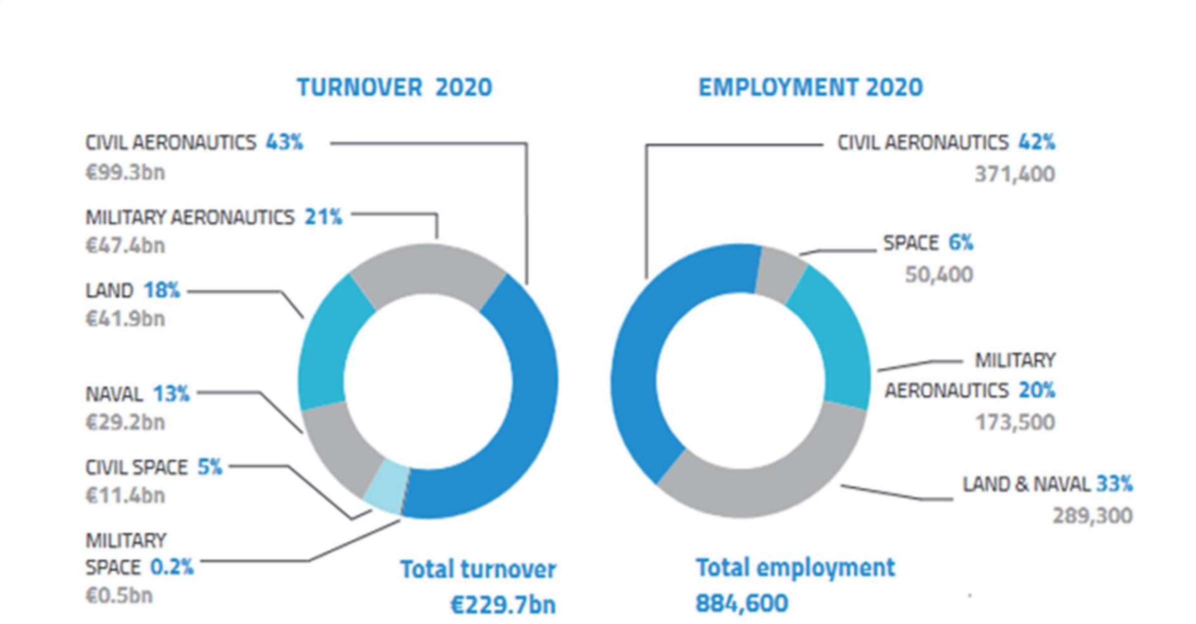

Figure 4-2: Turnover and Employment for the European Aerospace and Defence Industry in 2020
Based on ASD, 2021, available at: https://www.asd-europe.org/sites/default/files/atoms/files/ASD_Facts%26Figures_2021_.pdf

As can be seen from **Figure 4-2**, civil and military aeronautics alone accounted for 64% of turnover and 75% of employment for the sector in 2020.

Civil aeronautics alone accounted for over 370,000 jobs, revenues of over €99.3 billion and exports of €88.3 billion. Note, these figures are lower than those for 2019, reflecting the impacts of Covid-19 on the sector. For example, the 2019 figures for civil aeronautics were around 405,000 jobs and €130 billion in revenues, with exports amounting to around €109 billion.

The defence industry accounted for around 462,000 jobs, revenues of over €119 billion and exports of €45.6 billion. These figures reflect reductions in exports, employment and revenues compared to 2019, stemming from the impacts of COVID-19 on the sector.

The A&D sector is therefore recognised as important to the ongoing growth and competitiveness of the EU and UK economies. It is also recognised that both require long-term investments, with aircraft and other equipment being in service and production for several decades:

- Aircraft and other A&D products remain in service over long time periods. For example, the Boeing 747 first entered service in 1970, and continues to be flown and produced in 2022

[41] https://ec.europa.eu/defence-industry-space/eu-aeronautics-industry_en

[42] ASD, 2021: Facts & Figures, available at: https://www.asd-europe.org/facts-figures. Note that as of 10th November 2022, the name of the "AeroSpace and Defence Industries Association of Europe" becomes the "Aerospace, Security and Defence Industries Association of Europe"

(although it will now go out of production but remain in service). Given the need to ensure on-going airworthiness and due to certification requirements, there will continue to be a "legacy" demand for the use of chromates in the production of components for maintenance, repair and overhaul of existing aircraft and equipment, as well as for models that are still in production long periods after the first aircraft or military products were placed on the market;

- A&D technologies take many years to mature. Product development is a five- to ten-year process, and it can take 15 years (or more) before the results of research projects are applied in the market. As part of the development and roll-out of new A&D products, OEMs must be ready to demonstrate fully developed technologies, or they risk losing contracts that may have a lasting effect on business.[43]

- The long product development process applies not only to the introduction of new technologies, but also to any activities aimed at adapting existing technologies as required for the substitution of the safety critical uses of the chromates. As indicated below with respect to R&D activities, research on substitution of the chromates has been underway for several decades, with the substitution of the chromates in chemical conversion coatings processes proving one of the most difficult tasks, in part due to its process flow (see Figure 2-2) and relationship with other surface treatments.

- There are over 20,000 commercial aircraft and 15,000 business jets currently in operation globally. Given the global nature of civil aviation, it is important that global solutions are found to the use of the chromates, with respect to maintenance, overhaul and repair operations (MRO). Actors involved in MRO activities must adhere to manufacturers' requirements and ensure that they use certified components and products. They have no ability to substitute away from the chromates where these are mandated by the original equipment manufacturers.

4.2.3 Economic characteristics of Companies undertaking chemical conversion coating

4.2.3.1 Profile of Downstream Users

As noted in Section 2, chemical conversion coating is one of the most widespread uses of CT, SD and PD and the only use of DtC within A&D. As a treatment, it can be expected to be carried out across the largest number of downstream users, spanning products produced for aerospace, defence and as aeroderivatives. This includes in-house use by the major OEMs and DtB companies, as well as use by BtP suppliers and both military and civilian MROs.

CCC is relevant to production, repair, maintenance and overhaul of a range of different components. As noted above, it is particularly important for protection of Aluminium and Magnesium substrates. Examples (non-exhaustive) of the types of components identified through consultation as being treated by CCC are:

- Airframes, panels, flaps and airframe fasteners (rivets, bolts and screws);
- Engines;
- Landing gear;

[43] ATI (2017): The Economics of Aerospace: The Economic Impacts of UK Aerospace Industrial Strategy.

- Actuation systems;
- Propellers;
- Electronic components;
- Helicopter components;
- Military and naval sub-assemblies; and
- Components for spacecraft.

Given the widespread use of the four chromates in CCC, SEA questionnaire responses were provided by 79 organisations (operating on over 166 sites), with their size distribution by reporting company (not by site, unless sites are located in both the EEA and UK) as follows. The data highlight the fact that some of the companies have operations in both the EEA and UK:

Company size[44]	EEA	UK
• Small	6	9
• Medium	21	10
• Large	30	14
• Total	57	33

The above figures also highlight the importance of small and medium sized companies within the supply chain, with these comprising over half of the responses (taking into account the fact that it is mainly the larger companies that have legal entities in both the EEA and UK).

As would be expected by the composition of the ADCR and by the nature of their key suppliers, respondents to the SEA survey tended to be the medium and larger sized companies within their sectors of activity.

4.2.3.2 Economic characteristics

Table 4-1 provides a summary of the number of companies identifying their activities against different NACE codes, which are used here to develop the economic characteristics of the "typical" OEM, DtB, BtP or MRO company. Companies may have indicated more than one NACE code as being relevant to their activities, such that the number of relevant NACE code counts is higher than the number of SEA responses relevant to chemical conversion coating alone. It is notable that most companies identified "treatment and coating of metals" as a relevant NACE code, while at the same time identifying other relevant codes.

The table also provides relevant Eurostat data for each code on turnover (weighted average provided here, based on % of respondents by company size), Gross Value Added (GVA) per employee, average personnel costs and average GOS as a percentage of turnover.

[44] https://ec.europa.eu/growth/smes/sme-definition_en

Table 4-1: Economic characteristics of "typical" companies by NACE in sectors involved in Chemical Conversion Coating (2018 Eurostat data, covering the EU 28)					
	Number of responses by NACE code	Weighted average turnover per company € million	GVA per employee €	Average personnel costs per employee €	Average GOS as a % of turnover
C2561 - Treatment and coating of metals	51	20.88	54,000	35,500	15.5%
C2540 - Manufacture of weapons and ammunition	4	306.44	70,000	42,500	12.3%
C2594 - Manufacture of fasteners and screw machine products	7	57.20	65,000	43,200	9.7%
C2599 - Manufacture of other fabricated metal products n.e.c.	15	57.20	65,000	43,200	9.7%
C265 - Manufacture of instruments and appliances for measuring, testing and navigation;	3	159.30	84,000	57,500	11.1%
C2732 - Manufacture of other electronic and electric wires and cables	2	34.39	76,000	51,700	4.8%
C2815 - Manufacture of bearings, gears, gearing and driving elements	7	284.64	72,000	44,500	7.9%
C3030 - Manufacture of air and spacecraft and related machinery	19	1,214.65	98,000	76,400	11.2%
C3040 - Manufacture of military fighting vehicles	8	1,214.65	99,000	64,800	9.8%
C3316 - Repair and maintenance of aircraft and spacecraft	27	71.33	85,000	56,400	8.4%
Other	3	NA	NA	NA	NA
Total count	146				
Note: The count total is by number of NACE code identifications by company and not by sites, with 79 companies providing data					

Turnover is calculated as the weighted average by company size, as this is the most appropriate means of reflecting the level of turnover across the EEA (including UK) linked to conversion coating treatments and taking into account the size distribution of the companies[45] that are involved in such activities. GVA per employee, numbers of employees, and average personnel costs are given as the sector average and not per company size for several of the NACE codes, so it was not possible to calculate weighted averages for these. Note that the count total is by company and not by site.

Data on Gross Operating Surplus[46] as a percentage of turnover (the GOS rate) is also used here to provide an indication of the profits associated with the turnover generated by these sites. This is based on a figure of 10.5% which is the average across the various NACE codes weighted by the number of companies declaring each NACE code.

As can be seen from **Table 4-2**, the 166 sites for which data were collected via the SEA questionnaire represent an estimated €68.8 billion in turnover and €7.2 billion in GOS as a proxy for profits. Across all 430 sites (350 in the EEA and 80 in the UK) expected to be undertaking chemical conversion coating, these figures rise to over €121 billion in turnover and €12.7 billion in GOS.

Table 4-2: Key turnover and profit data for market undertaking chemical conversion coating (based on 2018/2019 Eurostat data)

Sites covered by SEA responses/ Extrapolated number of sites	Estimated turnover based on weighted average € million	Gross operating surplus (estimate based on 10.5%) € million
120 EEA Sites	49,590	5,206
46 UK sites	19,211	2,017
Extrapolation to all sites involved in chromate-based CCC in the EU or UK		
350 EEA sites	87,248	9,161
80 UK sites	34,172	3,588

Source: Based on SEA questionnaire responses, combined with Eurostat data
Note: See Section 2.3.3.6 for basis of extrapolation from the 64 responses to 210 sites in the EEA and UK combined

4.2.3.3 Economic importance of chemical conversion coatings to revenues

Chemical conversion coating will only account for a small percentage of the calculated revenues, GVA and jobs given in the above table. However, while costs and revenues directly attributable to CCC for any company, and particularly for an OEM, DtB or MRO may be small, it is a vital portion of their value stream (by providing anti-corrosion, adhesion promotion, chemical resistance, layer thickness, resistivity and other benefits) and cannot for either technical or economic impact assessment purposes be separated from the rest of the manufacturing process. By way of example, one engine

45 Microenterprises have been excluded from the turnover calculations as very few such enterprises will be acting as key suppliers within the supply chain. The calculations taken into account the percentage of turnover for each relevant sector attributed to small, medium and large companies to derive the average weighted per site by role figures used in these calculations.

46 EUROSTAT defines the GOS rate (i.e. % of turnover) as an indicator of profits. GOS equals gross output (turnover or gross premiums in Eurostat)) less the cost of intermediate goods and services to give gross value added, and less compensation of employees and taxes and subsidies on production and imports. It is gross because it makes no allowance for consumption of fixed capital (CFC).

manufacturer notes that while the production costs related to CCC are less than 5%, the total revenue lost under the NUS would be around 80%.

In addition, responses to the SEA questionnaire highlight that pre-treatment, inorganic finish stripping (to repair defects) and primer applications using the chromates may also be important with respect to production costs and turnover linked to chemical conversion coating. **Table 4-3** sets out the number of companies that indicated that they also carry out pre-treatments (deoxidising, etching, pickling), as well as inorganic finish stripping combined with CCC. This includes both Cr(VI)-based and non-Cr(VI) based pre- and post-treatments as part of the certified process for manufacturing components/final products.

Table 4-3: Number of companies providing SEA data undertaking relevant pre- and post-treatments to CCC (out of 79)

Role	Number of companies also undertaking pre-treatments		Number of companies also undertaking inorganic finish stripping	
	Cr(VI) based	**Non-Cr(VI) based**	**Cr(VI) based**	**Non-Cr(VI) based**
Build-to-Print	16	16	10	8
Design-to-Build	5	5	5	4
MRO only	7	2	4	2
OEMs	2	2	1	1
Total	30	25	20	15

Of note is the fact that a significant number of companies undertake Cr(VI)-based pre-treatments and inorganic finish stripping (although not necessarily both). There is also some overlap in the use of both the chromate-based and chromate-free treatments, when the latter is permitted under the design owners' performance requirements and associated EASA certification/military qualification. The pre-treatments and inorganic finish stripping may also be relevant to other "uses", as they are a common part of the process flow for several of the uses being supported by the ADCR.

Given the importance of CCC to protecting metal substrates such as aluminium and magnesium, its loss would have a far greater impact on revenues and the financial viability of companies than suggested by its share of production costs. The loss would also be greater than the share of production costs accounted for by pre-treatments, CCC and inorganic finish stripping combined, as illustrated by the example given above for an engine manufacturer which also holds true for aircraft and defence product manufacturers.

As a result, we have taken the combination of these activities as the relevant process flow for assessing economic impacts, regardless of whether the pre-treatments, CCC and inorganic finish stripping are chromate or non-chromate based, as it is the series of processes and profits and employment linked to them as an overall activity that is relevant for this SEA.

As might be expected given the example of the engine manufacturer cited above, responses to the SEA questionnaire by companies carrying out CCC using chromium trioxide, sodium dichromate, potassium dichromate and/or dichromium tris(chromate) indicate that each of the three processes on their own contribute to less than 11% of their aerospace and defence related production costs, as indicated in **Table 4-4**. When considered together as a process flow (see Figure 2-2), the responses indicate that the three processes will generally account for between 11% to 30% of production costs for the majority of companies.

Table 4-4: Revenues generated by or linked to each of the three chromate using processes					
	<11%	**11% - 30%**	**31% - 50%**	**51% or higher**	**Total responses across all three uses**
Build-to-Print	37	10	6	14	67
Design-to-Build	21	3	2	6	32
OEMs*	10	0	0	0	10
*These responses cover multiple sites and only reflect those companies carrying out the activities					

It is important to note that roughly half of the Design-to-Build suppliers carry out surface treatment activities for sectors other than the aerospace and defence sectors. This includes producing parts and assemblies for machinery, food manufacturing, medical equipment, automotive uses, oil drilling and electrical equipment. These surface treatment activities may or may not also involve the use of chromates (e.g. for automotive uses) for chemical conversion purposes.

As would be expected, although CCC in of itself does not account for a significant percentage of turnover, all of the OEMs highlighted the critical importance of CCC for a wide range of aircraft and defence hardware. They stressed the impossibility of certifying an aircraft as meeting airworthiness requirements or defence equipment as meeting safety requirements without the use of chromate-based CCCs mandated in the drawings and performance requirements for those components unless there are certified alternatives. DtBs as design owners also noted that CCC is critical to their components/final products and hence to their customers.

It is also of note that four military MROs – including those operated by MoDs – have all highlighted the importance of chromate-based CCC to their maintenance, repair and overhaul activities. Should this use not be allowed to continue, there would be significant impacts on their ability to maintain current aircraft and equipment.

4.2.3.4 Investment in alternatives, risk management measures and monitoring

OEMs

OEMs have carried out R&D into the substitution of the chromates for over 30 years, but as detailed in the AoA technical difficulties remain in substituting the use of chromium trioxide, sodium dichromate, potassium dichromate and dichromium tris(chromate) in CCC. Although some have developed, validated, qualified and are currently certifying alternatives for use in the manufacture of their final products, others are still in the testing and development phase. These differences are driven by differences in operating performance requirements, geometries and substrates across final products.

Examples of R&D expenditure outside of the larger joint programmes include (expenditure after 2014):

- One of the companies that has indicated that it has identified an alternative and is in the later TRL stages in terms of progressing substitution notes that it has spent €150k per annum over the last five years in getting to a point where it is ready to qualify the alternative, with additional remaining costs estimated at around €260k.

- One of the OEMs, with an annual R&D budget of €2.4 million, is currently progressing the use of Chrome III-based processes as a substitute for CCC. They note R&D costs related to pilot-scale trials of around €2.5 million. If these demonstrate that the alternatives can meet performance requirements, then they will need to re-design components/final products, introduce a second-processing step, and undertake qualifications and certifications prior to industrialisation. No cost estimates are available for the later activities.
- A second company has investigated a range of alternatives to chromate-based conversion coatings, citing R&D costs of circa. €1.7 million per annum. They have yet to progress sufficiently to be able to provide estimates as to the level of future investment required.
- A third company incurred costs of €2.6 million over a three-year period at one site into R&D into alternative processes (substitution activity), where these costs include engineering activities together with the support from their production facility to manufacture and process samples using the potential new processes, together with the existing processes as a baseline for comparison. Design of alternative components where applicable for new developments is covered under the specific programmes, and the additional costs incurred in relation to these could not be separated out; additional sites spent circa €200,000 into further testing and development work;
- A fourth company quotes annual R&D costs aimed at substitution of €6.2 million per annum across all substitution work with this budget increasing over time. They are evaluating three different test candidates to use of Cr(VI)-based CCC at present but are unable to estimate the likely future costs of moving to any of them.
- Another company has carried out R&D across a number of its sites, with this involving expenditure of around €2 million at one site and over €100k at a further two sites. The costs of moving to a Cr(III)-based alternative are estimated at €10.5 million, over a 10 year period (from design and installation of new equipment, demonstration, qualification and agreeing changes to drawings). They also cite costs of €45 million related to the qualification of changes across the process line, with these related to just one customer aircraft platform; qualification related activities at another site are quoted as equating to around €200k (this is on top of investments into additional RMM across the three sites). In total, this company consumes less than one tonne per annum of the chromates across all of its locations, and incurring costs of such magnitude for just one aircraft platform would not be economically feasible.
- One of the remaining OEMs has spent €180k per annum since 2014, with this including R&D into the use of a Cr(III)-based alternative to CCC. On top of this, €120k was spent installing a pilot plant and they expect to have spent another €250k developing the alternative. Investment in new plant costing €1.8 million would then follow, together with costs of around €80k in gaining new qualifications across 14 units, and €360k in agreeing changes to drawings. Additional costs will be incurred in the future to roll such changes out over other units.

In addition to the above considerations, companies also note that they have a lack of space available to be able to accommodate the multiple new process lines, with this being an issue for some CCC alternatives which would involve a two-step process. They also note concern over the level of financing that will have to be raised and their ability to do so, especially given the current high interest rates that apply in the EEA and UK.

An ADCR member notes that between the period 2018 to 2021 alone, they spent €5.9 million on the certification of alternatives for use in the manufacturing in their products – including to the use of chromate-based CCC - where substitution was established as technically and economically feasible. This followed €186,600 in own R&D, on top of annual expenditure of around €100,000 into co-financed R&D projects.

The SEA questionnaire also sought data on the level of investment that has been undertaken into new plant and equipment since 2014, with the aim of gaining insight into the cost of the additional risk management measures that had to be introduced in response to the conditions of use placed on the parent authorisations. These questions included information on the expected life of the capital investments. Note that such investments have been made in addition to the on-going costs of developing, qualifying and certifying alternatives, which will also include testing costs and often the construction of pilot plants.

Examples of such expenditure include the following, with all this expenditure having taken place in 2017 or later:

- Investment of €5 million in new baths in both the EU and UK used in CCC;
- Expenditure of over €1.8 million on improvements to water treatment systems across a number of sites and on new degreasing plants, as well as monitoring activities (air and environmental);
- Expenditure of over €5 million in capital equipment over the past 15 years to replace chromate-based processes involving the use of all four chromates and across uses including CCC;
- €1.7 million in expenditure in 2019/2020 on collective protection equipment, including new vacuum and exhaust ventilation equipment;
- Expenditure of almost €2.5 million on collective protection measures, new vacuum systems, and additional PPE, new health and safety studies including improvement of exposure monitoring systems;
- Expenditure of around €3.77 million on new process lines, including engineering controls and extraction equipment, and additional PPE.
- Expenditure of €135,00 in 2021 to reduce emissions from CCC baths.

The lifetime quoted for the various capital investments are generally 10 years for smaller items and 15-20 years for new baths, extraction equipment and wastewater treatment plants.

Further information on the R&D carried out by the OEMs (and DtB companies) is provided in Section 3.4.

Design-to-Build suppliers

Ten DtB companies have carried out R&D into alternatives for CCC either themselves or in cooperation with their customers or suppliers (i.e. the OEMs), with the others relying on R&D carried out by their customers. This has included repurposing plant to enable pilot trial activities, as well as participation in some of the larger research initiatives described in Section 3.4.

Reasons given in responses to the SEA questionnaire by suppliers to ADCR members for not moving to alternatives include: the need for the alternative to be qualified; the alternative not being available on the market in sufficient quantities; the need for additional time to implement the alternative (i.e. to invest in new equipment and gain certifications from their customer); and the alternative not being acceptable due to inadequate technical performance. Those who cannot move cite the need for "years" until substitution is feasible.

Ten of the 15 DtB suppliers (covering 19 sites) have also undertaken capital investments relevant to the continued use of the chromates in CCC. These have included modernisation of production lines (e.g. automation to reduce worker exposures), purchase of new baths and speciality equipment, new air filter equipment, and new effluent control equipment. Such investments have ranged from €15,000 to €60,000 to over €800,000 and are expected to have a 10-year minimum life. These investments were undertaken in various years by the different companies, starting in 2017 up to 2021.

One of the companies quotes the following costs for modifying production processes to enable a move to alternatives across three chromate using processes, including CCC, with the costs incurred over the period 2018 to 2021:

- Capital costs of change in production processes for a defence product: €2 million
- Process development costs: €0.5 million
- Testing and verification: €1.5 million
- Re-qualification (including a flight and other tests): €30 million
- Patent costs: €0.1 million
- Total costs: €33.1 million

Clearly such costs are significant, even for a large company. In this case, the costs relate to substitution of less than 50kg per annum of chromate (CT, SD and DtC) consumption.

Build-to-Print suppliers

Build-to-Print suppliers rely on their customers (OEMs and/or DtBs) to mandate the requirements of the products they manufacture, with this including the use of chromates in CCC. As a result, BtP suppliers have little involvement in R&D activities, unless they are supporting R&D activities such as pilot testing the use of an alternative. This has been the case for two BtP members of the ADCR. They have been involved in supporting testing and R&D carried out by their OEM customers. These include testing of alternatives to CCC involving expenditure ranging from €20,000 to €50,000. Another Build-to-Print supplier indicated total expenditure of over €1.35 million as their contribution to collaborative EU Research programmes on substitution of the chromates (APACA, ECOCONV and NEPAL).

Several of the Build-to-Print suppliers have undertaken investments in the period from 2010 to 2021 relevant to their use of the chromates. Examples include investments carried out in 2012/13 to improve processing lines (including improved air extraction and filtration systems) and to expand processing capacity in response to the then increasing demand for aircraft deliveries. These investments ranged from ca. €30k to €1 million (with an average of 15 year's expected lifetime). Since 2012, several companies have also invested in improved emissions control equipment (stack improvements, LEV and tank lids).

It should also be noted that some of these suppliers will have to be National Aerospace and Defence Contractors Accreditation Program (NADCAP) accredited and will be subject to International Standards Organisation (ISO) audits of their processes using the chromates, in order to secure and hold accreditations/certifications required by their customers (in other cases, the OEM will qualify/certify their suppliers rather than require NADCAP accreditation). This expenditure varies by company size, with related costs quoted as varying from e.g. €10,000 to €60,000 to €200,000 per company.

Only two Build-to-Print suppliers indicated that they had undertaken investment in new facilities. One has invested €40 million in a new Build-to-Print components production and a legacy parts manufacturing facility.

MROs

As would be expected given their role in the value chain, MROs have not been involved in R&D regarding substitution of the chromates in CCC.

The MROs have undertaken significant investments into new equipment, however, including for waste management and emissions reduction. Specific to chromate-based CCC, investments have included:

- Installation of new baths for CCC activities in 2020, at a cost of around €460,000 with this expected to have a lifetime of at least 15 years;
- Purchase of various capital equipment at a cost of around €4 million across a range of sites to reduce emissions from existing processes (although not relevant to CCC, they also invested €0.5 million in equipment to enable a substitute to be used in separate process lines, following changes being qualified, certified and approved in an OEM's Maintenance Manuals); and
- Investment in new facilities at a cost of over €10-50 million, with this including equipment specific to the continued use of the chromates in CCC (and other uses) and to their substitution in the maintenance and repair of a set of components and end products.

4.2.3.5 Potential benefits from on-going substitution under the Continued Use Scenario

In addition to collecting information on economic characteristics, companies were also asked whether they expected there to also be potential benefits (under the continued use scenario) in the future with a move to alternatives once these had been certified for their components and products and implemented. A range of potential types of benefits were identified in the SEA questionnaire, with companies asked to identify those that they thought might arise as progression is made in the substitution of the chromates.

Across respondents, regardless of role in the supply chain, most companies identified better relations with authorities as a benefit. Significant numbers also identified better public, shareholder and community relations, with this identified as particularly important by the OEMs and DtB companies. Increased customer satisfaction was identified by some DtB companies.

4.2.4 End markets in civil aviation and defence

The use of chromate-based conversion coatings provides extremely important beneficial properties to A&D products that must operate safely and reliably, across different geographies, often in extreme temperatures and precipitation, and in aggressive environments with a high risk of corrosion (due to extreme temperatures, precipitation, salt spray and altitudes).

Because the use of the chromates in CCC cannot be fully substituted at present, they play a critical role in ensuring the reliability and safety of final products. Thus, although the economic importance of the chromates in CCC is indirect in nature, its significance is clear with respect to:

- The ability of MROs (civilian and military) to undertake their activities within the EEA and UK, with this including the ability to carry out repairs with short turn-around times;
- The importance of timely MRO services to airlines and military fleets, reducing the amount of time that aircraft are grounded or are out of service;
- The impacts that increased groundings of aircraft (Aircraft on the Ground - AoG) would have on the availability and costs of flights for passengers and for cargo transport, with reductions

in passenger km and cargo km translating into significant economic losses not just within the EEA and UK but globally; and

- The importance of timely MRO services for military forces, given the critical importance of mission readiness and the avoidance of impaired operations, which could only otherwise be guaranteed by the purchase of additional aircraft and weapon systems to compensate for AoG or systems out of service.

The economic importance of ensuring that aircraft retain their airworthiness is illustrated by the figures quoted in Section 2 above for the number of air passengers transported in the European Union in 2019 (over one billion), as well as the net profits of the airlines in 2019 at US$ 6.5 billion (€5.8 billion, £5.1 billion).

The military importance of ensuring that military aircraft, land and naval hardware maintain their mission readiness cannot be quantified in the same manner; however, the involvement of MoDs (as well as the MROs supporting military forces) in preparing this combined AoA/SEA through the provision of information that demonstrates the critical nature of chromate-based CCC to the on-going preparedness of their military forces in particular.

4.2.5 Expected growth in the EEA and UK A&D sector

4.2.5.1 Civilian aircraft

Demand for new civilian aircraft is expected to grow into the future. Projected global compound annual growth rates (CAGR) for different aircraft classes for the period 2020-2031 are given in the figure below[47], with this suggesting a CAGR from 2020 to 2031 of around 2.5%.

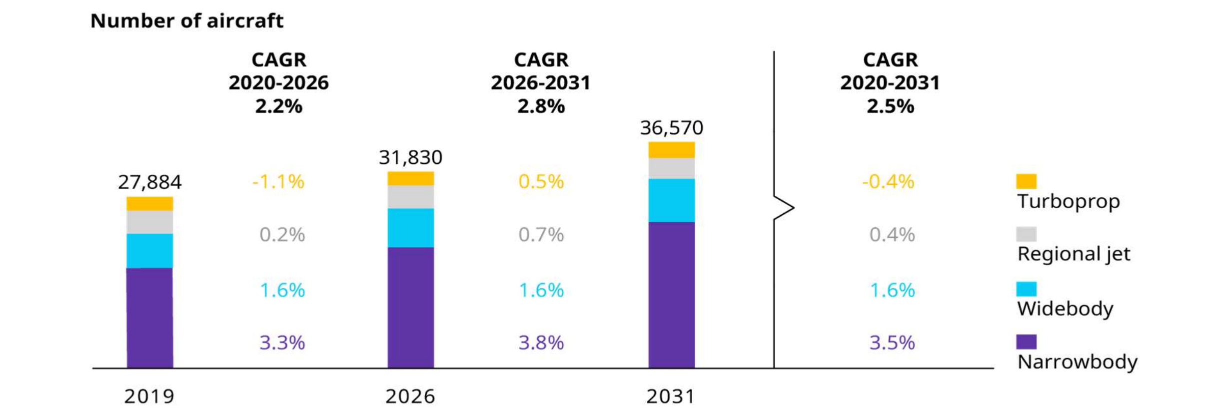

Figure 4–3: Global fleet forecast by aircraft class, 2020-2031
***Source:* Oliver Wyman analysis, 2021[21]**

Market reports issued by Airbus and Boeing indicate that future growth is expected to extend beyond 2031. Airbus' Global Market Forecast for 2022-2041 predicts that passenger air traffic will grow at 3.6% CAGR and freight traffic will grow at 3.2% CAGR globally. By 2041, there will be some 46,900 aircraft in service, with this including an estimated 39,500 new passenger and freighter aircraft (and

[47] Oliver Wyman Analysis (2021): https://www.oliverwyman.com/our-expertise/insights/2021/jan/global-fleet-and-mro-market-forecast-2021-2031.html

the retirement of some of the older aircraft. This includes delivery of new aircraft for the European market, as well as the Asian and Chinese markets.[48]

Boeing's 2022 Commercial Market Outlook[49] indicates a similar level of increase, noting that the global fleet will increase by around 80% through to 2041 with the forecast value of new airplane deliveries at around US $7.2 trillion (based on a slightly higher growth in traffic at around 3.8% CAGR).

Based on figures publicly available on Airbus' website, the demand for new aircraft will progressively shift from fleet growth to accelerated replacement of older, less fuel-efficient aircraft. This will mean a need for over 39,000 new passenger and freighter aircraft, delivered over the next 20 years; around 15,250 of these will be for replacement of older less fuel-efficient models. By 2040, the vast majority of commercial aircraft in operation will be of the latest generation. Projections based on generic neutral seating categories (100+ seater passenger aircraft and 10 tonnes+ freighters) are given in **Table 4-5** below.

Table 4-5: Airbus Global Market Forecast: projected new deliveries 2021-2040

Category	Africa	Asia-Pacific	CIS	Europe	Latin America	Middle East	North America	Total
Pax Units								
Small	860	13,660	1,160	5,220	2,170	1,570	5,050	**29,690**
Medium	140	2,350	120	1,040	180	420	640	**4,890**
Large	80	1,380	80	600	100	980	340	**3,560**
Total	**1,080**	**17,390**	**1,360**	**6,860**	**2,450**	**2,970**	**6,030**	**38,140**
Freight Units								
Small	-	-	-	-	-	-	-	**-**
Medium	10	120	40	40	10	20	210	**450**
Large	10	110	40	60	-	30	180	**430**
Total	**20**	**230**	**80**	**100**	**10**	**50**	**390**	**880**
Total Units								
Small	860	13,660	1,160	5,220	2,170	1,570	5,050	**29,690**
Medium	150	2,470	160	1,080	190	440	850	**5,340**
Large	90	1,490	120	660	100	1,010	520	**3,990**
Total	**1,100**	**17,620**	**1,440**	**6,960**	**2,460**	**3,020**	**6,420**	**39,020**

Source: Ascend, Airbus (undated): Global Market Forecast 2021 – 2040. Available at: https://www.airbus.com/en/products-services/commercial-aircraft/market/global-market-forecast

When considering these figures, it is important to recognise that the European aerospace sector is a global exporter of aircraft, and A&D products make a significant contribution to the overall balance of trade. For example, France and Germany alone had export markets totalling over US$ 57 billion in 2020, while the UK export market was around US$13.2 billion in 2020.[50]

However, unless operations in the EEA and UK can remain technically and financially viable in the short to medium term, the ability of EEA/UK based OEMs to carry out manufacturing at the levels implied by these compound annual growth rates is unlikely to be feasible. As a result, manufacture of the newer generations of aircraft and military products may shift to locations outside the EEA/UK with a consequent loss in GVA to the EU and UK economies, with enormous impacts on employment. This is

48 https://www.airbus.com/sites/g/files/jlcbta136/files/2022-07/GMF-Presentation-2022-2041.pdf

49 https://www.boeing.com/commercial/market/commercial-market-outlook/index.page

50 https://www.statista.com/statistics/263290/aerospace-industry-revenue-breakdown/

despite the fact that the move to newer generation aircraft which could reduce future reliance on the chromate-based CCC.

4.2.5.2 The MRO market

Not only would the manufacture of new aircraft in the EEA and UK be impacted but anticipated growth in the aftermarket parts segment would also be affected. The aircraft spare components/final product market encompasses the market for both new and used rotable[51] components available as spares for aircraft and other products. This market was projected to grow with a CAGR of over 4% over the period from 2022-2027, although this rate may now be lower due to Covid-19. Growth is due to the increase in the commercial aircraft fleet as well as the need for timely MRO services to keep aircraft in-service.

The MRO market was significantly affected by COVID-19 in 2020 but saw a gradual increase in demand as travel restrictions were lifted in 2021 and is expected to see positive growth over the next five to ten years. Globally, the market is expected to have a CAGR of over 3% over the period from 2022-2027, as illustrated in the figure below.[52, 53]

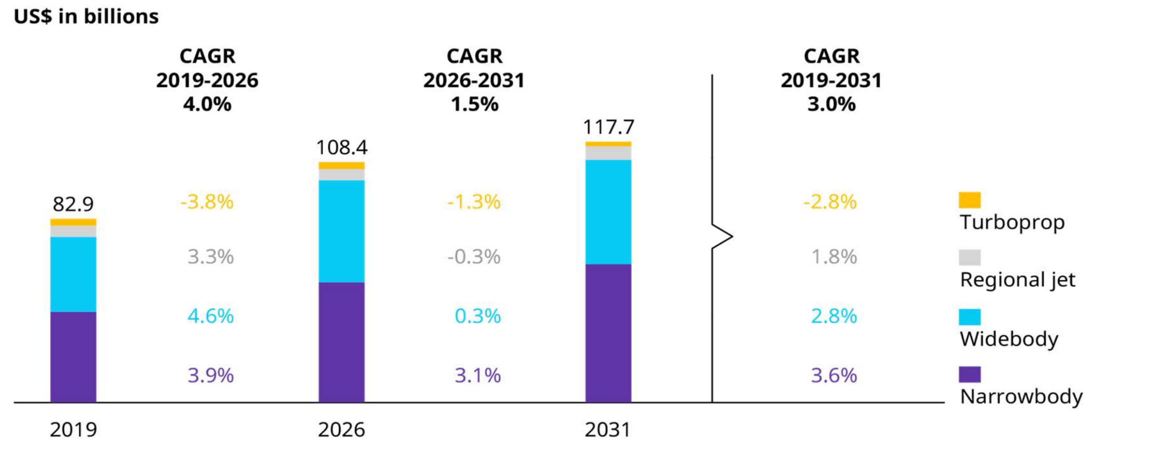

Figure 4–4: MRO market forecast by aircraft class, 2019-2031
Source: Oliver Wyman analysis

This growth is due to three factors: 1) Airlines are risk averse and try to maintain their fleets in an optimum condition, so as to delay the need to procure new aircraft, owing to the high investment costs of such aircraft - with COVID-19 severely impacting revenues and profit margins, more airlines are expected to resort to MROs to maintain fleet efficiency; 2) Airlines face very stringent MRO requirements so are not able to postpone MRO requirements; and 3) Increases in fleet sizes over the next five years will also lead to a continued growth in demand for maintenance and repair activities.

51 A component which is removed and replaced at pre-determined intervals measured in elapsed flight hours and/or flight cycles after which the removed item is sent for overhaul and will be subsequently re-used.

52 Mordor Intelligence, Commercial Aircraft Maintenance, Repair, and Overhaul (MRO) Market – Growth, Trends, Covid-19 Impact and Forecasts (2022 - 2027)

53 Oliver Wyman analysis: at: A forecast update on the global commercial airline fleet and aftermarket for 2020

4.2.5.3 The defence market

The war in Ukraine has led to several EEA countries and the UK to revisit their defence expenditure. In particular, several countries that are NATO members and which previously did not meet the target of spending 2% of GDP on defence are now committed to meeting that target. This compares to Eurostat figures for total general government expenditure on defence in 202 of around 1.3% of GDP for the EU[54]. The increase in investment will equate to hundreds of billions of Euros (e.g. Germany alone has pledged €100 billion in defence spending). Similarly, defence spending in the UK is expected to increase to over 2%, with projections in June 2022 suggesting 2.3% of GDP but Government commitments announced in October 2022 aiming for a target of 3% of GDP by 2030[55]. This equates to an increase in spending of around £157 billion between 2022 and 2030.

Such investment, which will include new spending on existing technologies, may also result in a continued reliance on the use of the chromates for CCC in the short to medium term until alternatives are certified for use in the manufacture of the relevant components and final products.

With respect to currently in-service products, the global military aviation maintenance, repair, and overhaul market registered a value of US $38 billion (€32 billion, £28 billion) in 2021, and it is expected to register a compound annual growth rate (CAGR) of over 2.5% during the forecast period 2022-2031. The European segment of this market is the fastest growing segment. The global civilian aircraft MRO market has a market size of US $70 billion (€59 billion, £51 billion) in 2021 and is growing even faster at a CAGR of over 4.6%.[56]

4.3 Annual tonnages of the chromates used

4.3.1 Consultation for the CSR

As part of preparation of the CSR, site discussions were held with ADCR members and some of their key suppliers. This work included collection of data on the tonnages of the different chromates used per site. The tonnages assumed in the CSR range from 0 to 332 kg Cr(VI) per year per site using multiple chromates, with tonnages for individual sites as follows:

- 0 to 500 kg CT used per year, translating to a maximum of 260 kg Cr(VI);
- 0 to 250 kg SD used per year, translating to a maximum of 100 kg Cr(VI);
- 0 to 210 kg PD used per year, translating to a maximum of 73.5 kg Cr(VI); and
- 0 to 10 kg DtC used per year, translating to a maximum of 5.8 kg Cr(VI).

As indicated above, the upper Cr(VI) tonnage/year has been estimated based on sites using several chromates for CCC. This will be an overestimation for sites using only one chromate, for example, those only using DtC for touch-up purposes. Data from consultation highlight the fact that most sites will use significantly less than the maximum values quoted above.

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[54] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Government_expenditure_on_defence

[55] https://www.bloomberg.com/news/articles/2022-09-25/defence-spending-to-increase-by-at-least-52bn-in-response-to-russian-aggression or https://rusi.org/explore-our-research/publications/occasional-papers/famine-feast-implications-3-uk-defence-budget

[56] https://www.prnewswire.com/news-releases/at-4-61-cagr-aircraft-mro-market-is-expected-to-reach-usd-97-12-billion-to-2028---exclusive-report-by-brandessence-market-research-301500861.html

4.3.2 Article 66 notifications data

The number of Article 66 notifications made to ECHA in the various tonnage bands at which this is publicly reported is presented in **Table 4-6**.

A key difficulty in using the Article 66 data is that reporting is based on tonnage bands rather than actual tonnage information. It is therefore difficult to derive estimates of annual tonnages based on this information, especially as actual tonnages used at individual sites making notifications may be significantly lower than the upper limit for each of the tonnage bands. This is especially true for Dichromium tris (chromate). In addition, the notifications data covers multiple treatments and hence its use for conversion coating alone would be misleading.

A further difficulty is that it is unclear what some notifications represent. Consultation with individual notifiers as part of preparation of this combined AoA/SEA indicates that some notified volumes may be very approximate as Article 66 does not oblige declaration of volumes; in other cases, companies notified the volume of the mixtures that they used rather than the tonnage of the chromate within the mixtures. In addition, some mis-notified in units other than tonnes (e.g. in kg or fractions of kg). This has been identified in particular with respect to DtC, which is present only in very small concentrations in touch-up pens/solutions. When challenged as to the quantities used, members covering multiple sites indicated that they notified use at 0.1-1 tonnes per year, when in practice it is only around 5 kg per site. Similarly, another notified in tonnes when the proper unit was kg. This may explain some of the non-credible notifications for DtC, which is only used in touch-up activities.

In general, however, the notifications data supports the figure of 350 EEA sites, calculated using supply chain information provided by ADCR OEM members, other ADCR members, SEA responses and taking into account other companies submitting their own authorisations. It also takes into account the on-going drive towards substitution of the chromates in CCC, which has reduced the use of CT, SD, PD and DtC within the supply chain.

Table 4-6: Article 66 notifications to ECHA by chromate and tonnage

Substance	Authorised Use(s)	Tonnage bands	Number of notifications
Chromium trioxide	Slurry coating and chemical conversion coating REACH/19/29/0	<0.1 tonnes per year	18
		0.1 - 1 tonnes per year	5
		1 - 10 tonnes per year	13
		NA	7
		Total	**43**
	Passivation of non-Al metallic coatings, Passivation of stainless steel, chemical conversion coating and anodising and anodise sealing – **aerospace only** REACH/20/18/14 to REACH/20/18/20	<0.1 tonnes per year	42
		>1000 tonnes per year	2
		0.1 - 1 tonnes per year	89
		1 - 10 tonnes per year	41
		10 - 100 tonnes per year	10
		100 - 1000 tonnes per year	6
		NA	90
		Total	**280**
	Passivation of non-Al metallic coatings, Passivation of stainless steel, chemical conversion	<0.1 tonnes per year	74
		>1000 tonnes per year	2
		0.1 - 1 tonnes per year	53

Table 4-6: Article 66 notifications to ECHA by chromate and tonnage			
Substance	**Authorised Use(s)**	**Tonnage bands**	**Number of notifications**
	coating, slurry coating and anodising and anodise sealing – **industrial** REACH/20/18/21 to REACH/20/18/27	1 - 10 tonnes per year	22
		10 - 100 tonnes per year	1
		100 - 1000 tonnes per year	2
		NA	156
		Total	**310**
		Grand total	**633**
Sodium Dichromate	Chemical conversion coating REACH/20/4/1	<0.1 tonnes per year	14
		0.1 - 1 tonnes per year	14
		1 - 10 tonnes per year	7
		100 - 1000 tonnes per year	1
		NA	25
		Total	**61**
	Passivation of non-Al metallic coatings, passivation of stainless steel and chemical conversion coating REACH/20/5/3 to REACH/20/5/5	<0.1 tonnes per year	12
		0.1 - 1 tonnes per year	8
		1 - 10 tonnes per year	8
		NA	48
		Total	**76**
		Grand Total	**137**
Potassium Dichromate	Passivation of non-Al metallic coatings, passivation of stainless steel and chemical conversion coating REACH/20/3/1	<0.1 tonnes per year	4
		1 - 10 tonnes per year	5
		NA	9
		Total	**18**
	Chemical conversion coating REACH/20/2/1	<0.1 tonnes per year	22
		0.1 - 1 tonnes per year	8
		1 - 10 tonnes per year	2
		NA	25
		Total	**57**
		Grand Total	**75**
Dichromium tris(chromate)	Chemical conversion coating REACH/20/10/0 and REACH/20/1/3	<0.1 tonnes per year	81
		0.1 - 1 tonnes per year	12
		1 - 10 tonnes per year	2
		10 - 100 tonnes per year	1
		NA	149
		Grand Total	**245**

4.3.3 Consultation for the SEA

The consultation for this SEA generated responses identifying the following numbers of sites as using each of the chromates for CCC:

- 95 sites identified use of chromium trioxide;
- 23 sites identified use of sodium dichromate;
- 20 sites identified use of potassium dichromate; and
- 110 sites identified use of dichromium tris (chromate).

Table 4-7 provides the calculated total maximum tonnages that may be used by these sites based on the data collected for the CSR. These figures provide the starting point for extrapolating out to the estimated 350 EEA sites and 80 UK sites that are expected to use the chromates for CCC in 2024 and thereafter.

The SEA questionnaire also asked for information on the chromates used in CCC formulations by site, with these data providing an additional basis for estimating the maximum volumes used in CCC per site. So as to protect the confidential information of the applicants and formulators, the percentages are not given here. The figures presented in Table 4-7 take them into account, in developing estimates of the maximum amounts of each chromate used in CCC formulations in the EEA and UK based on current consumption patterns.

Table 4-7: Estimated tonnages for each chromate based on SEA, Article 66 and CSR data

	Chromium trioxide	Sodium dichromate	Potassium dichromate	Dichromium tris(chromate)
EEA	Up to 125 t/y	Up to 40 t/y	Up to 18 t/y	Up to 2.6 t/y
UK	Up to 30 t/y	Up to 7 t/y	Up to 6 t/y	Up to 1 t/y

4.3.3.1 OEMs

With respect to on-going trends in use, as noted in Section 3.6 (the AoA), the OEMs are progressing their substitution plans for the use of the four chromates in CCC. This is demonstrated by their substitution plans, which are further substantiated by responses to the SEA questionnaire.

OEMs are gradually reducing requirements for the use of chromate-based CCCs in their own production activities, as well as their supply chains where they are design owners and they have been able to certify alternatives. However until alternatives that meet customers' performance requirements and strict airworthiness requirements have been qualified, certified and then deployed use will continue; this includes in the production and delivery of new aircraft and other products. In addition, although COVID-19 led to some impacts on usage in 2020 due to the reduction in demand/cancellation of aircraft deliveries, no significant changes in usage compared to 2019 levels are foreseen up to 2024.

4.3.3.2 Design and build suppliers

Across the 19 DtB sites undertaking chromate-based CCC and for which detailed responses were provided to the SEA questionnaire two indicated that their use of the chromates (generally, not just in CCC) had increased by 10-15% over the last seven years due to increases in aircraft and other final product deliveries. Over half indicated that use remained steady from 2014 to 2020, with the remainder indicating a decrease in use varying from 50% to 80% compared to 2014 levels. COVID-19 led to further reductions in use of the chromates with 60% indicating that their use of the chromates had decreased; for the majority of respondents this was by less than 30%, although for two it was between 40% and 60%. This is consistent with information on the rate of capacity utilisation for conversion coating activities, as most companies' utilisation rates remained at around the same levels pre-COVID as for 2020. Going forward, the DtBs expect use of the chromates in CCC to decrease steadily over the 12 year review period. This can be seen from the substitution plan provided by ADCR members, which are also supported also by SEA responses for DtBs which are not members but in the ADCR supply chain.

4.3.3.3 Build-to-Print suppliers

Prior to COVID-19, most of the SEA respondents indicated that their sites were operating at 75% or higher utilisation rates with respect to their chemical conversion coating activities; the lowest level of utilisation reported across the different sites was 55% utilisation. In 2020, i.e. post-COVID, rates fell dramatically for some of the BtP sites, to as low as 15% of capacity as demand for new aircraft stalled. For most sites, however, the decrease in capacity utilisation was less significant. Many sites saw a decrease by 20 to 30%, but others saw no change with production levels remaining the same or close to the pre-COVID levels.

Companies were also asked whether the use of the chromates had been impacted by COVID-19. In line with the above responses, 50% of Build-to-Print companies (and just over 50% of sites) responding to the SEA indicated that it had.

About 25% of the 51 BtP sites indicated that use of the chromates had remained steady over the past seven years, another 25% stated that it had reduced (by anywhere from 15% to 60%), while 15% had seen increases of up to 30% due to new contracts (the remainder did not respond). In the short term, most respondents to the SEA questionnaire expected their consumption of the chromates across all uses to return to pre-COVID levels by 2024, as the aerospace industry recovers from COVID-19 (i.e. use would return back to pre-COVID levels).

It should be noted though that BtP suppliers will often have no knowledge of their customers' R&D or substitution plans. As a result, one would expect that their consumption of chromate-based formulations in CCC will decrease at the same rate as for the OEMs and DtBs.

4.3.3.4 MROs

The picture for MROs is more complicated. Five of these operators – a mix of civilian and military – indicated that use had remained steady over the past seven years, while four indicated increases in use of between 5% - 20% and a fifth reported a 100% increase (due in part to expansion in its services levels of activity in general). In contrast, three indicated decreases in use of between 10% - 30% with a fourth indicating a 95% reduction in use overall (with only DtC-based touch-up activities still being required at its sites). More generally, ADCR members note that defence related MRO activities were less impacted than civilian MRO services during Covid.

With respect to the period from 2021/22 to 2024, six of the MROs expected consumption to increase from their 2020 levels back to 2019 levels by 2024, with only a few indicating decreases. Thereafter, it is anticipated that quantities used will remain about the same or increase between 2024 and 2028; respondents expected to be required to continue using the chromates in CCC after 2030.

The MROs also noted that the extent to which use of the chromates would be required up to and past 2032 depended on design owners and whether substitutes become qualified, and the maintenance/repair of products certified.

4.3.4 Projected future use of the chromates

The A&D sector is actively working to phase out the use of the four chromates. As indicated by the substitution plan, however, it will take further time however to qualify, validate, certify implement alternatives within the supply chain across all components and products for A&D industry. Individual companies are at different points along this path, although this also varies by specific aircraft/defence application and across different types of components/final products.

Where possible, the use of chromate-based CCC in new designs is being phased out, however, aircraft that require their use remain in production and in-service. As discussed above, increasingly new planes will be replacing older models, potentially reducing the on-going need for the use of chromate-based CCC where alternatives have proven to meet performance requirements or the need for conversion coatings has been designed out. As a result, by 2036, the main uses should relate to any on-going MRO /legacy parts requirements for in-service aircraft or defence products.

Responses to the SEA questionnaire indicate a downward future trend in the use of the chromates over the review period despite the increase in demand for new aircraft and defence final products (although these responses were also provided prior to the war in Ukraine). By 2028, five of the OEMs providing detailed data expect use of the chromates to decrease; this increases to two-thirds of the companies decreasing use by 2030 and planning on phasing it out altogether after 2032. As these do not account for the total volumes of the chromates used in CCC, it is not possible to give an overall percentage reduction in volumes consumed on a year-by-year basis across the market.

It is important to note though that the planned reduction in usage by the OEMs will also impact on their DtB and BtP suppliers and MROs, given that OEMs are key design owners and their requirements are the driver for all suppliers/MROs. With respect to their designs, as reported above, the DtBs expect usage of chromate-based CCC formulations to decrease over the period to 2036.

4.4 Risks associated with continued use

4.4.1 Classifications and exposure scenarios

4.4.1.1 Human health classifications

The four chromates covered by this combined AoA/SEA were included into Annex XIV of Regulation (EC) No 1907/2006 due to their intrinsic properties (mutagenic, carcinogenic, toxic for reproduction; depending on the chromate).

Chromium trioxide is classified as a Carcinogen 1A and a Mutagen 1B under the CLP Regulation. The most important route of exposure and target organs are inhalation causing lung cancer and oral exposure causing intestinal cancer. The substance is also classified as a Skin and Respiratory Sensitiser 1 and is a Reproductive Toxicant 2.

Sodium dichromate is classified as a Carcinogen 1B and a Mutagen 1B under the CLP Regulation. The most important route of exposure and target organs are inhalation causing lung cancer and oral exposure causing intestinal cancer. The substance is also classified as a Skin and Respiratory Sensitiser 1 and a Reproductive Toxicant 1B.

Potassium dichromate is classified as a Carcinogenic 1B, a Mutagen 1B, and as a Reproductive toxicant 1B under the CLP Regulation. The most important route of exposure and target organs are inhalation causing lung cancer and oral exposure causing intestinal cancer. It is also classified as a Skin and Respiratory Sensitiser 1.

Dichromium tris(chromate) (DtC) is classified as a Carcinogen 1B and as a Skin Sensitiser 1. As for the other chromates, the most important route of exposure is inhalation causing lung cancer.

Reproductive toxicity for the above chromates is an effect of oral exposure. However, according to information from the Chemical Safety Report (CSR), the calculated exposure levels were below the DNEL for reproductive toxicity. Therefore, the risks associated with that endpoint are considered adequately controlled and as such it will not be examined further in this SEA.

4.4.1.2 Overview of exposure scenarios

Due to the different levels in the supply chain to which the individual companies may be associated, and the variation in the size of the sites, the conditions under which the use is carried out can be variable. The conditions of use cover small sites and repair shops with rare and infrequent applications up to large sites with high throughput, and thus, a low to high level of automation for specific activities. This variability was also observed in extensive consultation processes during the preparation of the CSR. **Table 4-8** lists all the exposure scenarios (ES) and contributing scenarios assessed in the CSR.

Table 4-8: Overview of exposure scenarios and their contributing scenarios

ES number	ES Title	Environmental release category (ERC)/ Process category (PROC)
ES1-IW1	Chemical conversion coating – use at industrial site	
Environmental contributing scenario(s)		
ECS 1	Chemical conversion coating - use at industrial site leading to inclusion (of Cr(VI) or the reaction products) into/onto article	ERC 5
Worker contributing scenario(s)		
WCS 1	Line operators	PROC 9, PROC 13, PROC 28
WCS 2	Brush and pen application operator	PROC 9, PROC 10
WCS 3	Storage area workers	PROC 5, PROC 8b, PROC 28
WCS 4	Laboratory technicians	PROC 15
WCS 5	Maintenance workers	PROC 28
WCS 6	Machinists	PROC 21, PROC 24
WCS 7	Incidentally exposed workers	PROC 0
Exposure scenario for industrial end use at site: ES1-IW1		

All A&D sites that perform CCC within the ADCR value chains are specialised industrial sites active in the EEA or the UK. They have rigorous internal health, safety and environment (HSE) organisational plans. A mix of technical, organisational and personal-protection-based and organisational measures are in place to reduce workplace exposures. The sites adhere to best practices to reduce workplace exposures and environmental emissions to as low as technically and practically feasible and use automated processes to the maximum extent possible. The possibility for and the degree of automation can vary between different sites and depend, amongst other factors, on the size of the site and the frequency with which the use in question is carried out.

As reported in Section 4.3 above, due to the conditions placed on the continued use of the four chromates in surface treatments (including CCC), additional risk management measures were implemented by A&D companies with this involving significant investment. A full summary of these conditions is provided in the CSR that accompanies this combined AoA/SEA.

4.4.2 Exposure and risk levels

The CSR provides details of the approach and assumptions underlying calculation of exposures and risks from the use of the chromates in CCC. The calculated exposure levels and associated excess cancer risks are presented below. For further information on their derivation see the CSR.

4.4.2.1 Worker assessment

Excess lifetime cancer risks

The findings of the CSR with respect to worker exposures, are summarised in **Table 4-9**, which presents the excess lung cancer risks to workers involved in CCC treatment related activities. The risks are calculated using a combination of measured inhalation data and modelling for different SEGs (Similar Exposure Groups). The SEGs include:

- WCS1: Line operators who are usually involved in numerous activities related to the conversion coating process. They spend most of their working time in a hall where the conversion coating tanks are located and where the immersion process takes place, as well as on activities either with direct or indirect Cr(VI) exposure. They may also be involved in touch-up applications (by brush, swab, wipe, syringes or touch-up pen) (although at many sites these tasks are mainly performed by dedicated brush and pen application operators (i.e. at MRO or machinist workshop), and may also carry out a series of secondary tasks.
- WCS2: Brush and pen operators, who undertake localized treatment of small surfaces or undertake touch-up activities after the immersion process on any damaged layers or surface defects; their activities may include preparation of solutions for brush or swab application.
- WCS3: Storage area workers, who decant liquids and measure solids, clean containers, handle solid wastes, undertake bath make-up additions and cleaning of baths as part of bath renewal.
- WCS4: Laboratory technicians may be involved in activities related to CCC with potential for Cr(VI)-exposure, such as undertaking sampling laboratory analysis of treatment bath solutions.
- WCS5: Maintenance and/or cleaning workers who maintain pipes, pumps, sensors, scrubbers, electrical systems installed in treatment baths, and LEV systems.
- WCS6: Machinists involved in several activities related to the mechanical treatment (including cleaning) of metallic parts as part of both production and repair activities.
- WCS7: Incidentally exposed workers, who include those workers spending part of their time in the work area where treatment baths are located but do not carry out the tasks with direct exposure themselves.

Table 4-9 sets out the excess lifetime cancer risk for workers involved in each of the above tasks.

Table 4-9: Excess lifetime cancer risk by SEG			
#	SEG	Average number of workers exposed per site	Excess lifetime lung cancer risk [1/ ug /m³]
WCS1	Line operators	5 per site	2.41E-03
WCS2	Brush and pen operators	5 per site	2.80E-04
WCS3	Storage area workers	4 per site	7.52E-05
WCS4	Laboratory technicians	1 - 4 per site	NA
WCS5	Maintenance and/or cleaning workers	3 per site	3.84E-04
WCS6	Machinists	4 per site	8.51E-04
WCS7	Incidentally exposed workers	6 per site	1.00E-03
	Total	27 per site	
Source: Information from CSR Note: Excess lung cancer risk refers to 40 years of occupational exposure			

Table 4-9 also indicates the number of workers that may be exposed per typical site and within each SEG. It also indicates the maximum number per shift and the number of shifts that may take place particularly at larger sites. These figures are taken into account in estimating the total number of workers exposed across all EEA and UK sites that would continue to undertake CCC.

4.4.2.2 Humans via the environment

Excess lifetime cancer risks

The assessment of risks for humans via the environment presented in the CSR has been carried out for the general population at the local level only. No regional assessment has been carried out as it can be assumed that Cr(VI) from any source will be reduced to Cr(III) in most environmental situations and therefore the effects of Cr(VI) as such are likely to be limited to the area around the source, as described in the EU Risk Assessment Report for chromates (see the CSR for further details). The approach to not perform a regional assessment for human Cr(VI) exposure via the environment as part of AfAs for chromate uses was also supported in compiled RAC and SEAC (Socio-economic Analysis Committee) opinions, as described for example in the *Opinion on an Application for Authorisation for Use of Sodium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites and sealings of anodic films (ID 0043-02)*. This reference states that regional exposure of the general population is not considered relevant by RAC[57].

The assessment presented in the CSR is based on measured data for emission to air and wastewater. For this assessment combined exposure of humans via the inhalation (air) and the oral (uptake of water and fish) route is considered. The resulting 90th percentile risk estimates are presented in the table below. To account for the potential that a worker uses both a touch-up pen and undertakes other processes, the combined risk for "all processes" is used for this assessment, even though this will over-estimate worker exposures for those facilities that only use the touch-up pens.

[57] RAC/SEAC "Opinion on an Application for Authorisation for Use of Sodium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites and sealings of anodic films", consolidated version, 2016; https://echa.europa.eu/documents/10162/658d42f4-93ac-b472-c721-ad5f0c22823c

Table 4-10: Excess lifetime cancer risk estimates for humans via the environment (general population, local assessment)					
	Inhalation		Oral		Combined
	Local Cr(VI) PEC in air [µg/m3]	**Inhalation risk**	**Oral exposure [µg Cr(VI)/kg x d]**	**Oral risk**	**Combined risk**
90th percentile - all processes	2.93E-04	8.51E-06	2.77E-04	2.21E-07	8.60E-06
90th percentile - Touch-up pen only	5.87E-06	1.70E-07	5.53E-06	4.42E-09	1.72E-07
a) RAC dose-response relationship based on excess lifetime lung cancer risk (see CSR): Exposure to 1 µg/m3 Cr(VI) relates to an excess risk of 2.9x10-2 for the general population, based on 70 years of exposure; 24h/day. b) RAC dose-response relationship based on excess cancer risk for tumours of the small intestine (see CSR): Exposure to 1 µg/kg bw/day Cr(VI) relates to an excess risk of 8x10-4 for the general population, based on 70 years of exposure; daily exposure.					

4.4.3 Populations at risk

4.4.3.1 Worker assessment

Numbers of workers exposed based on Article 66 data

The Article 66 data on numbers of staff – or workers – exposed to the chromates is summarised in **Table 4-11** below for those Authorisations relevant to the continued use in CCC. Included in this table are Authorisations which will expire in 2024 and whose holders will not be seeking re-authorisation for the aerospace supply chain relevant to ADCR; these are shaded in blue. Use of sodium chromate is no longer being supported, but these staff may still be involved in the use of the other chromates. Use of sodium dichromate and potassium dichromate by the aerospace and defence industry under parent Authorisations, which are not being renewed may shift to those covered by this RR, and figures associated with them are included here for completeness.

Taking a simple total of the figures for the number of staff exposed could result in an over-estimate given that some of the Authorisations cover multiple types of surface treatment.

No similar data are publicly available for the UK.

Table 4-11: Number of workers exposed - Article 66 Notifications data				
Substance	**Authorisation number**	**Use(s)**	**Staff Exposed**	**% assumed exposed to CCC use**
Chromium trioxide	REACH/19/29/0	Slurry coating and chemical conversion coating	461	75%
	REACH/20/18/14 to REACH/20/18/20	Passivation of non-Al metallic coatings, Passivation of stainless steel, chemical conversion coating and anodising and anodise sealing	1107	30%
	REACH/20/18/21 to REACH/20/18/27	Passivation of non-Al metallic coatings, Passivation of stainless steel, chemical conversion coating, slurry coating and anodising and anodise sealing – **industrial only**	1064	0% (this Authorisation covers industrial use which is not considered relevant to CCC)

Table 4-11: Number of workers exposed - Article 66 Notifications data				
Substance	**Authorisation number**	**Use(s)**	**Staff Exposed**	**% assumed exposed to CCC use**
Dichromium Tris(chromate)	REACH/20/10/0 and REACH/20/1/3	Chemical conversion coating	460	100%
Potassium Dichromate	REACH/20/3/1	Passivation of non-Al metallic coatings, passivation of stainless steel and chemical conversion coating	26	100%
	REACH/20/2/1	Chemical conversion coating	473	100%
Sodium Chromate	REACH/19/32/2 and REACH/19/32/3	Chemical conversion coating	490	50%
Sodium Dichromate	REACH/20/4/1	Chemical conversion coating	408	100%
	REACH/20/5/3 and REACH/20/5/5	Passivation of non-Al metallic coatings, passivation of stainless steel and chemical conversion coating	77	30%

Number of workers based on SEA questionnaire data

Responses to the SEA questionnaire indicate that some 5,200 workers are directly employed in undertaking chemical conversion coating. The breakdown for these is given in the **Table 4-12** below by role in the supply chain and for the EEA and UK, and as extrapolated out to the 350 EU sites and 80 UK sites.

Table 4-12: Employees directly involved in chromate-based CCC treatment activities					
Number of workers 166 sites	**Number of sites EU**	**Number of sites UK**	**No of employees EEA**	**No of employees UK**	**Total**
Number of workers 166 sites involved in chemical conversion coating					
Build-to-Print	32	19	264	93	357
Build to design	12	7	267	52	319
MRO only	40	6	1399	144	1543
ADCR Members	36	14	2153	837	2990
Total 166 sites	**120**	**46**	4,083	1,126	5,209
Number of workers at 350 EU sites and 80 UK sites involved in chemical conversion coating					
Build-to-Print	145	25	1,196	122	1,319
Build to design	60	15	1,335	111	1,446
MRO only	90	15	3,148	360	3,508
ADCR Members	55	25	3,289	1,495	4,784
Total 430 sites	350	80	8,968	2,089	11,057

In total, this translates to around 9,450 exposed workers in the and 2,160 in the UK. These figures correspond well to the estimates derived using the average figures from the CSR for the number of workers exposed to the chromates under WCS1 to 7 (excluding WCS4).

The CSR figures are taken here as being more reliable, as they are based on site visits and detailed discussions with companies. The average figures assumed in the CSR extrapolated out to the total numbers of sites gives the figures set out in **Table 4-13** as the number of workers exposed under each WCS. Note that WCS4 related to laboratory technicians is not considered here as the handling of substances in laboratories for quality control purposes under controlled conditions and in amounts below one tonne per annum (t/a) falls under the REACH Art. 56(3) exemption[58]. Furthermore, the sampling activities that may be carried out by lab technicians are covered under other WCS.

Table 4-13: Number of employees undertaking CCC across the EEA and UK				
Worker Contributing Scenarios		Average No. Exposed from CSR	350 EU sites	80 UK sites
WCS1	Line operators	5	1750	400
WCS2	Brush and pen operators	5	1750	400
WCS3	Storage area workers	4	1400	320
WCS5	Maintenance and/or cleaning workers	3	1050	240
WCS6	Machinists	4	1400	320
WCS7	Incidentally exposed workers	6	2100	480
Total		**27**	**9450**	**2160**
Source: CSR				

4.4.3.2 Humans via the Environment

The relevant local population for humans via the environment has been estimated based on the following information:

- Number of downstream user sites in total and then as assumed in terms of their distribution across the EEA/UK;
- The population density per km^2 for each relevant EU country and the UK;
- The relevant distance from sites for the local assessment, taken as the default assumption of a 1000m radius (or 3.14 km^2).

The resulting estimates of the number of people exposed within the general population are given in **Table 4-14** for the EU and UK. The total number of humans exposed via the environment in the EU is estimated at just over 165,700, with the UK figure being around 106,500) (with the UK figure being disproportionately higher due to its population density).

As noted above, no assessment of risks for humans via the environment at the regional level has been carried out based on RAC's previous opinion that regional exposure of the general population is not relevant.

[58] https://echa.europa.eu/de/support/qas-support/browse/-/qa/70Qx/view/ids/585-1442-1443-1498-1565

Table 4-14: General public, local assessment exposed population from CCC across the EEA and UK			
Countries with DUs	No. Sites per country	Population density per km^2	Exposed local population within 1000m radius
France	100	118	37,071
Germany	50	232	36,442
Italy	45	200	28,274
Spain	30	92	8,671
Poland	36	123	13,911
Czech Republic	13	135	5,513
Sweden	12	23	867
Finland	9	16	452
Netherlands	12	421	15,871
Belgium	9	376	10,631
Denmark	4	135	1,696
Hungary	4	105	1,319
Norway	7	14	308
Romania	4	82	1,030
Bulgaria	3	64	603
Ireland	4	69	867
Greece	2	82	515
Lithuania	2	43	270
Portugal	2	112	704
Slovakia	2	111	697
Total EEA	**350**		**165,716**
UK	**80**	**424**	**106,560**

4.4.4 Residual health risks

4.4.4.1 Introduction

Under the Applied-for-Use Scenario, use of chromates for CCC will continue up to the end of the requested 12 year review period.

In December 2013, the Risk Assessment Committee (RAC) agreed lifetime (i.e. for 40 years and 70 years of exposure) mortality risk estimates associated with carcinogenicity for workers and humans via the environment exposed to Cr(VI) substances[59]. It assumes a linear relationship for both lung and intestinal cancer.

As the excess cancer risk estimates apply to each exposed worker for a total working life of 40 years, they need to be adjusted to reflect exposures over the length of the review period. Exposures are thus treated as separable over time, meaning that annual risk is equivalent to 1/40 of the risk over 40 years of exposure. For members of the general population, excess cancer risks estimates apply for a lifetime of 70 years, meaning that annual risk is equivalent to a 1/70 of the risk of 70 years of exposure.

[59] ECHA (2013): Application for authorisation: Establishing a reference dose response relationship for carcinogenicity of hexavalent chromium. Helsinki, 04 December 2013. RAC/27/2013/06 Rev. 1 (agreed at RAC-27).

4.4.4.2 Morbidity vs mortality

Excess cancer cases need to be split between fatal and nonfatal ones. To this end, estimates of fatality and survival rates associated with lung and colorectum[60] cancer cases were derived from the Cancer Today database, see **Table 4-15** below.

Table 4-15: Estimated incidence and mortality of cancers across the EU-27 and the UK, both males and females (in 2020)			
Type of cancer	Cases	Deaths	Survivals
Lung	370,310	293,811 (79%)	76,499 (21%)
Colorectum (intestinal)	393,547	177,787 (45%)	215,760 (55%)
Source: Source: http://gco.iarc.fr/today/home (accessed on 20/02/2022) Note: Percentages have been rounded			

To calculate the number of additional non-fatal lung cancer cases, a ratio of deaths to survivals is applied to the number of additional fatal lung cancer cases, as shown below:

(1) $(0.21/0.79) \times \pi = \sigma$

where π is the number of additional fatal lung cancer cases and σ is the number of additional non-fatal lung cancer cases.

In a similar fashion, the figures from Cancer Today reported above are applied to the estimates to calculate the total number of additional fatal and non-fatal intestinal cancer cases[61].

(2) $(0.55/0.45) \times \delta = \eta$

where, δ is the number of additional fatal intestinal cancer cases and η is the number of additional non-fatal intestinal cancer cases. Note, however, that the CSR provides combined excess risk estimates. To err on the side of conservatism, the fatality versus morbidity ratio for lung cancer has been adopted for valuation of risks to humans via the environment (HvE).

4.4.4.3 Predicted excess cancer cases with continued use: workers directly exposed

Total excess cancer risk cases are based on the excess lifetime risk estimates derived in the CSR for the different worker contributing scenarios (WCS as presented in Table 4-9). These risk estimates reflect the additional safety measures that have been implemented due to the conditions placed on continued use by the initial authorisations. The number of excess risk cases is calculated by multiplying the number of workers assumed to be exposed in each task by the value of the excess cancer risk given above adjusted for the requested review periods, i.e. over 12 years. This value is then multiplied by the number of workers exposed in each SEG to calculate the total excess cancer cases arising from the continued use of chromates in CCC. The results are shown in **Table 4-16** for the EEA and **Table 4-17** for the UK.

60 Colorectum is taken as a proxy for intestinal cancer cases.

61 It is assumed that here the dose response relationship pertains to both additional fatal and non-fatal intestinal cases.

Table 4-16: Number of excess lifetime cancer cases to EEA workers					
WCS	Number of persons exposed	LUNG CANCER - Excess lifetime cancer risk	Excess number of lifetime cancer cases	LUNG CANCER - Number of excess lifetime fatal cancer cases	LUNG CANCER - Number of excess lifetime non-fatal cancer cases
WCS1	1750	2.41E-03	**4.22**	**3.33**	**0.89**
WCS2	1750	2.00E-04	**0.35**	**0.28**	**0.07**
WCS3	1400	7.52E-05	**0.11**	**0.08**	**0.02**
WCS5	1050	3.84E-04	**0.40**	**0.32**	**0.08**
WCS6	1400	8.51E-04	**1.19**	**0.94**	**0.25**
WCS7	2100	1.00E-03	**2.10**	**1.66**	**0.44**
		Years - Lifetime	**40.00**	**6.61**	**1.76**
		Years - Review period	**12.00**	**1.98**	**0.53**
		Years - Annual	**1.00**	**0.17**	**0.04**

Table 4-17: Number of excess lifetime cancer cases to UK workers					
WCS	Number of persons exposed	LUNG CANCER - Excess lifetime cancer risk	Excess number of lifetime cancer cases	LUNG CANCER - Number of excess lifetime fatal cancer cases	LUNG CANCER - Number of excess lifetime non-fatal cancer cases
WCS1	400	2.41E-03	**0.96**	**0.76**	**0.20**
WCS2	400	2.00E-04	**0.08**	**0.06**	**0.02**
WSC3	320	7.52E-05	**0.02**	**0.02**	**0.01**
WCS5	240	3.84E-04	**0.09**	**0.07**	**0.02**
WCS6	320	8.51E-04	**0.27**	**0.22**	**0.06**
WCS7	480	1.00E-03	**0.48**	**0.38**	**0.10**
		Years - Lifetime	**40.00**	**1.51**	**0.40**
		Years - Review period	**12.00**	**0.45**	**0.12**
		Years - Annual	**1.00**	**0.04**	**0.01**

4.4.4.4 Predicted excess cancer cases with continued use: humans via the environment

The total number of people exposed as humans via the environment as given in **Table 4-14** is multiplied by the excess cancer risk estimates to calculate the total excess cancer cases arising under the continued use scenario. The results are given in **Table 4-18**. The basis for estimating the number of people exposed per country is the percentages of Article 66 notifications made to ECHA per country, as described in Section 4.2.

Table 4-18: Number of people in the general public exposed via the environment(local assessment) across the EEA and UK							
Countries with DUs	No. Sites per country	Population Density per km2	Exposed local population	Combined excess lifetime cancer risk	Excess number of lifetime cancer cases	Number of excess lifetime fatal cancer cases	Number of excess lifetime non-fatal cancer cases
France	100	65,426,180	37071	3.16E-05	1.17E+00	**0.93**	**0.25**
Germany	50	83,900,470	36442	3.16E-05	1.15E+00	**0.91**	**0.24**
Italy	45	60,367,480	28274	3.16E-05	8.93E-01	**0.71**	**0.19**
Spain	30	46,745,200	8671	3.16E-05	2.74E-01	**0.22**	**0.06**
Poland	36	37,797,000	13911	3.16E-05	4.40E-01	**0.35**	**0.09**
Czech Republic	13	10,724,560	5513	3.16E-05	1.74E-01	**0.14**	**0.04**
Sweden	12	10,160,170	867	3.16E-05	2.74E-02	**0.02**	**0.01**
Finland	9	5,548,360	452	3.16E-05	1.43E-02	**0.01**	**0.00**
Netherlands	12	17,173,100	15871	3.16E-05	5.02E-01	**0.40**	**0.11**
Belgium	9	11,632,326	10631	3.16E-05	3.36E-01	**0.27**	**0.07**
Denmark	4	5,813,298	1696	3.16E-05	5.36E-02	**0.04**	**0.01**
Hungary	4	9,634,164	1319	3.16E-05	4.17E-02	**0.03**	**0.01**
Norway	7	5,465,630	308	3.16E-05	9.73E-03	**0.01**	**0.00**
Romania	4	19,127,775	1030	3.16E-05	3.26E-02	**0.03**	**0.01**
Bulgaria	3	6,896,663	603	3.16E-05	1.91E-02	**0.02**	**0.00**
Ireland	4	4,982,907	867	3.16E-05	2.74E-02	**0.02**	**0.01**
Greece	2	10,370,744	515	3.16E-05	1.63E-02	**0.01**	**0.00**
Lithuania	2	2,689,862	270	3.16E-05	8.54E-03	**0.01**	**0.00**
Portugal	2	10,167,925	704	3.16E-05	2.22E-02	**0.02**	**0.00**
Slovakia	2	5,460,721	697	3.16E-05	2.20E-02	**0.02**	**0.00**
Total	**350**		**165,716**	3.16E-05	5.24	**4.14**	**1.10**
				Years – Lifetime cases	**70.00**	4.14E+00	6.16E-01
				Years - Review period	**12.00**	7.09E-01	1.89E-01
				Years - Annual	**1.00**	5.91E-02	1.57E-02
UK	**80**	424	**106,563**	3.16E-05	3.37E+00	2.66	0.71
				Years – Lifetime cases	**70.00**	2.66E+00	7.07E-01
				Years - Review period	**12.00**	4.56E-01	1.21E-01
				Years - Annual	**1.00**	3.80E-02	1.01E-02

4.4.5 Economic valuation of residual health risks

4.4.5.1 Economic cost estimates

In order to monetise human health impacts, a timeframe that goes from the end of 2024 to the end of 2036 (i.e. a 12 year review period) has been used and a 4% discount rate has been employed for calculating net present values[62]. It has been assumed that the levels of exposure to Cr(VI) for workers and members of the general population remains constant throughout the length of the review period, even though this is a very conservative assumption. In fact, downstream users will gradually reduce the amount of Cr(VI) consumed as the transition to an alternative proceeds. Combined with the investment in risk management measures put in place by the sites to protect workers as a result of the conditions placed on continued use by the initial authorisations, this should ensure that excess lifetime cancer risks reduce over the review period.

The economic valuation of the health impacts takes into account two important welfare components, the costs associated with mortality and morbidity. The basis of our calculations is the study led by the Charles University in Prague[63] and undertaken for ECHA.

That study was critically reviewed by ECHA in 2016 and the results of that review have been the basis of the economic valuation performed here[64]. The values used are:

- Value of statistical life for the avoidance of a death by cancer: €3.5 million (2012 prices); and
- Value of cancer morbidity: €0.41 million (2012 prices).

It is appropriate to update these two figures to 2021 prices (updated to second and third quarter values of 2021, more recent data are not available). This has been achieved by use of the Eurostat EU GDP deflator[65]. This suggests that the aforementioned figures should be multiplied by a factor of 1.12. Thus, the following values are employed in the analysis below:

- Value of statistical life (mortality): €3.5 million × 1.12 = €3.92 million (rounded); and
- Value of cancer morbidity: €0.41 million × 1.12 = €0.46 million (rounded).

In addition to these valuations, for the purpose of quantifying human health impacts, consideration has also been given to annual medical treatment costs for morbidity. A range of studies were identified that provide estimates of the costs of medical treatment for patients surviving lung and intestinal cancer. These are summarised in **Table 4-19**.

62 EC Better Regulation Toolbox – Tool #61: https://ec.europa.eu/info/sites/default/files/file_import/better-regulation-toolbox-61_en_0.pdf

63 Alberini, A. and Ščasný, M. (2014) Stated - preference study to examine the economic value of benefits of avoiding selected adverse human health outcomes due to exposure to chemicals in the European Union - Part III: Carcinogens.

64 ECHA (2016b) Valuing selected health impacts of chemicals. Available at: http://echa.europa.eu/contact

65 https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=teina110&plugin=1

Table 4-19: Alternative estimates of medical treatment costs			
Study	Year for prices	Average direct costs in original units (per annum)	Direct costs in € 2021
Lung cancer[66]			
Leal (2012)	2012	£9,071	€11,160
Braud et al (2003)	2001	€12,518	€15,800
Dedes et al (2004)	1999	€20,102	€23,460
Intestinal cancer (colon, colorectal and rectal cancer taken as proxies)[67]			
Luo et al (2010)	2000 (assumed)	US$29,196	€36,230
Lang et al (2009)	2006	US$28,626	€31,740
York Health Economics Consortium (2007)	2004	£8,808	€12,180
York Health Economics Consortium (2007)	2004	£12,037	€16,410

The average cost across the four lung cancer studies is €17,314 per annum (2021 prices). The average cost figures reported for intestinal cancer are based on figures produced for colon, rectal and colorectal cancer in the US and UK. The US data are high compared to the UK data; as a result, the average across the two UK studies is taken here, with this being around €14,853 per case in 2021 prices, taking into account price inflation.

These average medical costs are annual figures and apply to survivors over the period of time that they continue to be treated. With respect to lung cancer morbidity cases, we have taken a percentage survival of 32% after one year since diagnosis, 10% after five years, 5% after 10 years[68]. With respect to intestinal cancer morbidity cases, we have taken a percentage survival of 76% after one year since diagnosis, 59% after five years, 57% after ten years. Based on these time periods, the NPV of average future medical costs per lung cancer case is estimated at €30,110 in 2021 prices, using a 4% future discount rate. The NPV of average future medical costs per intestinal cancer case is estimated at €82,620 in 2021 prices. It is noted that a large percentage of people survive intestinal cancer after a period of 10 years and any stream of health care costs incurred after that is not incorporated in our calculations. However, such costs are not likely to be relevant considering that those surviving after such a long period of time can either be considered as definitely cured or probably only in need of a small degree of medical attention.

The valuations of mortality and morbidity were multiplied by the estimated number of additional cancer cases, fatal and non-fatal, that can occur in the Applied for use scenario. The basic calculations for the value of an excess cancer case are presented below:

66 Leal, J., 2012. Lung cancer UK price tag eclipses the cost of any other cancer, presentation by Health Economics Research Centre, University of Oxford to the NCIR Cancer Conference, Wednesday, 7 November. s.l.:s.n. Braud, L. & al, 2003. Direct treatment costs for patients with lung cancer from first recurrence to death in France. Pharmacoeconomics, 21(9), pp. 671-679. Dedes, K. J. & al, 2004. Management and costs of treating lung cancer patients in a university hospital. Pharmacoeconomics, 22(7), pp. 435-444

67 Luo, Z. & al, 2010. Colon cancer treatment costs for Medicare and dually eligible beneficiaries. Health Care Finance Review, 31(1), pp. 33-50. Lang, K. & al, 2009. Lifetime and Treatment-Phase Costs Associated with Colorectal Cancer: Evidence from SEER-Medicare Data. Clinical Gastroenterology and Hepatology, Volume 7, pp. 198-204. York Health Economics Consortium, 2007. Bowel Cancer Services: Costs and Benefits, Final Report to the Department of Health, April 2007, York: University of York.

68 These values are based on a study conducted by Cancer Research UK on adults aged 15-99 in England and Wales. https://www.cancerresearchuk.org/health-professional/cancer-statistics/statistics-by-cancer-type/lung-cancer/survival.

(1) (π × (€ 3,920,000)) + (σ × (€ 460,000 + € 30,110) = Total lung cancer costs

(2) (δ × (€ 3,920,000)) + (η × (€ 460,000 + €82,620)) = Total intestinal cancer costs

4.4.5.2 Predicted value of excess cancer cases with continued use: workers

Table 4-20 applies the economic value of the associated health impacts to these additional statistical cases of cancer to generate the total economic damage costs of the excess lung cancer cases. Under the continued use scenario, the present value costs are around €2.89 million for the EU and €661,000 for the UK, based on the assumption that chromate-based CCC continues at the current level of use over the entire review period; this will lead to an overestimate of the impacts as the sector transitions to the alternatives over the 12 year period.

Table 4-20: Present value and annualised economic value of mortality and morbidity effects to workers (discounted over 12 years @4% per year, 20 year lag, figures rounded)

	EEA Workers		UK Workers	
	Mortality	Morbidity	Mortality	Morbidity
Total number of lung cancer cases	1.98	0.53	0.45	0.12
Annual number of lung cancer cases	0.17	0.04	0.04	0.01
Present Value (PV, 2024)	€ 2,806,051	€ 87,531	€ 641,383	€ 20,007
Total PV costs	**€ 2,893,581**		**€ 661,390**	
Total annualised cost	**€ 668,010**		**€ 152,688**	

Source: Derived estimates from responses to the SEA questionnaire, Article 66 data, Eurostat data and CSR

4.4.5.3 Predicted value of excess cancer cases with continued use: man via the environment

Table 4-21 applies the economic value of the associated health impacts to the additional statistical cases of cancer for humans via the environment to generate the total economic damage costs of the excess cancer cases. Under the continued use scenario, the present value costs are roughly €1.04 million for the EU and €667,300 for the UK, based on the assumption that CCC continues over the entire review period at 2024 tonnages and number of downstream user sites; as indicated above, this reflects an overestimate of the levels of exposures as use declines with a transition to the alternatives over the 12-year period.

Table 4-21: Present value and annualised economic value of mortality and morbidity effects to the general population, local assessment (discounted over 12 years @4% per year, 20 year lag, figures rounded)

	EEA General Population		UK General Population	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cancer cases	0.71	0.12	0.46	0.12
Annual number of cancer cases	0.06	0.02	0.04	0.01
Present Value (PV, 2024)	€ 1,003,504	€ 34,188	€ 645,299	€ 21,984
Total PV costs	**€ 1,037,692**		**€ 667,283**	
Total annualised cost	**€ 239,561**		**€ 154,048**	

Source: Derived estimates from responses to the SEA questionnaire, Article 66 data, Eurostat data and CSR

4.4.6 Human health impacts for workers at customers sites

The machining of surfaces for either production or repair activities following treatment via CCC by workers in the A&D sector has been accounted for in the worker estimates presented above. Similarly, touch-up activities that may take place at customers' sites using Dichromium tris(chromate) are also accounted for in the estimates provided above.

4.4.7 Environmental impacts

In accordance with RAC's conclusions (see e.g., the RAC/SEAC "*Opinion on an Application for Authorisation for Use of Sodium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites and sealings of anodic films*"), no regional assessment has been carried out as it can be assumed that Cr(VI) from any source will be reduced to Cr(III) in most environmental situations and therefore the effects of Cr(VI) as such are likely to be limited to the area around the source, as described in the EU Risk Assessment Report for chromates (ECB, 2005). Therefore, combined exposures from various sources on the regional scale are not considered further.

4.4.8 Summary of human health impacts

Table 4-22 provides a summary of the economic value of the human health impacts across the worker and local populations. When considering these figures, it should be remembered that they relate to use of the chromates in CCC activities across the sector at an estimated 350 EU sites and 80 UK sites covered by this combined AoA/SEA. It should also be recognised that workers using chromate-based CCC formulations may also be using the chromates for other processes. As a result, their monitoring data may reflect aggregate exposures rather than just CCC-related exposures.

Table 4-22: Combined assessment of health impacts to workers and general population value of mortality and morbidity effects to workers (discounted over 12 years @4% per year, 20 year lag, figures rounded)

	EEA		UK	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cancer cases	2.69	0.65	0.91	0.24
Annual number of cancer cases	0.22	0.06	0.08	0.02
Present Value (PV, 2024)	3,809,555	121,718	1,286,682	41,991
Total PV costs	**€ 3,931,273**		**€ 1,328,673**	
Total annualised cost	**€ 907,570**		**€ 306,736**	
Source: Derived estimates from responses to the SEA questionnaire, Article 66 data, Eurostat data and CSR				

5 Socio-Economic Impacts of the Non-use Scenario

5.1 The Non-Use Scenario

5.1.1 Summary of consequences of non-use

The inability of companies to undertake CCC activities across the EEA and in the UK using formulations based on one or more of the four chromates would be severe. This use is critical to the key functions provided by the chromates in CCC: corrosion resistance (self-healing); chemical resistance; adhesion promotion; layer thickness; electrical resistivity; temperature resistance; and pre-treatment compatibility. These functions are essential to a broad range of components and assemblies, including structural parts such as engines, wings and landing gear assemblies. This includes application to newly produced components, touch-ups during manufacturing activities and for ensuring on-going performance following maintenance and repair activities.

If use of chromate-based CCC formulations was no longer authorised and where qualified and certified alternatives are not available according to the definition of "generally available"[69], design owners (i.e. OEMs and DtB companies) would be forced to re-locate some or all of their parts production, manufacturing and maintenance activities outside the EEA or UK, where qualified and certified alternatives are not available.

A refused Authorisation would have impacts on the EEA/UK formulators and the critical set of key functions provided by CCC treatments would be lost to A&D downstream users in the EEA and UK

↓

Due to certification and airworthiness requirements, downstream users in the A&D value chain would be forced to undertake chromate-based CCC activities outside the EEA or shift to suppliers outside of the EEA/UK

↓

OEMs would shift manufacturing outside the EEA/UK due to the need for CCC to be carried out in sequence with other treatments. It would be inefficient and costly to transport components and products outside the EEA/UK for chemical conversion coating only (especially for touch-up repairs)

↓

DtB suppliers may have more flexibility and be able to shift only part their production activities outside the EEA/UK, resulting in the loss of profits and jobs inside the EEA/UK

↓

BtP suppliers in the EEA/UK would be forced to cease chromate-based CCC treatments, leading to loss of contracts and jobs due to relocation of this and related activities outside the EEA/UK

↓

MROs, which make up a significant percentage of users, would have to shift at least some (if not most) of their activities outside the EEA, as chemical conversion coating is an essential part of maintenance, repair and overhaul activities

↓

[69] As defined with respect to the "legal and factual requirements of placing on the market" in the EC note of 27 May, 2020, available at: 5d0f551b-92b5-3157-8fdf-f2507cf071c1 (europa.eu)

Relocation of MRO activities would cause significant disruption to the A&D sector itself

↓

Ministries of Defence would face logistical difficulties in maintaining aircraft and other equipment, severely impacting on mission readiness. Service agreements would need to be reached with non-EEA countries

↓

Civil aviation, passengers, freight shippers and emergency services would face reduced flight availability and routes, as well as increased costs

As indicated in the above diagram, because CCCs must be applied promptly to protect against corrosion and, depending on the follow-on process, to ensure the next process step is successful, there would be significant subsequent effects for other parts of the aerospace and defence supply chains. The most likely outcome would be the relocation of large portion of the entire value chain (production, repair and maintenance) outside of the EEA/UK, as summarised below.

5.1.1.1 Identification of plausible non-use scenarios

Consultation was carried out with the applicants, OEMs, MROs and the BtP and DtB suppliers supporting them.

These discussions acted as the basis for a series of questions in the SEA questionnaire aimed at pulling out information on the role of different types of companies and how this impacts on why they use the four chromates, past investments and R&D, and the most likely impacts of a refused re-authorisation. The first three of these were discussed in Section 3 and the continued use scenario.

Moving to a poorer performing alternative was ruled out based on the unacceptability of such an option to the OEMs due to safety & airworthiness requirements, as detailed further below. Producing components overseas, shipping them back to the EEA/UK and then warehousing them was ruled out due to logistic difficulties and economic feasibility.

Table 5-1 below presents the choices presented in the SEA questionnaire and a count of the number of companies selecting each (out of the 79 companies in total, covering 166 sites).

Respondents were asked to provide further comments to support their responses, and to explain any other possible responses not included in the above list. These comments demonstrate the differences that exist within the aerospace supply chain and hence how the most plausible scenarios will vary by role.

Further details on the non-use scenario for the different types of companies are provided below, starting with OEMs as the main design owners, followed by DtBs, BtPs and MROs.

Table 5-1: Responses to SEA survey on most likely non-use scenarios				
	OEM	Build-to-Print only	Design-to-Build only	MROs – only and combined with those mainly an MRO but also acting as B-t-P or D-t-B
The decision is up to our customer		16		3
We may have to cease all operations as the company will no longer be viable	1	7		7
We will focus on other aerospace uses or on non-aerospace and defence uses		3	2	
We will shift our work outside the EEA	6	3	2	4
We will stop undertaking use of the chromate(s) until we (or our customer) have/has a certified alternative	2*	10	7	2
Number of responses (companies/sites)	9 / > 50	39 / 51	15 / 19	16 / > 46
*Clarifications indicate that this would include a cessation of operations within the EEA/UK				

5.1.1.2 OEMs

In discussions, the OEMs stressed that the aim is the replacement of the use of the chromates in CCC to an alternative that enables the components to be qualified and certified. In some cases, a qualified alternative has been developed, but more time is required to implement the alternative across the entire supply chain (particularly where a significant number of BTP suppliers or MROs may be involved in CCC of similar parts, e.g. bolts and fasteners).

With respect to the plausibility of the different non-use scenarios identified above, the following are clear from consultation based on the choices provided in the SEA questionnaire:

- **We will shift our work involving Chromates to another Country outside the EEA/UK.** This is the most plausible scenario for the majority of OEMs directly involved in the use of chromate-based formulations for CCC. It would not be possible for the OEMs (or some divisions of the larger OEMs) to maintain manufacturing activities not using chromate-based CCC formulations inside the EEA/UK while transferring use of chromate-based CCC formulations outside the EEA/UK. This would result in huge numbers of components being transferred outside the EEA/UK for repairs or touch-up, which would not be economically feasible. Furthermore, given the reliance on the use of chromate-based CCC formulations in supply chains, it is also the most likely response for the OEMs or divisions of them who rely on their suppliers carrying out CCC on components prior to their delivery to the OEM. The reasoning behind this is detailed further below.

- **We will stop using the chromates until we have certified alternatives:** It is clear that in most cases substitution activities and especially the industrialisation phase of moving to alternatives will not be completed before the end of the current review periods, especially given the number of BtP suppliers and MROs involved, as well as the number of parts and components of relevance. In some cases, a significant number of additional years is required which would mean a potential stop to both production and associated MRO activities over this period. The current “road map” for substitution and industrialisation cannot be sped-up, and some margin is needed to allow for any delays or possible failures. The potential duration of such a production stoppage would not be economically feasible.

- **We may have to cease all operations as the Company will no longer be viable.** If shifting work to countries outside the EEA/UK is unacceptable due to the costs or timeframe involved in setting up the required manufacturing sites and supporting infrastructure, a cessation of all operations may be the ultimate outcome for some of the OEMs or divisions of them. It is important to note that this scenario translates to a cessation of aircraft production within the EEA/UK, with consequent reductions in revenues from aircraft assembly operations; the loss of this turnover would result in other operations (R&D, Engineering, Sales, etc.) also becoming non-viable with the final outcoming being a shut-down of all activities.

- **We will focus on other aerospace uses or on non-aerospace and defence applications**. The OEMs supporting the ADCR are mainly involved in the manufacture and repair of civilian and military aircraft. As a result, this scenario is not technically or economically feasible for most of them to switch all or most of their focus to other sectors, as their sole areas of expertise reside in the aerospace field and/or defence fields.

As a result, the OEMs indicated that if the viable alternatives are not qualified and implemented (or able to be implemented by the end of the current review period (e.g. September 2024 for chromium trioxide, sodium dichromate and potassium dichromate and January 2026 for dichromium tris(chromate), September 2024) , then their **most plausible response under the non-use scenario would be to relocate all or some of their manufacturing activities outside of the EEA or UK.** It may not be realistic given the efforts and expenditure involved in such relocation, which may be more likely to result in the complete closure of OEMs or divisions within them, with consequent impacts for the EEA/UK economies.

The extent to which companies would move all or only some of their manufacturing outside the EEA/UK depends on the activities undertaken at individual sites operated by these larger OEMs (where these may include up to 12 plus sites per OEM, each supported by regionally based Build-to-Print, Design-to-Build and MRO suppliers which may be involved in CCC). Responses by individual companies indicate that anything from 30% to 100% of manufacturing would be affected, with production expected to stop completely at large numbers of sites. These impacts would be experienced by sites involved in civil aviation and defence and space related uses of the four chromates used as substances in formulations for CCC.

It was also noted that due to the vertical integration of manufacturing activities at these sites, A&D manufacturing and MRO activities would cease in the EEA/UK. It is not feasible to only cease use of CCC formulations based on the chromates; all activities related to the manufacture of the relevant components and other products would need to be moved outside the EEA/UK. As indicated above, if manufacturing activities using the chromates and not using chromates are separated on both sides of the EEA/UK borders, then huge logistic issues would arise, and the level of transportation required would have a dramatic impact on resources and the environmental footprint of the sector. In most cases, CCC cannot be separated from other processes as the component will corrode while being shipped for corrosion protection.

Because aircraft manufacturing and MRO activities represent the largest share of the OEMs' activities, the impact on the European economy would be considerable, especially as their response would drive the responses of their suppliers.

In the A&D industry, reliance on proven corrosion prevention processes means that Cr(VI) and non-Cr(VI) operations/processes normally exist side-by-side, are inter-reliant and non-separable; as a result, there is no possibility to identify and distinguish manufacturing plants as Cr(VI) or Cr(VI)-free. Indeed, the aerospace industry has a very complex and interrelated supply chain and for many essential parts, only one designated supplier exists. Typically, this supplier will have worked in close partnership with its customer(s) for decades to develop a product. Critical suppliers often take occupancy on, or adjacent to, the premises of their customers. Therefore, relocation will often be based on strategic decisions, e.g. if the customer relocates, the suppliers might do the same to keep proximity.

A final assembly line for aircraft, engines or other major products will require Cr(VI) touch-up protection of components, as a minimum. This activity is clearly a tiny fraction of the overall value added by the facility; however, the ability to carry out the activity on-site is critical to the viability of the wider operations. As noted above, it would not be possible to relocate just the surface protection activities, due to the potential for corrosion during transport to another location. Hundreds of suppliers deliver parts from around the world which are ultimately connected in assembly lines. For example, the fuselage consists of several single sections (e.g. forward and centre fuselage, centre wing box, tailcone, etc.) which need to be joined.

Assembling is a mechanical process and tolerances of the components need to be corrected by machining. During this process, e.g. docking of wings or engines, the surface can suffer damage. Using small amounts for Cr(VI) compounds as part of rework during the assembly phase is mandatory and essential to the safety of the aircraft.

Damage on structural parts of aircraft as small as a single scratch on exposed bare metal increases the risk of corrosion, leading to loss of component strength, and, untreated, can lead to increased fatigue and cracking of the component. This damage can usually be reworked or repaired quickly without removing the part by blending out the scratch and using touch-up processes. As explained in the Analysis of Alternatives, Cr(VI) is critical for corrosion prevention, durability and for its self-healing properties, amongst others.

As a result, there are two main cases to consider.

- Small Components: Currently, some small components may be able to be removed and then repaired on-site or replaced with a new component from stock (from inside or outside Europe). In the case of a denied authorisation, no on-site repair would be possible. The component either must be sent outside of Europe for repair, or a new component from stock would ultimately have to originate from outside Europe; and

- Large Component: Some large parts, like wing or fuselage skins, are rarely removed, so processing in-situ is the primary method for touch-up. Without moving the entire aircraft outside the EEA/UK, touch-up (and repairs) would not be possible. It would be impossible to ship the entire fuselage to a non-EEA country for touch-up repairs, ship it back into the EEA for continued assembly, and so on.

In the best case, and for some components and products, touch-ups and repairs that require in-situ use of chromate-based CCC formulations can be planned to be performed outside Europe. This may entail the added cost of longer, non-revenue flights to the non-EEA repair centre. In the worst case, unplanned damage needs to be repaired before the aircraft can be moved. If this is in Europe, this creates an unworkable situation. From these examples, it is therefore crystal clear that relocation of single activities is in most cases not an option. Consequently, under the non-use scenario, more and more links in the supply/value chain, and associated jobs, know-how and R&D investments, will move out of Europe.

In conclusion, it is not possible to relocate the use of chromate-based CCC formulations on their own in most cases. These processes are an integral part in the production chain and cannot be separated from previous or following process steps. As a result, the entire production chain would need to be relocated, which although the most plausible scenario is also not realistic and would lead to severe impacts on the viability of the entire value chain.

Particular difficulties would be faced by companies in the space and defence sectors. Possibilities for relocating some activities outside the EEA/UK are limited due to the difficulties related to achieving specific customer requirements, national security considerations, work share agreements, and financial restrictions. As a result, it is likely that there would need to be requests for "defence exemptions" so that those activities that contractually must be maintained in their current location could continue within the EEA/UK. It would also have implications for the manufacture of products for the European space industry, damaging its ability to remain independent.

The above impacts also would have subsequent economic effects for the formulators supplying CCC formulations. These are covered in a separate dossier.

5.1.1.3 Design-to-Build

The potential responses by Design-to-Build companies are more varied:

- Cease operations
- Focus on other surface treatment activities for the aerospace or other sectors
- Shift operations outside the EEA/UK, or
- Stop undertaking chromate-based CCC activities until components using an alternative are certified.

As indicated earlier, DtBs are working on development, validation, qualification and certification of alternatives to chromate-based CCC (although it was also noted that the final decision may be up to their end customers). As this may take a significant length of time, then the lack of a certified alternative for their products means that the relevant CCC activities would cease until a certified alternative is in place. The CCC treatment work would be outsourced to another country depending on the expected length of stoppage/how close any alternative was to implementation at that time, customers' demand for the affected components, and/or the availability of customer-approved sources of supply elsewhere. In such cases, manufacture of the components or products involving the use of chromate formulations for CCC would cease, resulting in impacts on turnover, profits and employment. There would also be impacts on their customers, associated with increased costs and the potential lack of supply.

Several DtBs noted that the lack of qualified and certified alternatives is an industry-wide problem. The development, testing, qualification, certification and industrialisation of replacements is very costly and can only be carried out on a phased basis if they are to remain financially viable. They noted that the re-qualification costs are particularly high for the aerospace sector given the need to qualify conversion coating on products that have been in service for long periods (e.g. 30 years or more). As a result, it was noted that further time after the end of the initial review period is required for R&D to develop feasible alternatives which will meet the stringent airworthiness/certification requirements. Further time for technical and industrial qualification and implementation of suitable alternatives will be needed also, with this including implementation across their supply chain. As a result, there would be significant impacts on production activities. Furthermore, if OEMs were to stop production, then these companies would face closure.

For a small set of companies, the use of one or more of the four chromates in CCC is not a very important part of their total turnover. As a result, they will cease such activities with only some impacts on turnover and employment. Other companies would re-focus on servicing non-aerospace sectors where alternatives are already in use.

Those companies that indicated that they would shift their activities outside the EEA/UK, indicated that they would consider choosing from customer-approved sites (other companies under a sub-contract arrangement), shift to their own existing sites outside the EEA/UK or set up new facilities outside the EEA/UK.

None of the respondents indicated that they would move to a poorer performing alternative. This is not considered an option within the sector by design owners.

5.1.1.4 Build-to-Print

For Build-to-Print companies, the following are all potential scenarios:

- Cease operations;
- Focus on other surface treatment activities for the aerospace or other sectors;
- Shift operations outside the EEA/UK; or
- Stop carrying out chromate-based CCC activities until components using an alternative are certified.

In practice, the potential responses of Build-to-Print companies to the non-use scenario are constrained. Most confirmed that the choice of whether to use the chromates is not theirs but their customers'. Several noted that they could not shift to alternatives for CCC treatments until these were qualified and certified for use in the production of components by their customers and the authorities, and that the alternatives were suitable and sustainable for their customers' uses. It is also a concern that customers may each qualify and certify a different alternative, raising economic feasibility concerns in terms of capital investments, site infrastructure, etc. Others commented that if they could not use chromate-based CCC formulations in the EEA/UK, then they would have to either cease operations, sub-contract out some CCC processes or transfer multiple processes outside the EEA (more feasible for the larger companies). The subsequent effects would include redundancies and losses in turnover for EU operations, as well as the potential loss of NADCAP support.

A range of countries were identified as possibilities for relocation. Six of the 39 Build-to-Print companies already have facilities outside the EEA (with one having facilities in the UK as well as elsewhere) and UK. Four of these companies would consider shifting all production activities to such facilities rather than cease production while they wait for an alternative to be qualified for CCC. This includes potentially shifting operations to the US, Canada, China, Thailand, India, Turkey, Vietnam or Morocco. These companies indicated that this may require changes to their surface treatment portfolio, due to logistical issues and the need for CCC to be applied directly after a pre-treatment or surface preparation.

Of course, such a response would also have to be accepted by their OEM and DtB customers.

5.1.1.5 MROs

For companies that undertake a combination of BtP or DtB and MRO activities, the same options as identified above may apply to their non-MRO activities. For those that operate as MROs only, there is less choice. MROs do not undertake manufacturing, only the overhaul, repair and maintenance of different A&D components, which can differ in size and complexity (overhaul of a complete aircraft to maintenance of a single component in a land-based defence product).

When components enter under the services of an MRO, the required maintenance effort, including which surface treatment processes may be required, is not directly foreseeable. Very often, the level of work required only becomes clear after disassembling the component. The surface treatment steps required (e.g. from pre-treatment to CCC) for any given component is dependent on its condition and can differ for each maintenance event. As a result, not every component will pass through all potential surface treatment processes. Even where they do, levels of throughput are also dependent on the size and complexity of the component – processing times can range from five minutes to several days. Within these process flows, even if chromate-based treatments are required to a very limited extent, they remain essential. As part of maintenance activities, they play an essential role in ensuring that airworthiness regulations are met, and in the overall, economic feasibility of maintenance events.

For example, maintenance work may be performed at a customer's site on an assembled aircraft engine. This can involve non-destructive testing or component changes that do not require the complete disassembly of an engine. In the course of such maintenance work – depending on the findings – corrosion protection with prescribed chromate-containing materials, e.g. with a touch-up pen, must be carried out on individual cases in order to complete the maintenance work to the prescribed extent and to be able to release the engine under airworthiness requirements. If this step is not possible, the entire maintenance process of the engine and thus the product is compromised.
As a result, without the ability to use the chromates for CCC as part of maintenance, repair and overhaul, such services become unviable. There is no scope for them to operate outside the requirements detailed in the OEMs' service manuals, which are based on the qualified and approved uses of CCC. Where these requirements mandate the use of one of the four chromates, then the MRO must use that chromate as instructed unless the manuals also list a qualified alternative.

As a result, MRO business which are based on the re-implementation of upstream processes using one of the four chromates, would no longer be viable and would have to cease in the EEA/UK. For some companies, it may be possible to shift such activities outside the EEA/UK while for others this would require major changes in infrastructure. Shifting activities outside the EEA/UK is, however, neither practical nor feasible for their defence customers or civil aviation customers.

5.1.2 Non-plausible scenarios ruled out of consideration

5.1.2.1 Move to a poorer performing alternative

Moving to a poorer performing alternative would not be acceptable to the OEMs, either from a Design Organisation Approval (DOA) perspective as approved by EASA[70], MoDs and the European Space Agency (ESA), or from an engineering perspective taking airworthiness safety requirements into consideration.

As noted in the parent Applications for Authorisation, under the scenario of moving to a poorer performing alternative, OEMs would not accept an alternative that is less efficacious in delivering corrosion protection where no alternative provides an equivalent level of performance to the chromates. The use of a less effective alternative would downgrade the performance of the final product, and the reduction in the level of corrosion protection performance would give rise to several unacceptable risks/impacts:

- The highly likely risk of EASA (airworthiness authorities), MoDs or ESA not accepting a downgrade in performance;
- Increased maintenance operations, leading to an increase in the downtime of aircraft and military equipment, increased costs of maintenance, less flying hours, etc.; and
- Increased risks to passengers, cargo operators and operators of military equipment.

Corrosion issues likely would not appear suddenly, but over time they may affect hundreds of A&D components entered into in-service. Further, potential decreased corrosion protection performance from Cr(VI)-free coatings would necessitate shorter inspection intervals to prevent failures. Flight safety obligations preclude the aerospace industry from introducing inferior alternatives on components, and the long-term performance of alternatives that have not undergone rigorous testing and development can only be estimated.

In the purely hypothetical case where decreased or loss of corrosion protection is introduced to aircraft, the following risk mitigation actions may be required:

- Substantial increase in inspections – both visual checks and non-destructive evaluations, such as ultra-sound crack tests, etc. Some inspections are very difficult or hazardous to perform (e.g. inside fuselage/wing structures). All aircraft using less effective materials in repair/overhaul and/or unproven materials across the operating lifetime of an aircraft would be subject. A very conservative inspection frequency would be set to ensure safety until adequate in-service performance experience is obtained.
- Increased overhaul frequency or replacement of life-limited components. Possible early retirement of aircraft due to compromised integrity of non-replaceable structural parts.
- Whole fleets may be grounded until a repair/replacement plan is in place for the whole aircraft fleet (e.g. grounding Boeing 787 fleet due to battery problems).
- Due to similarity of technologies and aircraft uses, a fleet grounding event in such a scenario could impact many or all aircraft fleets.
- An increase in the number of aircraft and engines required by each airline to compensate for inspection/overhaul downtime and early retirement.

[70] As defined by Commission Regulation (EU) 748/2012 which sets out the requirements that must be fulfilled by organisations that design aircraft, make changes to aircraft, repair aircraft and the parts and systems used in aircraft.

- Defence systems would have similar impacts adversely affecting the continuity of national security.

Aerospace components are portions of major systems (fuselage; wings; engines etc.) and the components in these systems are designed to withstand similar criteria between overhauls. For example, a system is designed to achieve 25,000 cycles between overhauls and a new component is only rated for 5,000 cycles because of a Cr(VI)-free coating. By default, the entire system would now be de-rated to 5,000 cycles. Take a compressor blade that is located in the middle of an engine. If that blade can only survive for a portion of the life of an engine due to limitations of a new coating, the engine would require disassembly to access the blades. This means taking the engine off the wing, sending it to a repair centre, disassembling the engine and replacing the components at much shorter intervals than needed for the remainder of the engine; thus adding inherent inspection, maintenance, and repair costs to the manufacturers, operators, and end use customers, who will also be impacted by increased out of service times.

The lack of experience with Cr(VI)-free solutions can have a critical safety impact. As a result, the aerospace industry has a permanent learning loop of significant events and failure analysis and decisions for safety improvements. Part of this improvement is the introduction of the Maintenance Steering Group 3 Analyses (MSG-3), specifically developed for corrosion. MSG-3 provides a system for OEMs and the regulators to identify the frequency of inspection with respect to the stress corrosion, protection and environmental ratings for any component or system.

Without adequate experience, proven success, and therefore possible unknown or hidden properties, the performance of a chromate-free system cannot be highly rated. Consequentially, a significant reduction to the maintenance interval would be required, potentially cut in half. For cases with no long-term experiences or correlation to in-service behaviour, which is normally the case, a further reduction to the maintenance interval may be required.

As a result, OEMs rule out moving to a poorer performing alternative under the non-use scenario; the risks are unacceptable to all OEMs. The primary objective of these companies is to move to an alternative. This objective cannot be achieved, however, without sufficient testing and flight (or other) data surrounding the use of alternatives. Without such data, the necessary approvals cannot be gained as the safety risk becomes too great, whether related to civil aviation or military aircraft. The corrosion resistance and other benefits provided by CCC are crucial to the manufacture of aircraft components in the EEA/UK; if there are no qualified alternatives certified for use on components then manufacturing work would cease.

Given the above, this scenario is absolutely not considered plausible.

5.1.2.2 Overseas production followed by maintaining EEA/UK inventories

To be competitive, companies must keep inventory as low as possible ("just-in-time" delivery). Maintaining inventory clearly involves substantial capital costs (as elaborated below) and ties up cash. Stockpiling is also clearly not feasible for the repair and maintenance side of the business because the main aim of repair is to make components serviceable rather than replace them by spare components (which would run counter to the sectors drive towards increased sustainability).

The reasons why holding increased inventories is not a feasible option compared to maintaining and repairing damage include, but are not limited to, the following considerations:

- If no certified alternative is available or is likely to become available within months after the end of the review period, then there is no clarity on how long such inventories of components must be available. For legacy aircraft, inventories will certainly be required for the next 20 years or more. Additionally, there is no visibility or clarity on customer demand in the short or longer term. Planned maintenance can be taken into account, but it is not possible to anticipate which components will be needed for unplanned maintenance and repair. Consequently, an assumption regarding the inventory that needs to be available for a sufficient duration would have to be made, leading to the risk of wasted resources or aircraft/equipment becoming obsolescent due to inadequate inventories.

- Stockpiling results in increased costs and would reduce the opportunity to invest in other projects/R&D, etc. The inventory costs would also have to be added to product costs and would therefore reduce competitiveness for operations in the EEA/UK.

- The costs of building adequate warehouse facilities in the EEA and the UK would be prohibitive and would not be economically feasible. In the UK, an industrial warehouse without climate control (which would be required for the storage of some A&D inventory) costs around €1000 per m^2 to construct (a conservative estimate). Its assumed here that warehouses that would act as a hub for storing inventory would be around 10,000 m2 as a minimum, given the range of parts that would need to be stored. This implies a total build cost of around £10 million as a minimum, not taking into account the costs of land purchase, site preparation, design, construction, etc. which could easily add a further 25% even after taking into account any potential economies of scale in pricing due to the large size of the warehouse.[71] If such facilities are required at around 100 sites across the EEA and UK (to cover civilian and military requirements), then warehousing costs alone would lead to €1 billion in expenditure. These costs would be on top of the losses in profits that would occur from the need to subcontract manufacture to companies located outside the EEA/UK and the consequent profit losses and increased costs of shipping, etc.

- Facilities do not have enough production capacity to build up multi-year inventories, while also meeting current demand. Even if production capacities could be increased and adequate quantities of standard components be produced, there would be idle inventories for years beyond their need, which would in turn increase product costs for years. Importantly, the need to store this inventory under optimum conditions to avoid corrosion or damage over extended periods of stockpiling, would lead to further increases in costs.

- Existing facilities are not sized to store the amount of multi-year inventories required. Companies will need to build/invest in additional secure, high-quality warehouses to store the inventory. However, it is important to recognise that this scenario is not feasible at all for many parts, such as wing and fuselage skins, because these components are not removed from the aircraft; these parts only allow MRO activities in-situ. Therefore, the entire aircraft would need to be transported to a non-EEA country for repair. If the plane is not airworthy, the effort and cost relating to transportation alone (e.g. from Belgium to Egypt) would be overwhelming.

- Even then, when existing inventories become depleted and no longer support necessary repairs and maintenance, increasing numbers of aircraft on ground (AOG) scenarios are

[71] See for example the cost model available at: https://costmodelling.com/building-costs

inevitable, with associated costs. All transportable components would have to be sourced and produced from non-EEA suppliers sooner or later.

- Being dependent upon inventories and non-European suppliers (and in turn vulnerable to local economic and political issues affecting non-EEA countries or the UK), and thus unable to reliably fulfil MRO activities, will lead to inevitable delays and potential cancellation of flights, fines due to longer turn-around times and aircraft on ground scenarios.

- Companies make design modifications for single components as part of their normal course of business (for reasons other than chromate substitution). In these cases, all existing inventory would need to be written off for a loss. Furthermore, companies would not be able to produce the modified components in the EEA/UK anymore (if CCC is still required). Consequently, it is clearly not possible to rely on a long-term stock of spare parts that would fit all situations.

- It is impossible to hold a stock of all spare components at every airport. This would affect schedules, especially overnight stops as aircraft cannot be readily repaired and maintained. As a result, these aircraft would not be available for services next day and delays or flight cancellations would likely occur.

- Cost and environmental impacts of managing and disposing of waste components that could not be reused would be high. This seems to be inconsistent with the emphasis on waste reduction as a part of circular economy.

It is challenging to elaborate these quantitatively as they are multi-fold (i.e., increased cost of land and construction for warehousing, worker costs to secure and maintain inventory, increased delays and 'aircraft on the ground', writing-off stock) and there is no precedent to rely on, as this NUS is entirely contrary to current industry practice. However, it is immediately clear that the result would be that the cost of operating in the EEA/UK would increase considerably and the impact to society as a whole.

Furthermore, for certain types of components, increasing stock inventory is not feasible at all. In a very competitive industry, this would result in a migration of the entire industry (the inter-dependency of the industry is explained below and elsewhere in the SEA) to non-EEA/UK locations. As production moves outside the EEA/UK, related activities such as R&D will also re-focus to these countries. It can also be expected that future investment in associated industries and technologies will be most efficiently located alongside these activities.

Given the above, this scenario was not considered plausible by the OEMs and MROs due to the need for components to have CCC treatments quickly after other surface treatments. It was confirmed though that such an approach may be feasible for a small range of components for civilian aircraft and for a limited number of parts for military aircraft and equipment. However, as an overall strategy, it would not be feasible as use of chromium-based CCC formulations would still be required in the EEA/UK for the majority of components and on-site maintenance and repair activities.

5.1.3 Conclusion on the most likely non-use scenario

The most likely non-use scenario is driven by the responses of the OEMs to the non-use scenario. They are the customers that carry out the R&D and testing (sometimes in collaboration with their chemical suppliers and formulators) to determine whether an alternative is technically feasible, qualify and gain approvals for components using that alternative and then certify their suppliers against its use. In some cases, they also help their suppliers meet the financial costs of adapting existing facilities to enable them to move to the alternative.

As a result, the most plausible non-use scenario for the OEMs drives the most likely non-use scenario for the sector. The most likely scenario is therefore the following:

1. EEA/UK based producers of CCC formulations would either cease manufacturing their current formulations or move manufacture outside the EEA/UK for sale to companies relocating their activities. This would require recertification of these formulations given the change in manufacturing location, with consequent impacts on the downstream user supply chain. There is a risk that the formulations could not be re-certified across all components/final products, leading to the obsolescence of aircraft and military equipment. Even if they can be re-certified for a component or product, this would not be feasible before the end of the current authorisation period.

2. OEMs directly involved in CCC surface treatments would move a significant proportion of their manufacturing operations outside the EEA/UK, with the consequent loss of significant levels of turnover and employment. In particular, they would move those manufacturing activities reliant on the use of CCC where there is no qualified alternative or where implementation across suppliers after qualification and certification have been achieved is expected to require several years after the end of the current review period (e.g. 2-4 years after qualification due to the large number of suppliers using CCC). This includes the manufacturing of all magnesium and a large proportion of aluminium parts, as they require a conversion coating. The losses to the EEA/UK would range from around 30% of manufacturing turnover for some sites to 100% of manufacturing turnover at others. The net effect based on the size and number of OEMS indicating different levels of loss would be about 85% of turnover. Significant losses in jobs directly related to use of the chromates.

3. OEMs who do not carry out CCC surface treatments themselves would move some of their manufacturing operations outside the EEA/UK due to the desire to have certain treatment and production activities co-located within a region (i.e. to form clusters). This would facilitate the integration of manufacturing activities and associated maintenance and repair activities. As a result, there would be losses in turnover and employment associated with these companies also relocating.

4. As OEMs shift their own manufacturing activities outside the EEA/UK, they will have to carry out technical and industrial qualification of new suppliers or EEA/UK suppliers moving to the new location, to ensure suppliers have the capability to deliver the stringent airworthiness and certification requirements. This would then be followed by a ramping up of production in order to meet the manufacturing rate objectives.

5. In some cases, these newly located supply chains would be developed using BtP and DtB suppliers who have moved operations from the EEA/UK to other countries to continue supplying the OEMs. However, a significant proportion of the existing Build-to-Print companies involved in CCC – ranging from 60% to 100%, assumed 75% – will cease trading in the EEA as they do not also supply other sectors and are reliant on the aerospace sector; furthermore, the types of products that they manufacture are specific to the A&D sector. There will also be significant closures of Design-to-Build companies reliant on chromate-based CCC activities, with around half (40%) expected to either cease trading altogether or relocate outside the EEA/UK.

6. MROs will also be severely impacted and the larger operators indicated that they will either cease trading or move operations outside the EEA, due to the need to maintain vertical integration across the surface treatment processes that they are able to carry out. On this basis, it is estimated that between 60 - 80% (assumed 70%) of current MRO activities would cease in the EEA/UK.

7. The re-location of MRO activities will have consequent impacts for civil aviation and military forces, as well as for the maintenance of defence products, space equipment and aero-derivative products.

8. As noted above, this would run contrary to the EU's New Industrial Strategy[72], which identifies the A&D industry as one of the industrial ecosystems that requires support to ensure innovation, competition and a strong and well-functioning single market.

9. Airlines and their passengers would be impacted by increased costs and planes on the ground, while military forces' mission readiness would be impacted with the risk that equipment would also becoming obsolete and unavailable due to the inability to carry out repairs and/or maintenance activities according to manufacturers' requirements.

10. Significant economic impacts would therefore result from the loss of manufacturing and maintenance to both the EEA and UK economies, together with the loss of highly skilled jobs (and potentially a highly skilled labour force) and the benefits derived from the R&D carried out by a high-tech sector.

The justification for this NUS takes into account the fact that OEMs and DtBs will not have all components with certified alternatives which have been fully implemented across their supply chains by September 2024. Many will require a further 12 years to have fully implemented alternatives across all components/final products and EEA/UK supply chains. The regulatory requirements placed on the sector mean that unless components have certified alternatives there is no substitute which can be considered "generally available".

As noted previously, because of the complexity of the supply chain, and the close working partnerships that exist, a decision by an OEM or DtB to relocate will result in their suppliers relocating to keep proximity. Such relocation would involve not just CCC, but all associated pre- and post-treatment activities due to the potential for corrosion of unprotected surfaces during transport to another place.

The impacted operations and socio-economic impacts to industry under the non-use scenario will therefore go far beyond the specific processes directly reliant on CCC. Figure 5-1 illustrates the interdependency of every single component used, and the effect of only one component missing for the overall assembly process of the aircraft. In the first box, a component reliant on CCC would be impacted. If this can no longer be produced according to type certification, then manufacture of a sub-assembly is impacted. This then impacts on manufacture of an assembly and places the manufacture of the entire aircraft in jeopardy. As a result, it is not possible to relocate single Cr(VI) based activities on their own in most cases, as they are an integral part in the production chain and cannot be separated from previous or following process steps.

72 https://op.europa.eu/en/publication-detail/-/publication/52904a0b-ae95-11eb-9767-01aa75ed71a1/language-en

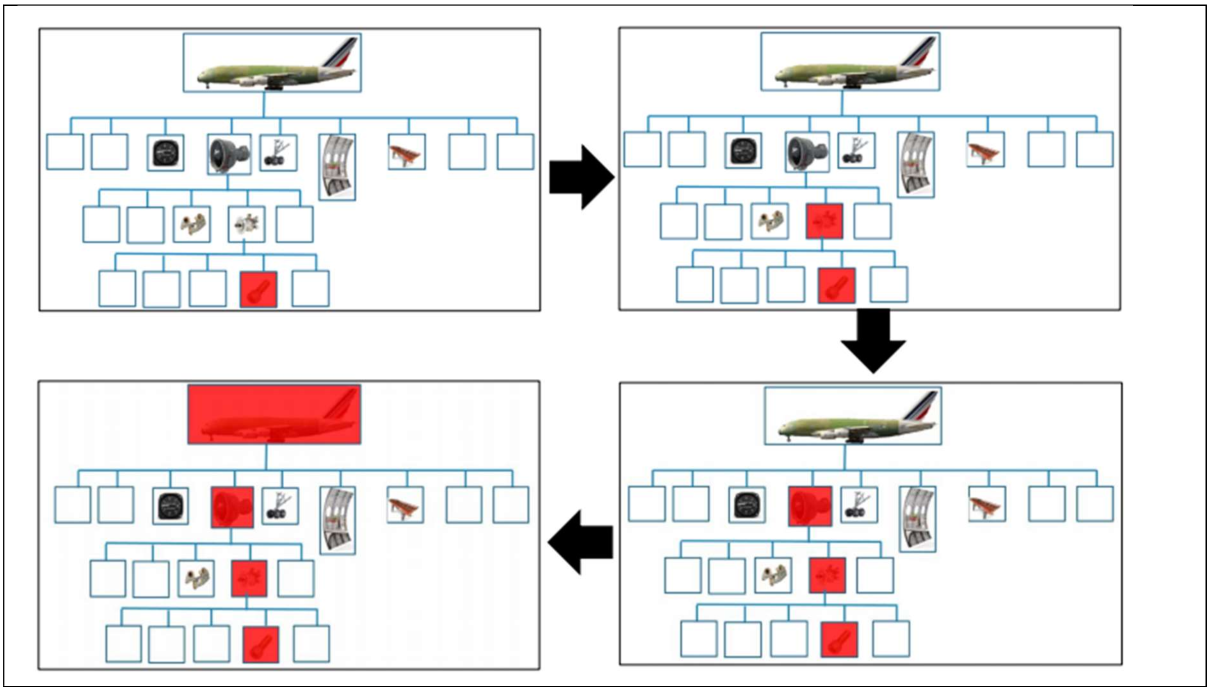

Figure 5–1: Interdependency of component availability in the manufacture of a final product

MROs will be similarly affected. It is technically not possible (or economically feasible) to carry out repairs to large components outside the EEA/UK, and then ship it back for reassembly in a final product in the EEA/UK. Apart from the fact that the surface of the component could be damaged during transport, adding to the technical infeasibility of this situation, the very tight turnaround times and budgets are impossible to hold in such a scenario.

Finally, although this is considered the most plausible scenario, OEMs note that the obstacles that would have to be overcome in a short period of time may make it overly optimistic. The infrastructure of the sector is based in part around manufacturing clusters or hubs (see also Figure 5-2), with smaller suppliers located around the sites operated by the larger OEMs. Not all these smaller sites, including those of critical suppliers, would be able to shift their activities outside the EEA/UK, leading to OEMs having to create entirely new supply chains outside the EEA/UK. This scenario also implies a huge economic investment would be carried out by the OEMs as well as their EEA/UK suppliers. This level of investment is unlikely to be feasible and in the meantime the OEMs would have to cease manufacturing activities until the new industrial facilities were in place and ready to operate outside the EEA /UK.

5.2 Economic impacts associated with non-use

5.2.1 Economic impacts on applicants

Under the non-use scenario, all applicants and the formulators of the CCC products would be impacted by the loss of sales of the four chromates or of imported formulations containing the chromates for use in CCC. At the specific supplier level, these impacts may vary in their significance, as the importance of the different chromates used in CCC formulations to their revenues varies across the suppliers (as does the level of supply of chromates for use in other treatment processes).

In the short term (i.e. first two years under the non-use scenario), the losses will be in the order of Euro/Pound sterling tens of millions per annum to the applicants and their downstream formulators.

Over time, as consumption of the chromates reduces in line with companies' substitution plans, sales and hence revenues will continue to decrease. However, the formulators producing the chromate-based CCC formulations are also the same companies that will be providing formulations based on the alternatives. As a result, sales of alternative formulations once they are certified and implemented across value chains would be expected to offset profit losses from declining demand for the chromate-based formulations.

No quantitative estimates for these losses are included in this SEA. These impacts are captured in the combined AoA/SEA for formulation.

5.2.2 Economic impacts on A&D companies

5.2.2.1 Introduction

It would be theoretically possible to move activities involving the chromates use outside the EEA /UK due to already existing supply chain sites in other countries, for example, the USA, Canada, China, India, etc. and to outsource manufacturing as the supply chain is spread around the world. There are several obstacles to such a scenario, however, which would make this economically unattractive even if it is the most plausible scenario. Firstly, the due diligence principle will continue to apply to the supply chain and would be exacerbated in case of relocation out of EEA/UK. Secondly, when activities are shifted to another site, there is an inevitable phase of technical and industrial preparation (site design, capital procurement and installation, worker training, pilot trials) and qualification to ensure the sustainability of these activities, including an assessment of the technical capability to deliver stringent airworthiness and certification requirements. Moreover, once the qualification phase is over, it is essential to get the right ramp up in order to meet the manufacturing rate objectives.

In the remaining time before the end of the initial review period, even if alternatives were qualified and certified across the manufacture of components and products, these two aspects are not realistic; it would require a huge economic investment that would significantly affect businesses with detrimental economic impacts. As a result, OEMs have indicated that they probably would be forced to stop manufacturing activities until the new industrial facilities and infrastructure are in place and ready to operate outside of the EEA/UK, with consequent impacts on the entire value chain. Given the current levels of civil aviation and anticipated growth, this would be catastrophic for aviation in the EEA/UK and globally.

5.2.2.2 Approach to assessing economic impacts

As noted in Section 1, the ADCR has been created as a sectoral consortium and downstream user members include competitors, which may also act as suppliers to each other; the larger companies also share many of the same BtP and DtB suppliers (an estimated 15-25% overlap in suppliers exists across some OEMs). These interlinkages have been taken into account in the estimation of economic impacts, which have been calculated separately for the OEMs, DtBs, their associated BtP suppliers and MROs.

Two separate approaches have been used to estimate the magnitude of the potential economic impacts. Both are based on responses to the SEA questionnaire, with one taking as its starting point the number of jobs that would be lost while the other considers losses in turnover and what these imply in terms of losses in profits. Both approaches are used as a greater number of responses provided estimates of jobs lost than of the likely impacts on turnover (in percentage or actual terms).

1. **Estimates based on loss of jobs**: The first approach takes as its starting point the number of jobs that would be lost at the sites of SEA questionnaire respondents, based on their most likely response to the non-use scenario. This includes loss of jobs directly linked to use of the chromates and losses in jobs at the site reliant upon the continuation of their use, i.e. jobs in related manufacturing and assembly activities. Importantly, it excludes losses in employment at local sub-contractors providing support services. The numbers of jobs lost are multiplied by the average Gross Value Added - GVA - per job (taking into account variations by role) to provide an estimate of total GVA lost. Personnel costs associated with this GVA are then subtracted to derive the implied losses in operating surpluses per annum.

2. **Estimates based on loss of turnover**: The second approach takes as its starting point the anticipated losses in terms of percentage of turnover reported by the respondents to the SEA questionnaire. Lost operating surplus is then calculated as an average per company based on role in the supply chain and Eurostat data on GOS as a percentage of turnover.

Both approaches provide proxy estimates of profit losses based on current levels of employment and turnover. They do not account for foregone future turnover under the continued use scenario due to the inability of the EEA/UK A&D sector to respond to growth in the global demand for air traffic or to increased military and defence spending as a result of either a cessation in manufacturing activities or their relocating outside the EEA/UK.

The two approaches have been applied to account for uncertainty in the data available from the SEA questionnaire responses. Together they provide an interval, with one estimate acting as an upper bound and the other as a lower bound to the economic impacts.

5.2.2.3 Estimates based on loss of jobs (and GVA lost)

The SEA questionnaire collected data on the number of employees who would lose their jobs under the NUS. This includes both those whose job directly involves use of the chromates and those whose jobs would be affected due to a cessation of production activities or due to companies moving outside the EU. The resulting figures collected for the 166 sites are presented in **Table 5-1** below.

The job losses reported by respondents, which range from a few per site where only a single operation would cease to all employees in the event of closure, are significant across the 166 responding sites:

- 18,840 jobs (around 15,130 in the EU and 3,710 in the UK) involving workers directly involved in use of the chromates, where this includes jobs undertaking other linked processes/treatments (chromate and non-chromate based) as well as follow-on manufacturing, assembly, repair and maintenance activities;

- Over 24,150 additional jobs due to the cessation of manufacturing activities across product lines or to the cessation of MRO services, including due to companies moving operations outside the EU.

It is important to note, that these losses do not equate to 100% of the jobs at these sites, as there would not be a full cessation of activities at all sites. They represent only a portion of the employees at the 166 sites. It is assumed that roughly half of the Build-to-Print and Design-to-Build companies would continue operations in the EEA, either with a reduced number of jobs or by shifting to the manufacture of parts for other sectors. For example, some sites that employ between 50 to 250 employees indicated a loss of less than 20 jobs. Furthermore, it is important to note that there will be A&D sites that are unaffected as they do not undertake CCC surface treatments.

Extrapolating these figures out across the entire 350 EEA sites and 80 UK sites undertaking CCC activities suggests that around 36,700 jobs could be lost that are directly linked to use of the chromate formulations for CCC, with almost 84,500 lost in total due to a cessation of linked manufacturing and assembling activities or companies moving all or part of operations outside the EEA/UK. Although these figures appear high, they should be seen within the context of the roughly 890,000 employees (2019[73]) within the European A&D sector, taking into account the critical importance of the chromates in CCC (and as part of a coating system also involving the use of strontium chromate for example).

These predicted job losses have been combined with Eurostat data on Gross Value Added (GVA) per employee to the EEA/UK economy as part of calculating the economic losses under the non-use scenario. A weighted GVA has been used for BtP and DtB suppliers and NACE code specific GVAs have been used for OEMs and MROs. The resulting estimated losses are given in **Table 5-3** below.

The estimated losses in GVA equate to:

- €6.22 billion per annum across the EEA and almost €1.06 billion per annum for the UK, extrapolated out to the 350 EU and 80 UK downstream user sites.

The magnitude of these GVA losses reflects the fact that use of chromate-based CCC formulations as a chromate-using surface treatment takes place across the largest number of sites in the EEA/UK, including large numbers of BtP suppliers and MROs (civil and defence).

For comparison, turnover for the EU A&D industry is around €259 billion[74] per annum, while that for the UK A&D sector is around €57 billion (£50 billion) in 2020[75]. Thus, although these figures appear high, they are considered to be underestimates by the ADCR members (particularly the OEMs) given the potential for much larger segments of the sector to move outside the EEA /UK should chromate-based CCC no longer be permitted.

[73] Statista 2022: https://www.statista.com/statistics/638671/european-aerospace-defense-employment-figures/

[74] https://www.statista.com/topics/4130/european-aerospace-industry/#topicHeader__wrapper

[75] https://www.statista.com/statistics/625786/uk-aerospace-defense-security-space-sectors-turnover/

Table 5-2: SEA survey responses and extrapolations on numbers of jobs lost under the non-use scenario						
	No. Company Responses		Direct job losses – workers undertaking processes linked to CCC		Additional direct job losses – due to a cessation of manufacturing/MRO activities	
From SEA Survey	EEA	UK	EEA	UK		
Build-to-Print (51 sites)	32	19	960	668	688	149
Design-to-Build (19 sites)	12	7	788	893	1,107	535
MROs (46 sites)	40	6	1,574	235	4,681	1,015
OEMs (50 sites)	36	14	11,813	1,914	14,777	1,201
Total 166 sites	**120**	**46**	15,134	3,710	21,253	2,900
Extrapolation of job losses under the non-use scenario to the estimated 430 sites undertaking CCC treatments						
Build-to-Print (170 sites)	145	25	4,349	879	3,117	196
Design-to-Build (75 sites)	60	15	3,940	1,914	5,535	1,146
MROs (105 sites)	90	15	3,541	588	10,532	2,538
OEMs (80 sites)	55	25	18,048	3,418	22,576	2,145
Total sites (430)	**350**	**80**	29,877	6,797	41,760	6,025
Total EU direct and indirect across 350 sites			**71,637**			
Total UK direct and indirect across 80 sites			**12,823**			

Table 5-3: GVA losses per annum under the non-use scenario						
By role	GVA per worker assumed by role		GVA lost due to direct job losses € million		Additional GVA lost due to due to a cessation of manufacturing/MRO activities - € million	
	EEA	UK	EEA	UK	EEA	UK
Build-to-Print (51 sites)	60,300*	60,300*	57.93	40.30	41.51	9.01
Design-to-Build (19 sites)	60,300*	60,300*	47.56	53.90	66.82	32.29
MROs (46 sites)	85,000	85,000	133.75	19.98	397.88	86.28
OEMs (50 sites)	98,500	98,500	1,163.58	188.53	1,455.53	118.30
Total 166 sites			1,402.83	302.71	1,961.74	245.88
		Total EU	**€ 3,365 million per annum**			
		Total UK	**€ 549 million per annum**			
Extrapolation of GVA losses to the estimated 430 sites undertaking CCC treatments						
Build-to-Print (170 sites)	60,300*	60,300*	262.51	53.03	188.11	11.86
Design-to-Build (75 sites)	60,300*	60,300*	237.82	115.50	334.09	69.20
MROs (105 sites)	85,000	85,000	300.94	49.94	895.22	215.69
OEMs (80 sites)	98,500	98,500	1,777.69	336.66	2,223.73	211.25
Total sites (430)			2,578.96	555.13	3,641.16	507.99
		Total EU	**€ 6,220 million per annum**			
		Total UK	**€ 1,063 million per annum**			
***Weighted average GVA calculated for Build-to-Print and Design-to-Build companies as the GVA by NACE code multiplied by the NACE code counts across responding companies, divided by the total number of relevant NACE responses. MRO and OEM GVA figures from Eurostat (2018).**						

Table 5-4: Implied GVA-based gross operating surplus losses per annum under the non-use scenario						
	Total GVA losses- € millions per annum		Total personnel costs associated with lost jobs - € millions per annum*		Implied operating surplus losses € millions per annum	
	EEA	UK	EEA	UK	EEA	UK
Build-to-Print (51 sites)	99.4	49.3	65.1	32.3	34.3	17.0
Design-to-Build (19 sites)	114.4	86.2	74.9	56.5	39.5	29.7
MROs (46 sites)	531.6	106.3	352.8	70.5	178.9	35.8
OEMs (50 sites)	2,619.1	306.8	1,877.3	219.9	741.9	86.9
Total 166 sites	**3,364.6**	**548.6**	**2,370.0**	**379.2**	**994.5**	**169.4**
Extrapolation of operating surplus losses to the estimated 350 EU and 80 UK sites undertaking CCC treatments						
Build-to-Print (170 sites)	450.6	64.9	295.1	42.5	155.5	22.4
Design-to-Build (75 sites)	571.9	184.7	374.6	121.0	197.3	63.7
MROs (105 sites)	1,196.2	265.6	793.7	176.3	402.5	89.4
OEMs (80 sites)	4,001.4	547.9	1,605.9	219.9	2,395.5	328.0
Total sites (430)	**6,220.1**	**1,063.1**	**3,069.3**	**559.6**	**3,150.8**	**503.5**
*Weighted personnel costs calculated for Build-to-Print and Design-to-Build companies as the GVA multiplied by the NACE code counts across responding companies, divided by the total number of relevant companies. MRO and OEM GVA figures direct from Eurostat (2018) for EU/UK as available.						

In order to convert these GVA losses to an estimate of lost operating surplus (profits), personnel costs for each lost job are subtracted. The results of this calculation are given in **Table 5-4** above. Personnel costs are based on Eurostat data for the relevant NACE codes, with an average weighted personnel cost adopted for BtP and DtB; the average personnel costs by NACE code from Eurostat for OEMs and MROs are adopted in these cases.

The estimated values of lost operating surpluses generated by this GVA-based approach equate to:

- €3.151 billion per annum across the EEA and almost €503 million per annum for the UK, extrapolated out to the 350 EU and 80 UK downstream user sites.

5.2.2.4 Estimates based on lost turnover

The SEA questionnaire also asked companies to provide information on the impacts that a refused authorisation would have on turnover/revenues. Fewer companies responded to this question, although the responses provided by the OEMs (as the end customer) and MROs enable estimates of the likely percentages of turnover lost by role to be developed. These estimates take into account the number of companies indicating that they also carry out activities other than chromate-based CCC for the A&D sector, as well as surface treatment and other processes for other sectors. They also take into account the level of turnover linked to other pre- and post-treatment activities as well as subsequent manufacturing and assembly activities.

Estimates of lost revenues per site are based on Eurostat data by NACE code with weighted averages used for BtP and DtB companies, and NACE code specific data for OEMs and MROs. Note that the weighted averages exclude micro-enterprises as few suppliers within the sector will fall into this size category. Gross operating surplus losses are then calculated by applying GOS rate data for the different NACE codes from Eurostat for 2019. The resulting losses are given in **Table 5-5**.

Table 5-5: Turnover and GOS losses under the non-use scenario – (avg. 10.6% losses across all roles)

	Turnover lost per annum € millions		GOS losses per annum € millions per annum	
	EEA	UK	EEA	UK
Build-to-Print (51 sites)	1,642	975	212	126
Design-to-Build (19 sites)	328	192	42	25
MROs (46 sites)	1,997	300	168	25
OEMs (50 sites)	37,168	14,454	3,903	1,518
Total 166 sites	41,135	15,920	4,325	1,694
Extrapolation of turnover and GOS losses to the estimated 430 sites undertaking CCC treatments				
Build-to-Print (170 sites)	7,439	1,283	962	166
Design-to-Build (75 sites)	1,642	410	212	53
MROs (105 sites)	4,494	749	377	63
OEMs (80 sites)	56,785	25,811	5,962	2,710
Total sites (430)	70,359	28,253	7,515	2,992

*Weighted average turnover and GOS calculated for Build-to-Print and Design-to-Build companies as the GOS multiplied by the NACE code counts across responding companies, divided by the total number of relevant companies. MRO and OEM figures direct from Eurostat (2018) for EU/UK as available.

5.2.2.5 Comparison of the profit loss estimates

The figures presented in **Table 5-5** are higher than those given in **Table 5-4** for both the EEA and UK, with the greatest differences being in the estimates for OEMs and MROs. This is due to the turnover-based estimates taking better account of the loss in associated manufacturing, maintenance or repair activities, given the importance of chromate-based CCC to both of these sets of companies.

- GVA based approach estimates of lost operating surplus across all sites:
  - Losses of €3,150 million per annum for the EEA
  - Losses of €503 million per annum for the UK

- Turnover based approach estimates of lost operating surplus across all sites:
  - Losses of €7,515 million per annum for the EEA
  - Losses of €2,992 million per annum for the UK

The two sets of figures are used in this SEA to provide lower and upper bound estimates of losses in producer surplus, with the ratios between the two sets of estimates for the different roles shown in **Table 5-6**. It is important to note that these losses apply to commercial enterprises only. No data could be provided by any of the military organisations reliant upon the continued use of chromate-based CCC which could be used in this analysis. These organisations simply stated that they would have to cease undertaking MRO related activities in their home country, resulting in severe impacts on their national air forces (in particular) and maintenance of other defence equipment.

Table 5-6: Comparison of profit loss estimates

	Total job losses		% turnover lost		Ratio of lost profits based on turnover to lost operating surplus based on jobs (based on €billions lost)	
	EEA	UK	EEA	UK	EEA	UK
Build-to-Print (170 sites)	7,466	1,075	75%	75%	6.19	7.41
Design-to-Build (75 sites)	9,475	3,060	40%	40%	1.08	0.83
MROs (105 sites)	14,073	3,125	70%	70%	0.94	0.70
OEMs (80 sites)	40,624	5,563	85%	85%	2.49	8.26
Total sites (430)	71,637	12,823	€7.5 billion	€3.0 billion	2.38	5.94

Offsetting profit losses and impacts on rival firms

The losses in operating surplus given above would result not only from a cessation of manufacturing activities, but also from the premature retirement of existing capital equipment. Some of this capital equipment would be replaced in any event as part of substitution, over the next 4 - 12 years; any such investment in new equipment would be focused on facilitating substitution (while the capital equipment associated with the continued use of the chromates over the next 7 - 12 years would not be expected to be replaced).

As there are no suitable alternatives which are generally available, following SEAC's latest guidance, consideration has been given to the need to offset the profit losses for downstream users against the potential resale or scrappage value of the sector's tangible EU and UK assets. However, given the potential scale of the impacts of a refused authorisation for the sector, any possible market for redundant equipment is likely to be overwhelmed by the number of sites ceasing activities, including related processes. As a result, it is not possible to estimate the potential scrappage value of equipment (e.g. immersion baths), especially as its current use for chromate-based treatments may further reduce its value.

Because this is a sectoral application and the ability to shift to alternatives is driven by qualification and validation by OEMs and obtaining certification approval by airworthiness authorities, the issue of potential losses incurred by rival firms undertaking CCC using alternatives is not relevant. The OEMs determine whether alternatives can be used, not individual downstream users. Furthermore, as previously indicated, the ADCR is a sectoral consortium and downstream user members include competitors, which may also act as suppliers to each other, while the larger companies share many of the same BtP and DtB suppliers (an estimated 15-25% overlap in suppliers exists across some OEMs). Relationships between the OEMs and BtP and DtB are developed over time and often reflect long-term commitments given the need for OEMs and DtB companies to certify their suppliers in the manufacturing of components. As a result, rival suppliers cannot readily step in and replace their production activity.

The economic losses are therefore based on consideration of losses in operating surplus/profits only. These have been estimated over three time periods in line with SEAC's new guidance for those cases where there are not suitable alternatives available in general. Discounted losses over 1, 2, 4, 7 and 12 years are given in **Table 5-7**.

As discussed earlier, these losses are based on Eurostat turnover figures for 2018 (most recently available by company size). They therefore represent an underestimate of the losses in turnover that would arise over the review period under the non-use scenario, given the anticipated level of future growth in turnover for the sector due to the importance of the EEA and UK in the global manufacture of aerospace and defence products (as highlighted by the publicly available forecasts of the demand for new aircraft cited earlier).

Table 5-7: Discounted profit /operating surplus losses under the non-use scenario – Discounted at 4%, year 1 = 2025

	Lost EBITDA/Profit - € millions		GVA-based Operating Surplus Losses	
	EEA	UK	EEA	UK
1 year profit losses (2025)	7,515	2,992	3,151	504
2 year profit losses (2026)	14,172	5,643.10	5,942	950
4 year profit losses (2028)	27,278	10,861.32	11,438	1,828
7 year profit losses (2031)	45,102	17,958.58	18,911	3,022
12 year profit losses (2036)	70,524	28,081	29,571	4,725

5.2.2.6 Other impacts on A&D Companies

Under the non-use scenario there would be an enormous impact on the A&D sector in the EU /UK, leading to a second wave of negative impacts on the EEA market. These impacts have not been quantified here but would include as a minimum:

- Cancelled future orders and loss of contracts for new products if supplies are significantly interrupted;
- Customer penalties for late/missed delivery of products;
- Extended durations of maintenance, repair and overhaul operations for products in service leading to e.g. “aircraft on the ground” (AoG) and other out-of-service final products, with consequent penalties and additional impacts on turnover;
- Increased logistical costs; and
- Reputational damages due to late delivery or cancelled orders.

5.2.3 Economic impacts on competitors

5.2.3.1 Competitors in the EEA/UK

This combined AoA/SEA has been prepared so as to enable the continued use of the CT, SD, PD and DtC in CCC formulations across the entirety of the EEA and UK aerospace and defence sectors. It is non-exclusive in this respect. It has been funded by the major (global) players in the EEA and the UK, with additional support provided by their suppliers and by MoDs, so as to ensure functioning supply chains for their operations.

As a result, there should be no economic impacts on competitors, especially as the major global OEMs and DtBs act as the main design owners which determine the ability of all suppliers to move to an alternative. As design owners they validate, qualify and certify components and products with new alternatives and gain new approvals (e.g. approvals from EASA, ESA or MoDs). Once these design owners have certified new alternatives in the manufacture of parts and components, these alternatives will be implemented throughout their value chain.

5.2.3.2 Competitors outside the EEA/UK

Under the NUS, and given the importance of chromate-based CCC, it is likely that many of the major OEMs and DtB suppliers would move outside the EEA/UK, creating new supply chains involving BtP and MROs. This would be to the detriment of existing EEA/UK suppliers but to the advantage of competitors outside the EEA/UK. These competitors would gain a competitive advantage due to their ability to continue to use chromate-based CCC treatments and due to their proximity to the OEMs and DtB, thus minimising logistic and transport issues.

5.2.4 Wider socio-economic impacts

5.2.4.1 Impacts on air transport

Under the non-use scenario there would be significant impacts on the ability of MROs to undertake repairs and to follow normal maintenance and overhaul schedules. As indicated previously, MROs are legally bound to adhere to the requirements set out in the OEMs’ manuals under airworthiness and military safety requirements. Where maintenance or overhaul activities would require chromate-based CCC, they would have to be performed outside the EEA/UK until the OEMs have gained approvals and certifications for the use of alternatives in maintenance and repair, and have adapted the manuals setting out maintenance and overhaul instructions.

If an aircraft needs unscheduled repairs (i.e. flightline or “on-wing” repairs), it will be grounded at the airport until these take place due to airworthiness constraints. This would result in AOGs and could result in an aircraft having to be dis-assembled and transported outside the EEA/UK for repairs, with dramatic financial and environmental impacts.

Should MRO facilities be relocated outside the EEA/UK, airlines will also experience additional delays to routine aircraft maintenance due to transport requirements and capacity constraints at MRO facilities outside the EU. Indeed, it may take some time to build up capacity to accommodate additional demand from EU-based operators, potentially resulting in a large number of aircraft being grounded until maintenance checks can be completed.

As a result, airlines would need to have additional spare components/engines/planes to account for the added time that aircraft would be out of commission due to extended MRO times. Airports may also have to build up large inventories of spare components to replace products (including e.g. spare engines, aircraft) that currently can be repaired, with this going against the desire to ensure sustainability within the sector.

The need to have maintenance carried out outside the EEA/UK would also lead to additional operational costs being incurred through increased fuel use. Small planes (e.g. business jets) that do not have the fuel capacity or airworthiness approvals for long haul flights would need to make multiple stops enroute to non-EEA MRO facilities and back to the EEA/UK. The impacts for larger aircraft would also be significant. For example, flying from Western Europe to Turkey or Morocco adds approximately 3,000 km each way and for a Boeing 737 this would take slightly less than four hours. For an airline which has 50 aircraft requiring an annual "D check" (heavy maintenance inspection of the majority of components, carried out every 6-10 years), this would involve 400 hours of flight time (return trip) or 20 days of foregone revenue, equivalent to €1.4 million. Scaling this up to the EU passenger aircraft fleet, which stands at approximately 6,700, suggests lost revenues in the tens of millions per annum just due to the need to have around 700 aircraft which require a "D check" each year. Using the above estimate for a fleet of 50 aircraft, this would amount to €20 million in revenue lost by European airlines for "D checks" alone. This figure excludes the costs of fuel and personnel, as well as the fact that additional flights bring forward maintenance interval requirements and impact on the total lifespan of an aircraft.

In addition, based on a leasing cost for a large passenger jet of around $500,000/month in 2021 (€421,500, £362,250)[76], the leasing costs alone of a plane being out of service would be roughly €14,000/£12,100 per day. On top of this will be the additional losses in revenues from not being able to transport passengers or cargo. For example, an Airbus A320 carries from 300 to 410 paying customers on one long-haul flight per day. If tickets cost on average €650 (£560) per customer (assuming 350 customers), the revenue lost due to being 'out of action' for one day amounts to €227,500 (£195,500). As a result, the cost of extending the period over which a plane is out of service for repair or maintenance reasons may lead to significant new costs for airlines, delays for passengers and in the transport of cargo, as well as subsequent effects for GDP and jobs due to planes being out of service for longer.

ICAO reported[77] a -49 to -50% decline in world total passengers in 2021 compared to 2019. In 2020, figures for Europe show a -58% decline in passenger capacity, -769 million passengers and a revenue loss of -100 billion USD. In addition, COVID-19 caused a 74% decrease in passenger demand for international travel in 2020 compared to 2019. The trend though is for the aircraft industry to continue expanding globally, with pre-covid estimates suggesting that demand for air transport would

76 https://www.statista.com/statistics/1258900/aircraft-lease-rates-aircraft-model/#statisticContainer

77 https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf

increase by an average of 4.3% per annum over the next 20 years, as illustrated in Figure 5–2 below. Similar growth is expected in air freight transport. If this growth path were to be achieved, by 2036 the air transport industry would contribute 15.5 million in direct jobs and $1.5 trillion of GDP to the world economy. Once the impacts of global tourism are taken into account, these numbers could rise to 97.8 million jobs and $5.7 trillion in GDP.

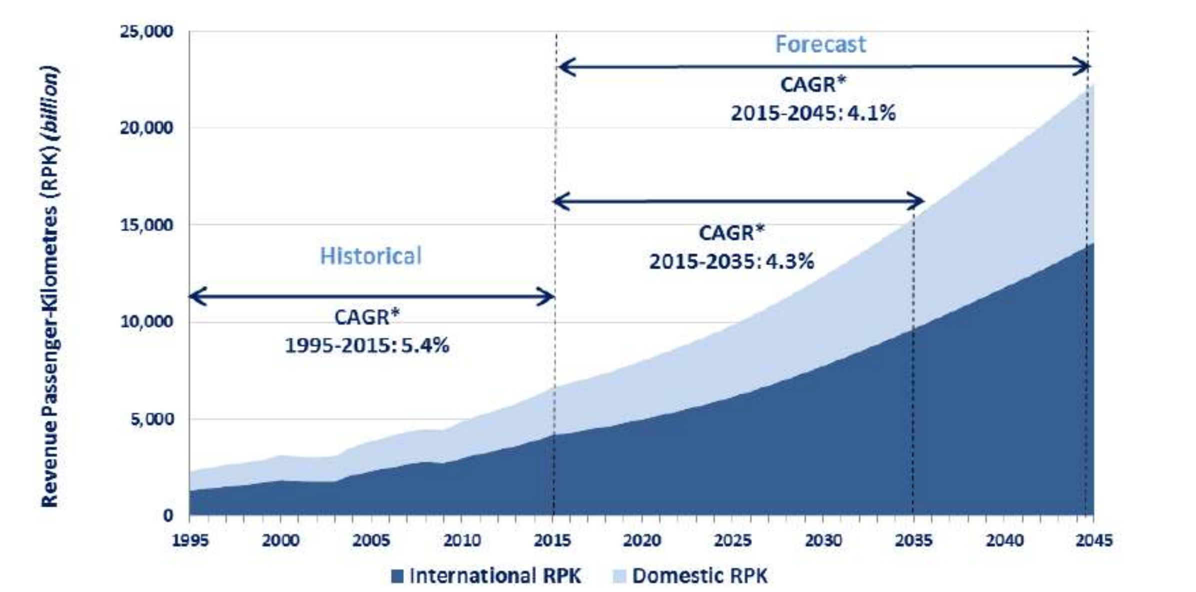

Figure 5–2: Forecast compound annual growth rates – Revenue Passenger-kilometres

Post Covid-19, projections are for a lower rate of increase in air traffic. A growth rate between 2019 and 2040 of around 3.9% CAGR is expected according to data available on the Airbus website.[78] The impact of COVID has resulted in an expected 2-year lag in growth, but the forecast remains unchanged with passenger numbers expecting to increase in line with the forecasts. This growth rate is relevant to global air traffic, with Europe expected to realise a lower compound annual growth rate of about 3.3% for total traffic[79] (covering inter-regional and intra-regional/domestic) for the period between 2018 to 2038.

This level of growth in EU air traffic, together with the jobs and contributions to GDP that it would bring, could be impacted under the NUS. In particular, impacts on the ability of MROs to undertake repairs and carry out maintenance where this would require the use of chromate-based CCC to ensure the continued airworthiness of aircraft could impact on the realisation of such growth. No quantitative estimate of the level of impact can be provided, but it is clear that the closure of EU-based MRO operations in particular could impact on the availability of aircraft and hence passenger and freight transport until substitution has taken place as expected over the requested review period (unless airlines responded by buying more planes, which would inevitably give rise to increases due to the costs of holding spares and/or bringing spare planes on-line).

[78] Airbus (undated): Airbus Global Market Forecast 2021 – 2040. Available at: [Global Market Forecast | Airbus]

[79] https://www.statista.com/statistics/1094689/annual-growth-rate-air-passenger-traffic-europe/

5.2.4.2 Defence-related impacts

Defence related impacts under the NUS would have two dimensions: impacts on military forces; and impacts on companies acting as suppliers to military forces.

Three national Ministries of Defence (MoDs – two in the EU and the UK MoD) have provided direct support to the ADCR out of the concern that the non-Authorisation of CCC could have a negative impact on their activities, while another has provided information to assist in preparation of this combined AoA/SEA. In addition, MROs providing services to a further two MODs located in the EEA have supported the ADCR to ensure that they are able to continue to maintain and repair military aircraft, ships and ground-based systems into the future. The implications of having to cease these activities are significant. Military equipment which could not be maintained to appropriate safety standards would have to be removed from service, with this also impacting on internal security services and emergency services. Not only would this impact on the availability of key equipment in the case of a military emergency, but it would also affect the size of potential operational forces.

It is also worth noting that military procurement agencies prefer key components of defence equipment to be produced in the EEA; they are likely to be reluctant to send military aircraft to MRO facilities located in non-EU countries, although there are also international agreements enabling manufacture in partner countries (e.g. the US, Canada and Turkey as NATO members). As a result, shifting production to a non-EU territory could create a dependence on a non-EU supplier in a conflict situation, and could impact on mission readiness. This could, in fact, be far more impactful than the economic impacts linked to the defence sector.

As a result, it is likely that under the NUS, companies manufacturing components for and servicing military products would have to apply for defence exemptions; although for some companies, the turnover generated by military contracts alone may not be sufficient to maintain current production levels and it may not be economically feasible to operate dual manufacturing lines for military and civilian customers.

Companies in the European defence sector represent a turnover of nearly €100 billion and make a major contribution to the wider economy[80]. The sector directly employs more than 500,000 people of which more than 50% are highly skilled. The industry also generates an estimated further 1.2 million jobs indirectly. In addition, investments in the defence sector have a significant economic multiplier effect in terms of the creation of spin-offs and technology transfers to other sectors, as well as the creation of jobs. For example, according to an external evaluation of the European Union's Seventh Framework Programme, through short-term leverage effect and long-term multiplier effects each euro spent by the Seventh Framework Programme (FP7) generated approximately an additional €11 billion of estimated direct and indirect economic effects through innovations, new technologies and products.[81]

If Governments did allow the manufacture and servicing of military aircraft and other defence products to move out of the EEA/UK under the NUS, then some proportion of such multiplier effects would be lost to the EEA/UK economy. In addition, the ability of the EEA/UK to benefit from some of

80 https://ec.europa.eu/commission/presscorner/detail/de/MEMO_16_146

81 https://www.evropskyvyzkum.cz/cs/storage/bf5134fec407f6e005288c0e2631ad232c38c013?uid=bf5134fec407f6e005288c0e2631ad232c38c013

the innovations and technological advances in products ahead of other countries could be lost, if the shift in manufacturing remains permanent and extends to new products.

5.2.5 Summary of economic impacts

Table 5-8 provides a summary of the economic impacts under the non-use scenario.

Table 5-8: Summary of economic impacts under the non-use scenario (12 years, @ 4%)

Economic operator	Quantitative	Qualitative
Applicants	• Not assessed	Lost profits to applicants in both the EEA and UK are assessed in the Formulation SEA
A&D companies	• Lost operating surplus EEA: €29.6 – 70.5 billion over 12 years (€3.1 – 7.5 billion over one year) • Lost operating surplus UK: €4.7 – 28.0 billion (€0.5 – 2.9 billion over one year)	Relocation costs, disruption to manufacturing base and future contracts, impacts on supply chain coherence, impacts on future growth in the EEA and UK sectors, loss of skilled workforce, impacts on R&D (and potential to deliver new more sustainable technologies)
Competitors	Not anticipated due to sectoral coverage of the application	Not anticipated due to sectoral coverage of the application
Customers and wider economic effects	Not assessed	• Impacts on airlines, air passengers, customers, cargo and emergency services, and thus society as a whole • Impacts on military forces' operation capacity and mission readiness • Lost output/value added multiplier effects due to impacts on civil aviation and loss of defence sector spending • Loss of spin-off effects – innovation and new technologies

5.3 Environmental impacts under non-use

As well as leading to increases in operating costs and lost revenues to airlines, the increased distances that airlines would need to fly planes in order for them to undergo normal maintenance and overhaul schedules would lead to significant increases in fuel consumption and hence CO2 emissions.

The most plausible non-use scenario in the event of a refused Authorisation - even if it may not be practical and would involve huge levels of investment - would be to shift the activity involving use of the chromates to another country (outside the EEA or UK).

Under this scenario, as noted above, the environmental impacts would be real and the effects enormous. If manufacturing activities using chromates and not using chromates are separated on both sides of the European border, huge logistics and transport related requirements would have to be introduced with dramatic impacts on the aerospace and defence sectors' environmental footprint.

For MRO activities, each time an aircraft would need a minor repair requiring chromate-based CCC use, it would force the manufacturer to go to a non-European site. In the case of a major repair, aircraft that could not fly would become stranded or, less likely, would have to be dis-assembled for transport to a non-European site. Some stranded final products would become obsolete prematurely, due to the lack of the parts needed for their maintenance and repair. This would go against the principles underlying the Circular Economy and the sustainable use of raw materials, by limiting the ability of the sector to repair and re-use parts and assemblies.

Today, the civil aviation industry strives to develop new technologies to reduce the amount of CO_2 emissions by 15 - 20% on each generation of in-service aircraft (make aircraft movements emission-free), since it is well aware that aviation continues to grow significantly.

Even despite the impact that the COVID-19 pandemic had on air traffic and the whole civil aviation industry, aviation is expected to double in the next 20 years. Consequently, a refused authorisation renewal would lead to aircraft manufacturing and MRO activities involving chromate uses to move outside the EEA. In addition to the socio-economic consequences this would have, the drastic increase in CO_2 emissions, would outweigh all the benefits achieved by aviation efforts to reduce fuel consumption and CO_2 emissions of in-service aircrafts.

5.4 Social impacts under non-use

5.4.1 Direct and indirect job losses

5.4.1.1 Estimated level of job losses

As argued above, if chromate-based chemical conversion coating was no longer allowed in the EEA or UK, the manufacture of entire components/final products may need to move because Aluminium and Magnesium components need to be coated (and touched up) within the same production line to ensure against corrosion of the unprotected parts. There are also time limits for some processes between chemical conversion coating and when the next process needs to be performed, such as application of primer coatings as part of ensuring the integrity of the overall corrosion protection process.

As a result, the main social costs expected under the NUS are the redundancies that would occur due to the closure or reduction of CCC-related treatment of parts and products, and the relocation of large portions of A&D manufacturing activities. As indicated in the assessment of economic costs, it is assumed that job losses will occur in proportion to the decreases in output expected under the NUS. Direct job losses will impact on both workers at the sites involved in chromate-based CCC as well as the other treatments/processes linked to this use, and those whose jobs which depend on such activities continuing at these sites. These are all referred to here as direct job losses (for avoidance with confusion of multiplier effects).

While redundant workers are expected to face a period of unemployment, in line with ECHA's guidance it is assumed that such a period would be only temporary. However, the length of the average duration of unemployment varies greatly across European countries, as do the costs associated with it.

It should be noted that the ECHA methodology has been followed here despite the fact that, due to the magnitude of the impacts across the A&D sector, it may be difficult for workers to find another job (especially as there may be a skill mismatch if there are large scale levels of redundancies).
Estimates of the direct job losses that would arise at downstream users' sites under the NUS were presented above. For ease of reference, the totals are repeated in Table 5-9 below. The magnitude

of these figures reflects the importance of chromate-based CCC to parts production and MRO activities carried out by the sector at present. It should be noted that the figures do not include any job losses at sub-contractors providing services such as cleaning, site maintenance, etc. to the BtPs, DtBs, MROs and OEMs.

As context, the civil aeronautics industry alone employees around 405,000 people in the EU, with the defence sector employing more than 500,000 and supporting a further 1.2 million[82]. The figures in **Table 5-9** indicate that approximately 71,600 of these aerospace and defence company jobs in the EEA and a further 12,800 in the UK could be in jeopardy under the NUS.

Table 5-9: Predicted job losses in aerospace companies under the NUS

Role	Job losses directly linked to use of the chromates		Additional job losses due to cessation of other manufacturing		Total A&D job losses under the NUS	
	EEA	UK	EEA	UK	EEA	UK
Build-to-Print (170 sites)	4,349	879	3,117	196	7,466	1,075
Design-to-Build (75 sites)	3,940	1,914	5,535	1,146	9,475	3,060
MROs (105 sites)	3,541	588	10,532	2,538	14,073	3,125
OEMs (80 sites)	18,048	3,418	22,576	2,145	40,624	5,563
Total sites (430)	29,877	6,797	41,760	6,025	71,637	12,823

5.4.1.2 Monetary valuation of job losses

The method for estimating the social costs of unemployment follows that recommended by ECHA (Dubourg, 2016[83]). Costs of unemployment are calculated by adding up lost output which is equivalent to the pre-displacement gross salary throughout the period out of work, search costs, rehiring costs for employers and scarring effects, and deducting the value of leisure time.

Dubourg (2016) estimated different ratios of the social cost per job loss over the annual pre-displacement wage for European countries and the EU-28 as a whole that varies according to the mean duration of unemployment. These vary by country, with the mean duration of unemployment weighted by the number of employees for each country relevant to aerospace and defence sector productions sites varying from 7 months to 1.6 years.

These figures are combined with the ratio of social costs per job loss provided in Dubourg (2016) and annual wages to calculate the social costs per lost job. Data were collected in the SEA questionnaire on the average salary for workers involved in the use of the chromates. The typical range given is from €30k to 50k, rising to an average maximum of around €76k, across all of the companies and locations. For the purposes of these calculations, a figure of €40k[84] has been adopted and applied across all locations and job losses. This figure is based on the NACE code data provided by companies but may

[82] https://www.eudsp.eu/event_images/Downloads/Defence%20Careers%20brochure_1.pdf

[83] Dubourg, R (2016): Valuing the social costs of job losses in applications for authorisation. Available at: https://echa.europa.eu/documents/10162/13555/unemployment_report_en.pdf/e0e5b4c2-66e9-4bb8-b125-29a460720554

[84] The weighted average personnel costs tend to be higher than €45k based on the number of companies falling into the different NACE codes. However, €40k has been adopted here to err on the side of conservatism, given the mix of companies by size and geographic location covered by this combined AoA/SEA.

underestimate the average salary given that aerospace and defence jobs in the prime OEMs and DtB companies are higher paid than those in other industries.

The resulting estimates are presented in **Table 5-10** based on the Article 66 notifications distribution of sites. In total, the social costs of unemployment within the A&D sector alone would equate to around €8.99 billion in the first one to two years after a refused Authorisation.

The model developed by Dubourg assumes that most of these jobs would be filled within one to two years, however, at this scale of unemployment and given the highly trained nature of workers in the sector, it is likely that they would fail to find equivalent jobs in the EEA/UK within this period. As a result, the ADCR members consider these figures to be an underestimate and highlight the risk of such highly trained workers emigrating to the new non-EEA/UK manufacturing facilities.

Table 5-10: Social Cost of Unemployment – A&D job losses for the most impacted countries under the NUS

Country	Assumed distribution of downstream user sites based on Art 66 notifications	A&D employment losses	Social costs of unemployment (€)
France	100	20,468	2,595,299,296
Poland	36	7,368	692,625,617
Italy	45	9,210	1,116,306,180
Germany	50	10,234	1,064,318,323
Spain	30	6,140	687,713,378
Czech Republic	13	2,661	291,623,221
Netherlands	12	2,456	230,875,206
Sweden	12	2,456	219,085,833
Romania	4	819	78,268,332
Ireland	4	819	80,233,227
Hungary	4	819	90,057,704
Malta	2	409	67,897,110
Norway	7	1,433	181,844,203
Belgium	9	1,842	223,261,236
Finland	9	1,842	158,419,689
Portugal	2	409	46,338,782
Slovakia	2	409	57,473,189
Austria	2	409	39,461,649
Bulgaria	3	614	64,595,935
Greece	2	409	54,689,588
Lithuania	2	409	45,028,852
EEA total losses	350	71,637	7,921,102,177
United Kingdom	80	12,823	1,071,963,821
Total rounded		**84,459**	**8,993,065,997**

5.4.2 Wider indirect and induced job losses

5.4.2.1 Aerospace and defence related multiplier effects

Employment in one sector is often the input to employment in another sector, so that fluctuations in employment of the latter will inevitably affect the former.

It is clear that, under the NUS, there could be significant wider impacts on jobs given the likelihood that some of the largest players in the EEA/UK aerospace and defence sector would relocate their activities elsewhere with a partial or full cessation of manufacturing in the EEA/UK.

A UK Country Report on the "Economic Benefits from Air Transport in the UK" produced by Oxford Economics (2014) indicates the following with respect to the aerospace sector's contribution to UK employment in 2012:

- Indirect employment effects: 139,000 jobs implying a multiplier effect of 1.36 indirect jobs for every direct job;
- Induced employment effects: 86,000 jobs implying an additional multiplier effect of 0.84 induced jobs for every direct job.

Indirect employment effects will to a degree be captured by the estimates of lost jobs presented in Table 5-10 given that it includes the loss of jobs in suppliers to the aerospace OEMs and Design and Build companies. It excludes however other service providers to these companies whose services would no longer be required. Induced effects are not captured by the above estimates and an employment multiplier of 0.84 suggests that they may be significant given the predicted numbers of jobs that would be lost across the key countries in which aerospace-related manufacturing takes place.

The loss of jobs within those companies that serve the defence industry would have their own multiplier effects. The external evaluation of FP7 referenced above[85] quotes an employment multiplier of between 2.2 to 2.4, with this covering both indirect and induced employment effects. The sector is identified as bringing a major contribution to the wider economy.

To successfully compete at a global level, the European and UK A&D industries have formed regional and industry clusters that includes local and national government partners. The clusters are part of the European Aerospace Cluster Partnership[86](EACP) which focuses on the exchange of experiences concerning both cluster policy and the implementation of effective solutions needed to address various challenges faced by the partners. It has members located in 44 aerospace clusters across 18 countries, thus covering the entire A&D value chain in Europe. Figure 5–3 below is a "snip" taken from the EACP website highlighting the location of these different hubs across Europe, to provide an indication of where effects may be experienced at the regional level.

Under the non-use scenario, the economic impact on each region could have severe consequences. For example, Aerospace Wales consists of over 180 members which employ 23,000 employees with a turnover of over £6.5 billion in Wales, while the Andalucía Aerospace Cluster has over 37 members, 16,000 employees with over €2.5 billion turnover (See Annex 3). Both of these clusters are an essential part of the local economy.

[85] European Commission (2017): Issue papers for the High Level Group on maximising the impact of EU research and innovation programmes. Prepared by the Research and Innovation DGs. Available at: https://www.evropskyvyzkum.cz/cs/storage/bf5134fec407f6e005288c0e2631ad232c38c013?uid=bf5134fec407f6e005288c0e2631ad232c38c013

[86] https://www.eacp-aero.eu/about-eacp/member-chart.html

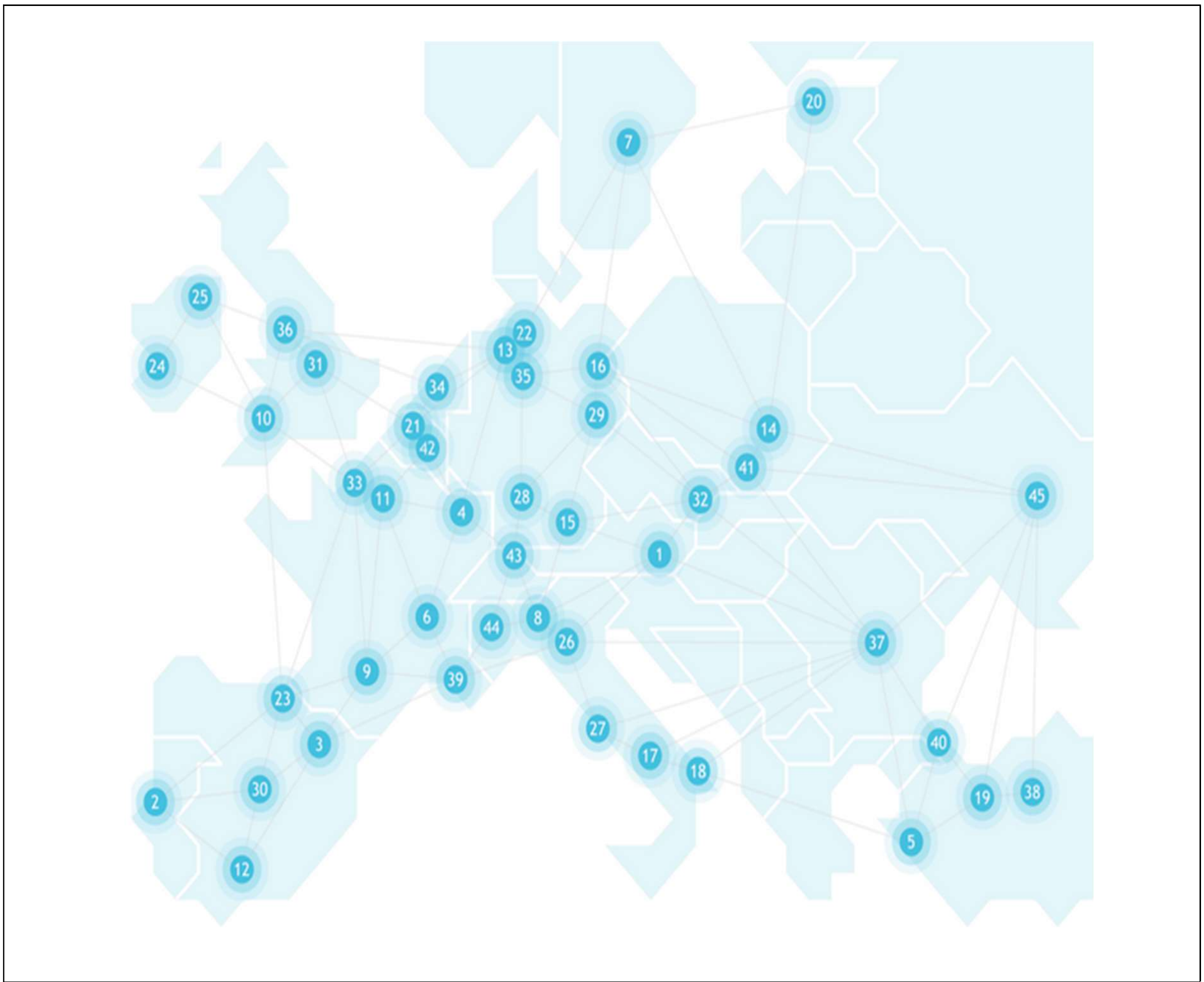

Figure 5–3: Aerospace clusters across Europe
Source: https://www.eacp-aero.eu/about-eacp/member-chart.html

5.4.2.2 Air transport multiplier effects

A 2019 "Aviation Benefits Report"[87] produced by a high-level group formed by the International Civil Aviation Organisation (ICAO) provides an assessment of the economic impacts of the aviation sector. These are linked to its direct impact as well as indirect, induced and catalytic effects. At a regional level, it is estimated that air transport supports 12.2 million jobs in Europe. 2.6 million of these jobs are direct within the aviation sector, with the remaining 9.6 million stemming indirectly from the aviation sector or relating to induced or catalytic effects.

Clearly not all these jobs would be impacted under the NUS, although some impact would be expected should there be reductions in the number of flights, increased delays and other effects from the loss of EEA/UK based MRO activities in particular.

[87] Published by the ACI, CANSO, IATA, ICAO and the ICCAIA, available at: https://www.icao.int/sustainability/Documents/AVIATION-BENEFITS-2019-web.pdf

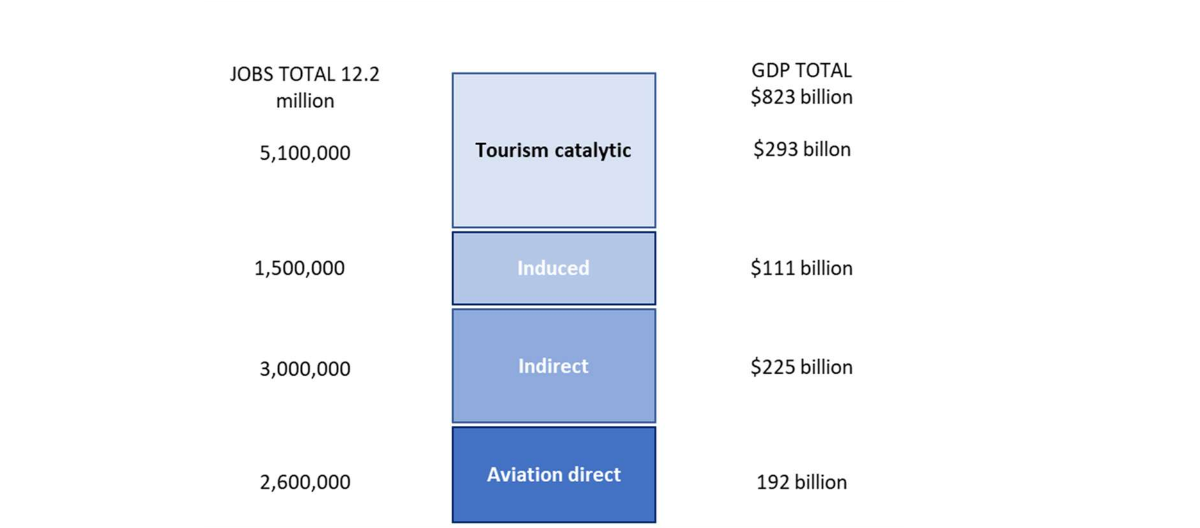

Figure 5-4: Aviation related multiplier effects

Based on: **https://www.icao.int/sustainability/Documents/AVIATION-BENEFITS-2019-web.pdf**

The potential employment losses associated with a decline in European aviation can be seen by reference to the impacts of COVID-19[88]. A "COVID-19 Analysis Fact Sheet" produced by Aviation Benefits Beyond Borders reports the following:

- A reduction from 2.7 million in direct aviation jobs in Europe supported pre-COVID to 2.1 million jobs post-COVID (i.e. at the end of 2021); and
- 13.5 million jobs in supported employment pre-COVID in Europe to 8.1 million at the end of 2021.

Although one would not expect the losses in supported employment (i.e. indirect, induced and catalytic effects) to be as great, it is clear that a disruption to civil aviation could have significant employment impacts.

5.4.3 Summary of social impacts

In summary, the social impacts that would arise under the NUS include the following:

- Direct job losses: 29,877 EEA and 6,800 UK workers involved in CCC and linked chromate treatment processes; an 41,760 EEA and 6,025 UK workers impacted by a cessation of other treatment and manufacturing activities;

- Social costs of unemployment: economic costs of around €7.92 billion for the EEA and €1.07 billion for the UK due to direct job losses;

- Indirect and induced unemployment at the regional and national level due to direct job losses; and

[88] https://aviationbenefits.org/media/167482/abbb21_factsheet_covid19-1.pdf

- Direct, indirect and induced job losses in air transport due to disruption of passenger and cargo services.

5.5 Combined impact assessment

Table 5-11 sets out a summary of the economic and social costs associated with the non-use scenario, to aid in preparation of the combined impact assessment which follows in Section 6.3. Figures are provided as annualised values, with costs also presented as a PV over a 2-year period as per ECHA's latest guidance; note that restricting losses to only those occurring over the first two years of non-use will significantly underestimate the profit losses to the A&D companies as well as the applicants. Most A&D companies would incur losses for at least a 4-year period, with over 60% incurring losses over the full 12-year period as design owners continue work towards development, qualification, validation, certification and industrialisation of an alternative over the full 12-year period.

Table 5-11: Summary of societal costs associated with the non-use scenario

Description of major impacts	Monetised/quantitatively assessed/qualitatively assessed impacts	
1. Monetised impacts	**PV @ 4%, two years**	**€ annualised values**
Producer surplus loss due to ceasing the use applied for[1]: Impacts on applicants - Lost profits EEA - Lost profits UK Impacts on A&D companies[1]: - Lost profits EEA - Lost profits UK	Applicants: Impacts in Euro millions – see Formulation SEA A&D companies EEA: €5.94 – 14.17 billion (£5.11 – 12.19 billion) UK: €1.0 – 5.6 billion (£0.73 – 4.82 billion)	Applicants: Impacts in Euro millions – see Formulation SEA A&D companies EEA: €3.15 – 7.52 billion (£2.71 – 6.47 billion) UK: €0.50 – 3.0 billion (£0.43 – 2.58 billion)
Relocation or closure costs	Not monetised	Not monetised
Loss of residual value of capital	Not quantifiable	Not quantifiable
Social cost of unemployment: workers in A&D sector only[2]	EEA: 71,600 jobs UK: 12,800 jobs	EEA: 71,600 jobs UK: 12,800 jobs
	EEA: €7.92 billion (£6.80 billion) UK: €1.07 billion (£0.92 billion)	EEA: €7.92 billion UK: €1.07 billion
Spill-over impact on surplus of alternative producers	Not assessed due to sector level impacts	Not assessed due to sector level impacts
Sum of monetised impacts	EEA: €13.86 – 22.09 billion (£11.92 – 19.00 billion) UK: €2.02 – 6.71 billion (£1.74 – 5.77 billion)	EEA: €11.07 – 15.44 billion (£9.52 – 13.28 billion) UK: €1.57 – 4.06 billion
Additional qualitatively assessed impacts		
Impacts on A&D sector	Impacts on R&D by the A&D sector, impacts on supply chain, impacts on technological innovation	
Civilian airlines	Wider economic impacts on civil aviation, including loss of multiplier effects, impacts on airline operations, impacts on passengers including flight cancellations, ticket prices, etc.	

Table 5-11: Summary of societal costs associated with the non-use scenario	
Description of major impacts	**Monetised/quantitatively assessed/qualitatively assessed impacts**
Ministries of Defence	Impacts on the operational availability of aircraft and equipment, premature retirement of aircraft and equipment, impacts on mission readiness
Other sectors in the EEA	Loss of jobs due to indirect and induced effects; loss of turnover due to changes in demand for goods and services and associated multiplier effects. Loss of jobs in other sectors reliant on aeroderivative uses of the chromates, such as the energy sector (e.g. use of CCC on turbines including wind turbines) Impacts on emergency services and their ability to respond to incidents Impacts on cargo transport
1) Lower bound figures represent lost EBITDA estimates, upper bound lost operating surpluses. 2) Estimated using the approach set out by Dubourg 3) Totals have been rounded	

6 Conclusion

6.1 Steps taken to identify potential alternatives

Potential alternatives to Cr(VI) for conversion coating should be "generally available"[89].

Alongside the various R&D activities as described in Section 3.3.1 and information reported in academic literature and patent reports as described in Sections 3.3.3, members of the ADCR have undertaken extensive testing into alternative technologies and processes with many programmes still ongoing. The steps taken by members in the implementation of a substitute for Cr(VI)-based conversion coating are shown in Figure 6-1.

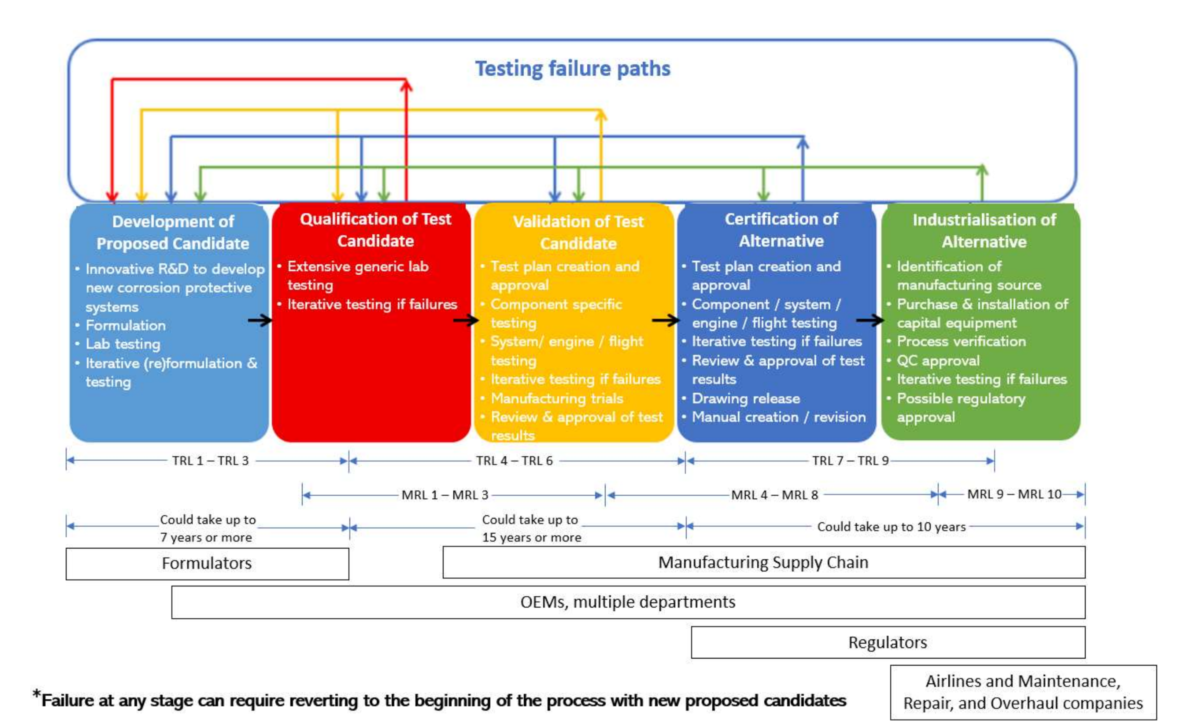

Figure 6-1: Schematic showing the key phases of the substitution process
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note that failures may not become apparent until a late stage in the process.
Source: Adapted from "Use of strontium chromate in primers applied by aerospace and defence companies and their associated supply chains, Application for Authorisation 0117-01, GCCA (2017)

Activities undertaken include:

- Development of test alternatives in laboratory environments up to TRL 6;
- Qualification of test alternatives and suppliers including:
    - Modification of drawings;
    - Updating specifications;
    - Introduction of new processes to suppliers;

89 As defined with respect to the "legal and factual requirements of placing on the market" in the EC note of 27 May, 2020, available at: 5d0f551b-92b5-3157-8fdf-f2507cf071c1 (europa.eu)

- Negotiation of supplier(s) contracts.
- Demonstration of compliance followed by industrialisation and deployment on sites along the supply chain; and
- Certification or approval.

6.2 The substitution plan

ADCR member companies have ongoing substitution plans in place to develop test candidates with the intent of replacing Cr(VI) in conversion coating. Individual members often have multiple substitution plans within conversion coating, reflecting the complexity of different components to be treated, the various substrates, and the different performance resulting from test candidates in these different situations. While there have been successes, with some members having been able to implement alternatives to Cr(VI) in certain limited situations and for certain substrates, thereby reducing their Cr(VI) usage, many technical challenges remain.

As discussed in Section 3.16.2, of the 78 distinct substitution plans for conversion coating assessed in this combined AoA/SEA, 14% of them are expected to have achieved MRL 10 by September 2024. MRL 10 is the stage at which it is expected production will be in operation and there will be a significant reduction in Cr(VI) use for the components covered in that substitution plan.

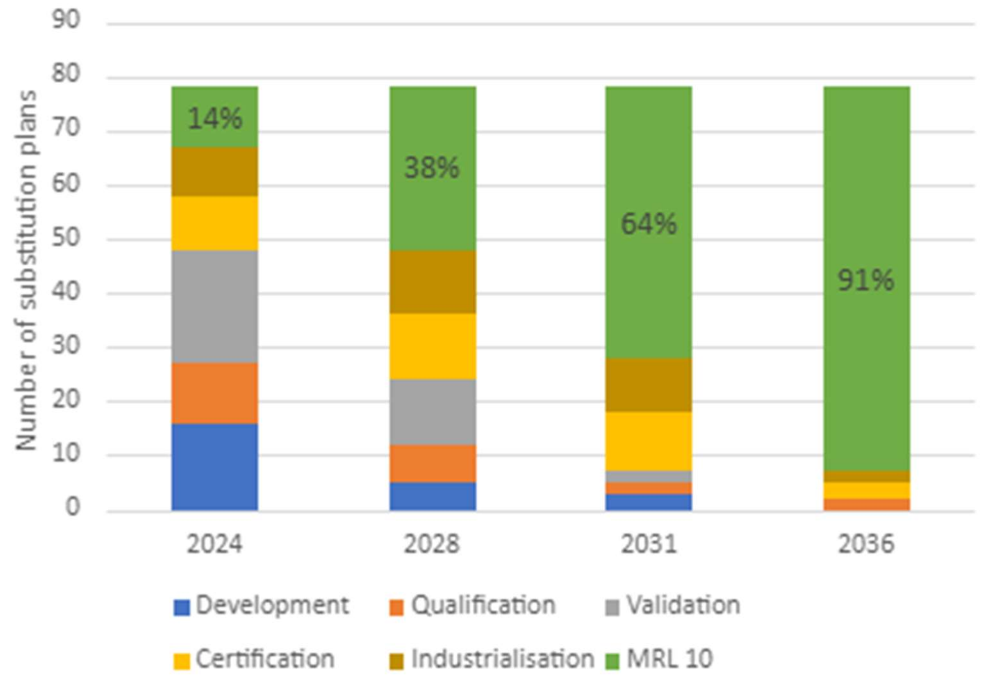

Figure 6-2: Expected progression of substitution plans for the use of Cr(VI) in conversion coating, by year. The vertical axis refers to number of substitution plans (some members have multiple substitution plans for conversion coating). The percentage value shown on each of the green bars indicates the proportion of substitution plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which there is expected to be a significant reduction in Cr(VI) usage.
Source: **RPA analysis, ADCR members**

The proportion of substitution plans that are expected to achieve MRL 10 is then expected to progressively increase to 38% in 2028, 64% in 2031, and 91% in 2036 (see Figure 6-2 above).

In 2031 (equivalent to seven years beyond the expiry date for the existing applications), while many substitution plans are expected to have successfully progressed to MRL 10 and the consortium is expected to have reduced its Cr(VI) use, an equally significant proportion are not expected to have achieved MRL 10 and are expected to be predominantly at the certification or industrialisation stages, with some substitution plans at earlier stages. For these substitution plans (which are from several member companies), there is still expected to be a need for the use of Cr(VI).

As a result of the individual members' substitution plans summarised above, **the ADCR requests a review period of 12 years for the use of Cr(VI) in conversion coating.**

6.3 Comparison of the benefits and risk

Table 6-1 summarises the socio-economic benefits of continued use of the four chromates in chemical conversion coating by companies in the aerospace and defence sector. Overall, net benefits of between ca. €13.9 - 22.1 billion for the EEA and €2.0 - 6.7 billion for the UK (Net Present Value social costs over two years/risks over 12 years, 4% discount) can be estimated for the continued use scenario. These figures capture continued profits to the A&D companies and the social costs of unemployment. They also include the monetised value of the residual risks to workers and humans via the environment (estimated at €3.93 million and €1.33 million for the EEA and UK respectively over 12 years).

As can be seen from **Table 6-1**, the ratio of societal costs to the monetised value of the residual health risks is around 3,500 to one on the lower bound assumptions for the EEA and greater than 1,500 to one on the lower bound assumptions for the UK.

Profits to the applicants are covered in the Formulation SEA, as are quantified health risks to their workers.

Table 6-1: Summary of societal costs and residual risks

Societal costs of non-use (2 years)		Risks of continued use (12 years)	
Profit losses to applicants	Losses in profits from reduced sales of the chromate substances and associated formulations. Losses quantified in the Formulation SEA	Health risks to workers at formulation sites over the review period, taking into account the reduction in risks due to adherence to the conditions placed on the initial authorisations. These risks are quantified and monetised in the Formulation SEA	
Monetised profit losses to A&D companies	EEA: €5.94 – 14.17 billion (£5.11b – 12.19 billion) UK: €0.95 – 5.64 billion (£0.82- 4.85 billion)	Monetised excess risks to directly and indirectly exposed workers (€ per year over 12 years)	EEA: €2.89 mill (£2.49 million) UK: €0.66 mill (£0.57 million)
Social costs of unemployment	EEA: €7.91 billion (£6.80 billion) UK: €1.07 billion (£0.92 billion)	Monetised excess risks to the general population (€ per year over 12 years)	EEA: €1.04 mill (£0.86 mill) UK: €0.67 mill (0.58 million)
Qualitatively assessed impacts	Wider economic impacts on civil aviation, impacts on cargo and passengers. Impacts on armed forces including military mission readiness. Impacts on R&D and technical innovation. Impacts from increased CO_2 emissions due to MRO activities moving out of the EEA/UK; premature redundancy of equipment leading to increased materials use.		
Summary of societal costs of non-use versus risks of continued use	- NPV (2 years societal costs/12 years residual health risks): o EEA: €13.86 – 22.09 billion o (£11.92 – 19.00 billion) o UK: €2.02 – 6.71 billion o (£1.74 – 5.77 billion) - Ratio of societal costs to residual health risks:		

	○ EEA: 3,526 : 1 to 5,620 : 1 ○ UK: 1,521 : 1 to 5,053 : 1

It should be appreciated that the social costs of non-Authorisation could be much greater than the monetised values reported above, due to the likely 'knock-on' effects for other sectors of the economy:

A refused Authorisation would have impacts on the EEA/UK formulators and the critical set of key functions provided by CCC treatments would be lost to A&D downstream users in the EEA and UK

↓

Due to certification and airworthiness requirements, downstream users in the A&D value chain would be forced to undertake chromate-based CCC activities outside the EEA or shift to suppliers outside of the EEA/UK

↓

OEMs would shift manufacturing outside the EEA/UK due to the need for CCC to be carried out in sequence with other treatments. It would be inefficient and costly to transport components and products outside the EEA/UK for chemical conversion coating only (especially for touch-up repairs)

↓

DtB suppliers may have more flexibility and be able to shift only part their production activities outside the EEA/UK, resulting in the loss of profits and jobs inside the EEA/UK

↓

BtP suppliers in the EEA/UK would be forced to cease chromate-based CCC treatments, leading to loss of contracts and jobs due to relocation of this and related activities outside the EEA/UK

↓

MROs, which make up a significant percentage of users, would have to shift at least some (if not most) of their activities outside the EEA, as chemical conversion coating is an essential part of maintenance, repair and overhaul activities

↓

Relocation of MRO activities would cause significant disruption to the A&D sector itself

↓

Ministries of Defence would face logistical difficulties in maintaining aircraft and other equipment, severely impacting on mission readiness. Service agreements would need to be reached with non-EEA countries

↓

Civil aviation, passengers, freight shippers and emergency services would face reduced flight availability and routes, as well as increased costs

Overall, it is clear that the benefits of the continued use of the four chromates in CCC formulations significantly outweigh the residual risks from continued use.

Three further points are relevant. **Firstly, the use of the four chromates in CCC is required (and may be required beyond 12 years) to ensure the operational capabilities of the military and the ability to comply with international obligations as partner nations at the EU level and in a wider field, e.g. with NATO.**

Secondly, the requirements of the ADCR members – as downstream users - have been carefully identified and analysed, taking as the starting point the parent authorisations and the substance-use combinations covered by these. Over the lifetime of the ADCR consortium, the number of uses identified as requiring authorisation and the number of OEMs and downstream users supporting each use has decreased (including the continued need for use of the different chromate substances), to ensure that authorisation is only sought for those cases where there is no substitute that is fully qualified and certified as per stringent airworthiness requirements and industrialised by all members and within their supply chains. The continual re-visiting of supply chain requirements fed into the narrowing of the substance-use combinations requiring re-authorisation compared to the original applications for authorisation.

Finally, the non-use scenario would involve the relocation of economically and strategically important manufacturing processes. This would be in contradiction to the EU policy on "Strategic dependencies and capacities", which highlights the need to minimise such dependencies where they could have a significant impact on the EU's core interests, including the access to goods, services and technologies.[90] The need to support the A&D industry (as one of the 14 priority industrial ecosystems) is explicitly recognised within the update to the 2020 New Industrial Strategy.[91]

6.4 Information for the length of the review period

6.4.1 Introduction

In a 2013 document, the ECHA Committees outlined the criteria and considerations which could lead to a recommendation of a long review period (12 years)[92]:

1. *"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.*
2. 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 used in very low tonnages for an essential use and the costs for developing an alternative are not justified by the commercial value.
3. *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.*
4. *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).*
5. *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."*

90 https://ec.europa.eu/info/sites/default/files/swd-strategic-dependencies-capacities_en.pdf

91 https://op.europa.eu/en/publication-detail/-/publication/52904a0b-ae95-11eb-9767-01aa75ed71a1/language-en

92 https://echa.europa.eu/documents/10162/13580/seac_rac_review_period_authorisation_en.pdf/c9010a99-0baf-4975-ba41-48c85ae64861

In the context of this combined AoA/SEA, it is assumed that qualification and certification requirements combined with the need for approvals from EASA, the ESA and MoDs are consistent with the requirements under criterion 4 above.

Further discussion was held at the 25th Meeting of Competent Authorities for REACH and CLP (CARACAL) of 15 November 2017. A document endorsed by CARACAL suggests that, "*in order to consider a review period longer than 12 years, in addition to the criteria for a 12-year review period established in the document "Setting the review period when RAC and SEAC give opinions on an application for authorisation", two additional conditions should jointly be met*:

6. *As evaluated by the RAC, the risk assessment for the use concerned should not contain any deficiencies or significant uncertainties related to the exposure to humans (directly or via the environment) or to the emissions to the environment that would have led the RAC to recommend additional conditions for the authorisation. In the case of applications for threshold substances, the appropriateness and effectiveness of the applied risk management measures and operational conditions should clearly demonstrate that risks are adequately controlled, and that the risk characterisation ratio is below the value of one. For applications for non-threshold substances, the applied risk management measures and operational conditions should be appropriate and effective in limiting the risks and it should be clearly demonstrated that the level of excess lifetime cancer risk is below* $1x10^{-5}$ *for workers and* $1x10^{-6}$ *for the general population. For substances for which the risk cannot be quantified, a review period longer than 12 years should normally not be considered, due to the uncertainties relating to the assessment of the risk.*
7. *As evaluated by the SEAC, the analysis of alternatives and the third party consultation on alternatives should demonstrate without any significant uncertainties that there are no suitable alternatives for any of the utilisations under the scope of the use applied for and that it is highly unlikely that suitable alternatives will be available and can be implemented for the use concerned within a given period (that is longer than 12 years)"* (CARACAL, 2017).

As far as the second criterion above is concerned, the same document provides some relevant examples, one of which (Example (d)) reads as follows:

> "(…) *the use of the substance has been authorised in accordance with other EU legislation (e.g. marketing authorisation, certification, type-approval), the substance being specifically referred to in the authorisation/certification granted and substitution, including the time needed for modification of the authorisation/certification/type-approval, would not be feasible within 12 years and would involve costs that would jeopardise the operations with regard to the use of the substance*".

6.4.2 Criterion 1: Demonstrably Long Investment Cycle

The aerospace and defence industry is driven by long design and investment cycles, as well as very long in-service time of their products. As noted previously, the average life of a civil aircraft is typically 20-35 years, while military products typically last from 40 to >90 years. Furthermore, the production of one type of aircraft or piece of equipment may span more than 50 years.

These long investment cycles and long product lives have been recognised in the FWC Sector 26 study on the Competitiveness of the EEA aerospace industry[93]. They are a key driver underlying the difficulties facing the sector in substituting the use of the chromates in CCC across all components within final products. The long service life of aircraft and other products makes it difficult to undertake all of the tests required to qualify and certify a component with the substitute, due to the level of investment and costs that would be involved in such an activity for out of production A&D products; it would require testing at multiple levels (components, sub-assemblies, assemblies, final aircraft/defence equipment).

The ADCR would like to emphasise the crucial role every single component within an A&D product plays with respect to its safety. An aircraft is a complex system involving not only design of the aircraft itself, but also its use and maintenance history in varied climates and service. For example, an aircraft engine is exposed to massive forces and extremely high stress levels due to high velocities and environmental impacts. Therefore, every single component needs to be designed and manufactured with serious attention and care.

In a complex system, change introduces new forms of failure. Any change will bring failures that can be anticipated – and some that are unanticipated. The components in an A&D product need to be adjusted to each other very precisely on the design as well as on the manufacturing level. When in the early design phase for completely new engines, for example, there is an opportunity to consider introducing a material change. Mostly such a material change will be a step improvement on a previous design, in line with the principle of proven engineering. Very rarely is a substantial design change introduced into an existing product, as this would involve substantial cost and risk.

Even where such a small change is considered feasible in principle, the implications are significant and highly complex; time consuming, systematic TRL-style implementation is required to minimise the impact of unanticipated failures and the serious repercussions they might cause. Even when an OEM has been able to undertake the required testing and is in the process of gaining qualifications and certifications of components with a substitute, it may take up to seven years to implement the use of a substitute across the value chain due to the scale of investment required and the need for OEMs to undertake their own qualification of different suppliers.

In addition, MoDs rarely revise specifications for older equipment, which must nevertheless be maintained and repaired. MROs servicing military equipment therefore must undertake any maintenance or repairs in line with the OEMs' original requirements. Similarly, MROs in the civil aviation field are only legally allowed to carry out maintenance and repairs in line with OEMs' requirements as set out in Maintenance Manuals. Long service lives therefore translate to on-going requirements for the use of the chromates in the production of spare parts and in the maintenance of those spare components and the final products they are used in.

As such, a review period of at least 12 years is warranted and requested for the highly substitution issues the ADCR is addressing in this combined AoA/SEA. A 12-year review period in itself may not be sufficient for the aerospace and defence industry to fully replace the chromates across all uses of chemical conversion coatings, however, the industry is committed to the goal of substitution. A 12-year review period will enable the implementation of the significant (additional) investment in R&D, qualification and certification of design/drawing changes and industrialisation required across the various OEMs.

[93] Ecorys et al (2009): FWC Sector Competitiveness Studies – Competitiveness of the EU Industry with focus on Aeronautics Industry, Final Report, ENTR/06/054, DG Enterprise & Industry, European Commission.

6.4.3 Criterion 2: Cost of moving to substitutes

Cr(VI) coatings were validated/certified in the 1950s and 60s and extensive in-service performance has demonstrated the performance of chromated materials. This includes modifications to design practice and material selection based upon resolution of issues noted in service. Chromate-based conversion coatings, due to their extensive performance history, represent the baseline that alternatives must match to demonstrate equivalence.

For example, modern commercial aircraft in their entirety consist of between 500,000 to 6 million components, depending on the model. Depending on the materials of construction, 15-70% of the entire structure of an aircraft requires treatment using Cr(VI) at some point during the manufacturing process. Older models generally require a larger percentage of Cr(VI) surface treatments as the aerospace industry has worked diligently to incorporate new base materials and Cr(VI)-free protective coatings in newer models wherever it is safe to do so.

There are literally billions of flight hours' experience with components protected from corrosion by chromate-based CCC formulations. Conversely, there is still limited experience with Cr(VI)-free formulations on components. It is mandatory that components coated using a Cr(VI)-free alternative are demonstrably every bit as safe as they had been when coated using a Cr(VI) product. The performance of Cr(VI)-free products can sometimes be demonstrated at the laboratory step but then fails at industrial scale, as it is impossible to replicate all in-service conditions in a laboratory. As a result, the time taken to progress through the TRL process may be increased until it is possible for the performance of the alternative to be demonstrated as per safety requirements at the aircraft level when operating under real life conditions.

Flight safety is paramount and cannot be diminished in any way. Take, for example, a compressor blade that is located in the middle of an engine. If that blade can only survive for a portion of the life of an engine due to service life (and hence maintenance requirement) limitations on a new coating, the engine would need to be disassembled to be able to access the blades. That means taking the engine off the wing, sending it to a Repair Center, disassembling the engine and replacing the components at much shorter intervals than previously needed for the remainder of the engine. This would add inherent maintenance time and costs to the manufacturers; operators; and eventually end-use customers.

Where possible, and for specific components and final products, some new designs have been able to utilize newly developed alloys that do not require a Cr(VI)-based coating (as typically used to provide corrosion protection on metallic components). However, even in newer designs there may still be a need for the use of chromate-based CCC formulations which cannot be replaced at present due to safety considerations.

These technical hurdles are a fundamental reason why the A&D industry requests a review period of at least 12 years.

6.4.4 Criteria 3 & 7: Results of R&D on alternatives and availability of alternatives over the longer term

Research into the substitution of the chromates has been on-going for several decades. Although use continues, it should be recognised that significant achievements have been made over this period in the substitution of the use of the chromates by alternative substances, formulations or technologies.

This is illustrated by the achievements of one of the OEMs in reducing by 75% (reduction by weight) of their level of dependency on use of the chromates (see Figure 6-3).

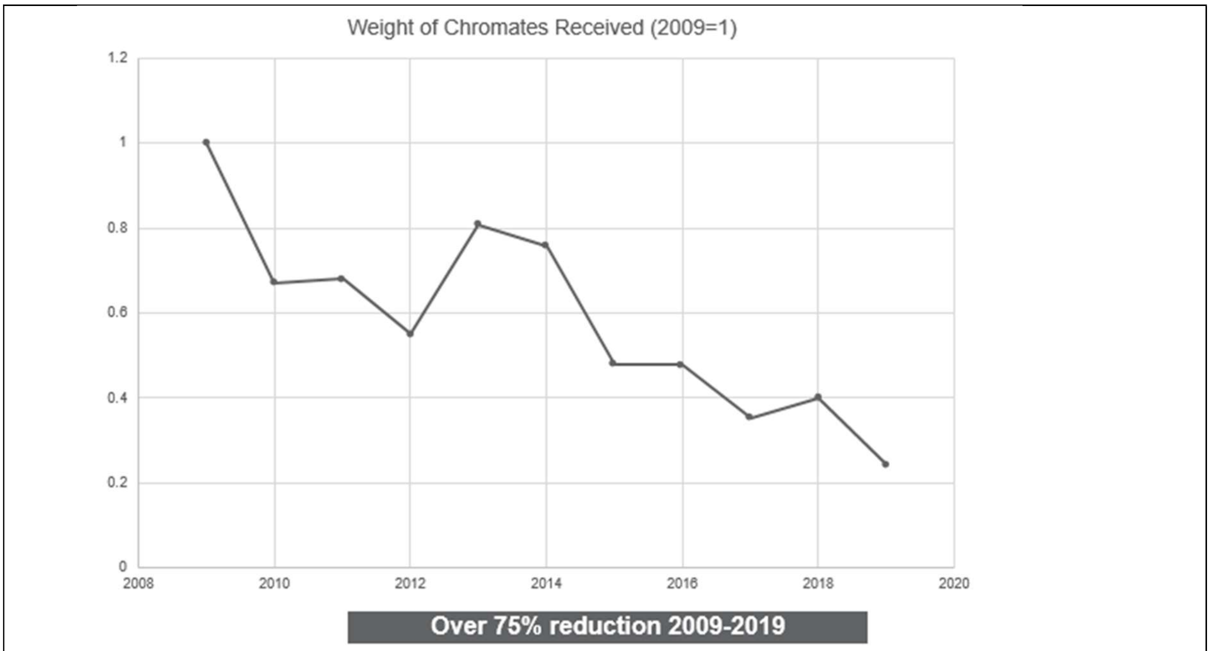

Figure 6-3: Reductions in chromate dependency over the period 2009 -2019

This 75% reduction in the use of the chromates by weight reflects the massive efforts and investment in R&D aimed specifically at substitution of the chromates. Although these efforts have enabled substitution across a large range of components and products, this OEM will not be able to move to substitutes for chromate-based CCC (its single most important on-going use of the chromates) across all components and products for at least 12 years, and perhaps longer for those parts and products which have to meet military requirements (including those pertaining to UK, EEA and US equipment).

Testing corrosion protection systems in environmentally relevant conditions to assure performance necessarily requires long R&D cycles for alternative corrosion prevention processes. A key factor driving long timeframes for implementation of fully qualified components using alternatives by the A&D industry is the almost unique challenge of obtaining relevant long-term corrosion performance information. In the case of CCC, it requires testing of changes in a process of corrosion protection, which may include changes in the primers (another possible step in the process) applied to a CCC treated component or product.

As a result, there are very long lead times before technologies developed from a research project can be implemented into real products. Technologies which are available on the market today are the result of extensive research, including research funded by grants and conducted over the last 25+ years. In 2020, the European A&D industries spent an estimated €18 billion in Research & Development (with an approximate 40:60 split between civil and military activities, and investment in R&D in the US roughly four times higher)[94].

[94] https://www.asd-europe.org/sites/default/files/atoms/files/ASD_Facts%26Figures_2021_.pdf

A PricewaterhouseCoopers (PwC) study[95] refers to the high risks of investments in the aerospace industry: “Historically, step changes have been the norm in aircraft R&D. But recent development efforts have been so expensive that it is unclear whether the companies will earn the anticipated return on their investments. Furthermore, slips in the programme schedule have worsened the economics”.

As stated many times already, A&D companies cannot simply apply a less effective corrosion protection process as aviation and defence substantiation procedures demand component performance using alternatives to be equal or better. If such performance is not achieved, then the alternatives cannot be used. The implications for repair, replacement and overhaul must also be understood before moving to an alternative. It must be recognised that the performance delivered by one component is dependent upon the performance of other components; thus, the performance delivered by a final product is dependent upon the components used. The number of configurations of components and final products is immense and each configuration may differ from the next in terms of its behaviour with a Cr(VI) alternative. There is a complex relationship between each part/component and its performance requirements within its own unique design parameters, which requires component certification for each individual substitution.

6.4.5 Criterion 4: Legislative measures for alternatives

As discussed in detail in Section 3.1.2, the identification of a test candidate Cr(VI)-free formulation is only the first stage of an extensive multi-phase substitution process leading to implementation of the alternative. This process, illustrated below, requires that all components, materials and processes incorporated into an A&D system must be qualified, validated, certified and industrialised before production can commence. Each phase must be undertaken to acquire the necessary certification to comply with airworthiness and other safety-driven requirements.

From start to finish, significantly more than 12 years is required to move from Phase 1 to Phase 5 (i.e. to identify, qualify, validate, certify and industrialise alternatives) for all critical A&D applications. The ADCR OEMs and DtBs as design owners are currently working through this process with the aim of implementing chromate-free conversion coatings by 2036; their current substitution plans are designed to ensure they achieve TRL9 and MRL10 within the next 12 years or sooner. This includes gaining airworthiness certification or military safety approvals, both of which can take up to several years to ensure safety. It may take more than 12 years to gain final approvals for some defence uses, particularly with respect to repairs, although the design owners are working to resolve current difficulties by 2036.

Several of the ADCR members also note that military procurement agencies prefer key components of defence equipment to be produced in the EEA, although there are also international agreements enabling manufacture in partner countries. In contrast to other industry sectors, shifting production to a non-EU territory and import of finished surface treated parts or products into the EU is more complex, as it could create a dependence on a non-EU supplier in a conflict situation.

Furthermore, the provision of defence exemptions, as allowed for in Article 2 (3) of the REACH regulation, is **not** a suitable instrument to ensure the continued availability of the chromates for CCC

[95] http://www.strategyand.pwc.com/trends/2015-aerospace-defense-trends

purposes if the renewal of the applicants' authorisations was not granted. While a national Ministry of Defence might issue a defence exemption out of its own interest, military equipment production processes can require the use of CCC formulations by several actors in several EU member states (i.e. it often relies on a transnational supply chain). In contrast, defence exemptions are valid at a national level and only for the issuing member state. Furthermore, the defence exemption process cannot be used as an alternative to the normal authorisation process unless this is necessary for confidentiality reasons and in the interest of defence. Thus, defence applications also need to be covered by the normal authorisation process.

Finally, the EU defence sector requires only small quantities of chromate-based CCC formulations. On the basis of a defence exemption alone, the quantities demanded would not be sufficient for manufacturers, formulators and surface treatment companies to continue to offer their services and products. As a result, CCC for military aircraft and equipment would not continue in the EEA or UK if other civilian applications were not also possible. This can only be ensured by the granting of an authorisation.

6.4.6 Criterion 5 & 6: Comparison of socio-economic benefits and risks to the environment and effective control of the remaining risks

As demonstrated by the information collected by the SEA questionnaire, A&D companies have invested in monitoring and the installation of additional risk management measures in response to the conditions placed on the continued use of the chromates under the initial (parent) authorisations. This has resulted in reduced exposures for both workers and reduced emissions to the environment. As substitution progresses across components and assemblies and the associated value chains, consumption of the chromates will decrease, and exposures and emissions will reduce further over the requested 12 year review period. As a result, the excess lifetime risks derived in the CSR for both workers and humans via the environment will decrease over the review period. These risks will also be controlled through introduction in 2017 of the binding occupational exposure limit value on worker exposures to Cr(VI) at the EU level under the Carcinogens and Mutagens Directive[96].

The European aerospace and defence industry is a world-class leader in technology and innovation. They are an essential part of the European economy contributing to job creation (880,000 direct jobs in 2020[97]) and Europe's trade balance (55% of products developed and built in the EEA are exported).

Civil aeronautics alone accounted for around €99.3 billion in revenues, with military aeronautics accounting for a further €47.4 billion in turnover; overall taking into account other defence and space turnover, the sector had revenues of around €230 billion. Of the €99.3 billion in civil aeronautics turnover, €88.3 billion represented exports from the EU.

Both acknowledged market reports of Airbus and Boeing find a growing trend in the aerospace industry. Passenger air traffic is predicted to grow at 3.6% CAGR for 2022-2041 and freight traffic to grow at 3.2% CAGR globally, according to Airbus' Global Market Forecast. By 2041, there will be some 46,900 aircraft in service, with this including an estimated 39,500 new passenger and freighter aircraft

96 Directive 2004/37/EC of the European Parliament and of the Council of 29 April 2004 on the protection of workers from the risks related to exposure to carcinogens or mutagens at work (Sixth individual Directive within the meaning of Article 16(1) of Council Directive 89/391/EEC), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32004L0037

97 https://asd-europe.org/sites/default/files/atoms/files/ASD_Facts%26Figures_2021_.pdf

(and the retirement of some of the older aircraft. This includes delivery of new aircraft for the European market, as well as the Asian and Chinese markets.[98]

Boeing's 2022 Commercial Market Outlook[99] indicates a similar level of increase, noting that the global fleet will increase by around 80% through to 2041 with the forecast value of new airplane deliveries at around US $7.2 trillion (based on a slightly higher growth in traffic at around 3.8% CAGR.

The socio-economic benefits of retaining the key manufacturing base of the EEA and UK A&D industries are clearly significant, given that they will be major beneficiaries of this growth in demand. As demonstrated in the socio-economic analysis presented here, even without accounting for such growth in demand under the continued use scenario, the socio-economic benefits clearly outweigh the associated risks to human health at social costs to risk ratios of over 3,560 to one for the EEA and 1,426 to one for the UK.

6.5 Substitution effort taken by the applicant if an authorisation is granted

As the AoA shows, where alternatives have been proven as technically feasible – on a component-by-component basis – they have been, or are in the process of, being implemented. However, there are still many cases where components do not have technically feasible alternatives available. Figure 3-2 highlights the actions that are being taken by A&D design owners to develop, qualify, validate, certify and industrialise alternatives for individual components.

This work will continue over the requested review period with the aim of phasing out all uses of chromate-based chemical conversion coatings. As illustrated in Section 3.16, on-going substitution is expected to result in significant decreases in the volumes of the four chromates used in CCC within the next seven years. However, technically feasible alternatives are still at the development phase (Phase 1 out of the 5 phases) for some components and final products, where alternatives have not been found to meet performance requirements.

6.6 Links to other Authorisation activities under REACH

This combined AoA/SEA is one of a series of applications for the re-authorisation of the use of chromium trioxide in surface treatments carried out by the A&D industry. This series of combined AoA/SEAs has adopted a narrower definition of uses originally Authorised under the CTAC, CCST and GCCA parent Applications for authorisation.

In total, the ADCR will be submitting 11 Combined AoA/SEAs covering the following uses and the continued use of chromium trioxide, sodium dichromate, potassium dichromate, sodium chromate and/or dichromium tris(chromate):

1) Formulation
2) Pre-treatments
3) Electroplating (hard chrome plating)
4) Passivation of stainless steel

98 https://www.airbus.com/sites/g/files/jlcbta136/files/2022-07/GMF-Presentation-2022-2041.pdf

99 https://www.boeing.com/commercial/market/commercial-market-outlook/index.page

5) Anodising
6) Chemical conversion coating
7) Anodise sealing
8) Passivation of non-Al metallic coatings
9) Inorganic finish stripping
10) Chromate rinsing after phosphating
11) Slurry coatings

7 References

Airbus SAS (2022) *Laboratory Testing | Engineering & Design Services | Expand | Services | Airbus Aircraft*. Available at: https://aircraft.airbus.com/en/services/expand/engineering-design-services/laboratory-testing (Accessed: 15 August 2022).

Bethencourt, M. *et al.* (1998) 'Lanthanide compounds as environmentally-friendly corrosion inhibitors of aluminium alloys: A review', *Corrosion Science*, 40(11), pp. 1803–1819. Available at: https://doi.org/10.1016/S0010-938X(98)00077-8.

CARACAL (2017) *REACH Authorisation - Criteria for longer review periods*.

CCST Consortium (2015) *Sodium dichromate AoA, use 2 (0043-02)*. Available at: https://echa.europa.eu/documents/10162/1816486e-348f-42a9-bc88-02d52ddfd891 (Accessed: 28 July 2021).

CTAC (2015) *Chromium trioxide AoA, use 4 (0032-04)*. Available at: https://echa.europa.eu/documents/10162/c82315c4-df7f-4e81-9412-eb90fcd92480 (Accessed: 26 August 2021).

Cui, X. *et al.* (2012) 'Preparation and Characterization of Phosphate Film for Magnesium Alloy AZ31', *Physics Procedia*, 25, pp. 194–199. Available at: https://doi.org/10.1016/j.phpro.2012.03.070.

EASA (2012) *European Aviation Safety Agency GOOD PRACTICES Coordination between Design and Maintenance First Installation of a Change to a Product*.

EPO (2020) *EPO - Espacenet: patent database with over 120 million documents*.

EU (2018) *Regulation (EU) 2018/1139 | EASA*. Available at: https://www.easa.europa.eu/document-library/regulations/regulation-eu-20181139 (Accessed: 2 September 2022).

GCCA (2017a) *Dichromium tris(chromate) AoA, use 1 (0116-01)*. Available at: https://www.echa.europa.eu/documents/10162/1a0be468-61e2-e452-bb57-f6e1375ccde0 (Accessed: 11 August 2022).

GCCA (2017b) *Dichromium tris(chromate) AoA, use 2 (0116-01)*.

Gharbi, O. *et al.* (2018) 'Chromate replacement: what does the future hold?', *npj Materials Degradation 2018 2:1*, 2(1), pp. 1–8. Available at: https://doi.org/10.1038/s41529-018-0034-5.

Grolig, J.G. *et al.* (2015) 'Copper Iron Conversion Coating for Solid Oxide Fuel Cell Interconnects', *Journal of Power Sources*, 297, pp. 534–539. Available at: https://doi.org/10.1016/j.jpowsour.2015.06.139.

Grolig, J.G., Froitzheim, J. and Svensson, J.E. (2015) 'Effect of Cerium on the Electrical Properties of a Cobalt Conversion Coating for Solid Oxide Fuel Cell Interconnects - A Study Using Impedance Spectroscopy', *Electrochimica Acta*, 184, pp. 301–307. Available at: https://doi.org/10.1016/j.electacta.2015.10.111.

Hou, L. *et al.* (2013) 'Chrome-free samarium-based protective coatings for magnesium alloys', in *Physics Procedia*. Elsevier B.V., pp. 261–266. Available at: https://doi.org/10.1016/j.phpro.2013.11.041.

Hughes, A. *et al.* (2016) *Active Protective Coatings. New-Generation Coatings for Metals*. Available at: https://www.google.co.uk/books/edition/Active_Protective_Coatings/O2iCDAAAQBAJ?hl=en&gbpv=1&dq=been+spent+to+develop+a+suitable+alternative+to+chromates+chemical+conversion+coatings.&pg=PA345&printsec=frontcover (Accessed: 30 March 2022).

Jiang, X., Guo, R. and Jiang, S. (2016a) 'Evaluation of self-healing ability of Ce–V conversion coating on AZ31 magnesium alloy', *Journal of Magnesium and Alloys*, 4(3), pp. 230–241. Available at: https://doi.org/10.1016/j.jma.2016.06.003.

Jiang, X., Guo, R. and Jiang, S. (2016b) 'Evaluation of self-healing ability of Ce–V conversion coating on AZ31 magnesium alloy', *Journal of Magnesium and Alloys*, 4(3), pp. 230–241. Available at: https://doi.org/10.1016/j.jma.2016.06.003.

Leggat, R.B., Taylor, S.A. and Taylor, S.R. (2002) 'Adhesion of epoxy to hydrotalcite conversion coatings: I. Correlation with wettability and electrokinetic measurements', *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 210(1), pp. 69–81. Available at: https://doi.org/10.1016/S0927-7757(02)00209-1.

Liao, S. *et al.* (2020) 'New design principles for the bath towards chromate- and crack-free conversion coatings on magnesium alloys', *Journal of Magnesium and Alloys* [Preprint]. Available at: https://doi.org/10.1016/j.jma.2019.12.013.

Liu, Q. *et al.* (2018) 'Investigation on adhesion strength and corrosion resistance of Ti-Zr aminotrimethylene phosphonic acid composite conversion coating on 7A52 aluminum alloy', *Applied Surface Science*, 458, pp. 350–359. Available at: https://doi.org/10.1016/j.apsusc.2018.07.044.

Mansfeld, F., Wang, Y. and Shih, H. (1992) 'The CeMo process for the development of a stainless aluminum', *Electrochimica Acta*, 37(12), pp. 2277–2282. Available at: https://doi.org/10.1016/0013-4686(92)85123-3.

Naden, B. (2019) *Chromate-free Coatings Systems for Aerospace and Defence Applications - PRA World*. Available at: https://pra-world.com/2019/08/21/chromate-free-coatings-systems-for-aerospace-and-defence-applications/ (Accessed: 30 March 2022).

Nezamdoust, S., Seifzadeh, D. and Rajabalizadeh, Z. (2019) 'Application of novel sol–gel composites on magnesium alloy', *Journal of Magnesium and Alloys*, 7(3), pp. 419–432. Available at: https://doi.org/10.1016/j.jma.2019.03.004.

Ni, L. *et al.* (2014) 'Direct-to-metal UV-cured hybrid coating for the corrosion protection of aircraft aluminium alloy', *Corrosion Science*, 89(C), pp. 242–249. Available at: https://doi.org/10.1016/j.corsci.2014.09.006.

O'Keefe, M.J., Geng, S. and Joshi, S. (2007) 'Cerium-based conversion coatings as alternatives to hex chrome. Rare-earth compounds provide resistance against corrosion for aluminum alloys in military applications', *Metal Finishing*, 105(5), pp. 25–28. Available at: https://doi.org/10.1016/S0026-0576(07)80547-2.

Oki, M. *et al.* (2020) ‘Corrosion rates of green novel hybrid conversion coating on aluminium 6061’, *Results in Engineering*, 7, p. 100159. Available at: https://doi.org/10.1016/j.rineng.2020.100159.

Pommiers, S. *et al.* (2014) ‘Alternative conversion coatings to chromate for the protection of magnesium alloys’, *Corrosion Science*, 84, pp. 135–146. Available at: https://doi.org/10.1016/j.corsci.2014.03.021.

Rocca, E., Juers, C. and Steinmetz, J. (2010) ‘Corrosion behaviour of chemical conversion treatments on as-cast Mg-Al alloys: Electrochemical and non-electrochemical methods’, *Corrosion Science*, 52(6), pp. 2172–2178. Available at: https://doi.org/10.1016/j.corsci.2010.02.036.

Rowbotham, J. and Fielding, T. (2016) ‘Intended and unintended consequences of REACH’, *Aerospace Coatings*, pp. 26–27. Available at: www.coatingsgroup.com (Accessed: 30 March 2022).

Royal Academy of Engineering (2014) ‘Innovation in aerospace’, (June 2014), pp. 1–21. Available at: http://www.raeng.org.uk/publications/reports/innovation-in-aerospace.

Saji, V.S. (2019) ‘Review of rare-earth-based conversion coatings formagnesium and its alloys’, *Journal of Materials Research and Technology*. Elsevier Editora Ltda, pp. 5012–5035. Available at: https://doi.org/10.1016/j.jmrt.2019.08.013.

Say, W.C., Chen, C.C. and Hsieh, S.J. (2008) ‘Electrochemical characterization of non-chromate surface treatments on AZ80 magnesium’, *Materials Characterization*, 59(10), pp. 1400–1406. Available at: https://doi.org/10.1016/j.matchar.2007.12.007.

Seth, A. *et al.* (2007) ‘Novel, one-step, chromate-free coatings containing anticorrosion pigments for metals-An overview and mechanistic study’, *Progress in Organic Coatings*, 58(2–3), pp. 136–145. Available at: https://doi.org/10.1016/j.porgcoat.2006.08.030.

Toorani, M. and Aliofkhazraei, M. (2019) ‘Review of electrochemical properties of hybrid coating systems on Mg with plasma electrolytic oxidation process as pretreatment’, *Surfaces and Interfaces*. Elsevier B.V., pp. 262–295. Available at: https://doi.org/10.1016/j.surfin.2019.01.004.

TREND Programme - Research & Development in the Czech Republic (no date). Available at: http://www.czech-research.com/rd-funding/national-funds/relevant-programmes/trend-programme/ (Accessed: 27 August 2022).

Wikipedia (2021) *Galling - Wikipedia*. Available at: https://en.wikipedia.org/wiki/Galling (Accessed: 4 September 2022).

Yeganeh, M. and Mohammadi, N. (2018) ‘Superhydrophobic surface of Mg alloys: A review’, *Journal of Magnesium and Alloys*. National Engg. Reaserch Center for Magnesium Alloys, pp. 59–70. Available at: https://doi.org/10.1016/j.jma.2018.02.001.

Zanotto, F. *et al.* (2011) ‘Protection of the AZ31 magnesium alloy with cerium modified silane coatings’, *Materials Chemistry and Physics*. Elsevier, pp. 1–8. Available at: https://doi.org/10.1016/j.matchemphys.2011.05.013.

Zarras, P. and Stenger-Smith, J.D. (2014) ‘Electro-active polymer (EAP) coatings for corrosion protection of metals’, in *Handbook of Smart Coatings for Materials Protection*. Elsevier Inc., pp. 328–369. Available at: https://doi.org/10.1533/9780857096883.2.328.

Zhao, M. *et al.* (2006) 'A chromium-free conversion coating of magnesium alloy by a phosphate-permanganate solution', *Surface and Coatings Technology*, 200(18–19), pp. 5407–5412. Available at: https://doi.org/10.1016/j.surfcoat.2005.07.064.

8 Annex 1: Examples of Standards

Table A-8-1 below shows examples of industry standards reported by ADCR members applicable to conversion coating. Test methods and requirements contained therein do not define success criteria for alternatives validation.

Table A-8-1: Examples of standards applicable to conversion coating key functions

Standard Reference	Standard description	Key function/standard type
AMS 2473	Chemical Film Treatment for Aluminium Alloys General Purpose Coating	Industry QC spec
AMS 2475	Protective Treatments for Magnesium Base Alloys	Industry QC spec
AMS 2477	Conversion Coating for Aluminium Alloys Low Electrical Resistance Coatings	Industry QC spec
ASTM B117	Standard Practice for Operating Salt Spray (Fog) Apparatus	Corrosion resistance
ASTM D3359 Method B	Standard test methods for measuring adhesion by tape test	Adhesion promotion
ASTM G85 Annex 4	Standard Practice for Modified Salt Spray (Fog) Testing	Corrosion resistance
DEF STAN 00-35	Environmental Handbook for Defence Material	Resistance to fluids (chemical resistance)
DIN EN ISO 1519	Paints and varnishes - Bend test (cylindrical mandrel)	Adhesion promotion
ECSS-Q-ST-70-04C	Thermal testing for the evaluation of space materials, processes, mechanical parts and assemblies[a]	Thermal testing (temperature resistance)
ECSS-Q-ST-70-14C	Corrosion – specifies the minimum requirements to qualify the materials and processes selected to provide corrosion protection[a]	Corrosion resistance
EN 3665	Test methods for paints and varnishes - Filiform corrosion resistance test on aluminium alloys	Filiform corrosion resistance
EN 4628-2	Paints and varnishes - Evaluation of degradation of coatings	Adhesion promotion Resistance to fluids (chemical resistance)
EN 6072	Constant amplitude fatigue testing	Influence on fatigue behaviour
EN ISO 2409	Paints and varnishes - Cross-cut test	Adhesion promotion
FED-STD-141 method 6301	Paint, varnish, lacquer, and related materials: methods of inspection, sampling and testing	Adhesion promotion
ISO 1463	Metallic and Oxide Coatings - Measurement of Coating Thickness - Microscopical Method	Film thickness (layer thickness)
ISO 1520	Paints and Varnishes - Cupping Test	Adhesion promotion Resistance to fluids (chemical resistance)
ISO 2409	Paints and varnishes - Cross-cut test	Adhesion promotion Resistance to fluids (chemical resistance)
ISO 2812	Paints and varnishes - Determination of resistance to liquids	Chemical resistance

Table A-8-1: Examples of standards applicable to conversion coating key functions		
Standard Reference	**Standard description**	**Key function/standard type**
ISO 9227	Corrosion tests in artificial atmospheres - Salt spray tests	Corrosion resistance
MIL-DTL-5541	Chemical conversion coatings on aluminium and aluminium alloys	Industry QC specification
MIL-DTL-81706	Chemical conversion materials for coating aluminium and aluminium alloys	Industry QC specification
MIL-STD-810 Method 504	Contamination by fluids[(b)]	Chemical resistance
Source: ADCR members “Standard description” obtained from https://standards.globalspec.com apart from: (a) European co-operation for space standardization, https://ecss.nl/ (b) https://www.crystalrugged.com/		

9 Annex 2: European Aerospace Cluster Partnerships

Table 9-1: European Aerospace Clusters

Cluster Name	Country	City	Number of Companies	Employees	Sales/turnover
ACSTYRIA MOBILITÄTSCLUSTER GMBH	Austria	Styria	80	3000	650 million Euros
Aeriades	France	Grand Est	65	3100	500 million Euros 7% of total French GDP
Aerospace Cluster Sweden	Sweden	Älvängen	50		
AEROSPACE LOMBARDIA	Italy		220	16000	5.4 billion Euros
AEROSPACE VALLEY	France	Toulouse	600	147000	
Aerospace Wales Forum Limited	UK	Wales	180	23000	£6.5 billion
Andalucía Aerospace Cluster	Spain	Andalusia	37	15931	2.5 billion Euros
Aragonian Aerospace Cluster	Spain	Zaragoza	28	1000	
ASTech Paris Region	France	Paris		100000	
Auvergne-Rhône-Alpes Aerospace	France	Rhône-Alpes	350	30000	3.3 billion Euros
AVIASPACE BREMEN e.V.	Germany	Bremen	140	12000	
Aviation Valley	Poland	Rzeszow	177	32000	3 billion Euros
bavAIRia e.V.	Germany	Bavaria	550	61000	
Berlin-Brandenburg Aerospace Allianz e.V.	Germany	Berlin	100	17000	3.5 billion Euros
Czech Aerospace Cluster	Czech Republic	Moravia	53`	6000	400 million Euros
DAC Campania Aerospace District	Italy	Campania	159	12000	1.6 billion Euros
DTA Distretto Tecnologico Aerospaziale s.c.a.r.l	Italy	Apulia	13	6000	78 million Euros
Estonian Aviation Cluster (EAC)	Estonia	Tallinn	19	25000	3% of GDP
Flemish Aerospace Group	Belgium	Flanders	67	3300	1.2 billion Euros
Hamburg Aviation e.V	Germany	Hamburg	300	40000	5.18 billion Euros
HEGAN Basque Aerospace Cluster	Spain	Basque Country	56	4819	954 million Euros
Innovation & Research for Industry	Italy	Emilia Romagna	30	2000	500 million Euros
International Aviation Services Centre (IASC)Ireland	Ireland	Shannon	60	46000	3.6bn GVA

Table 9-1: European Aerospace Clusters					
Cluster Name	**Country**	**City**	**Number of Companies**	**Employees**	**Sales/turnover**
Invest Northern Ireland	Northern Ireland	Belfast	100	10000	£6.7 billion
LR BW Forum Luft- und Raumfahrt Baden-Württemberg e.V.	Germany	Baden-Wuerttemberg	93	15000	4.8 billion Euros
LRT Kompetenzzentrum Luft- und Raumfahrttechnik Sachsen/Thüringen e.V.	Germany	Dresden	160	12000	1.5 billion Euros
Madrid Cluster Aeroespacial	Spain	Madrid		32000	8 billion Euros
Midlands Aerospace Alliance	UK	Midlands	400	45000	
Netherlands Aerospace Group	Netherlands		89	17000	4.3 billion Euros
Niedercachsen Aviation	Germany	Hanover	250	30000	
Normandie AeroEspace	France	Normandy	100	20000	3 billion Euros
Northwest Aerospace Alliance	UK	Preston	220	14000	£7 billion
OPAIR	Romania			5000	150 million Euros
Portuguese Cluster for Aeronautics, Space and Defence Industries	Portugal	Évora	61	18500	172 million Euros
Safe Cluster	France		450		
Silesian Aviation Cluster	Poland	Silesian	83	20000	
Skywinn - Aerospace Cluster of Wallonia	Belgium	Wallonia	118	7000	1.65 billion euros
Swiss Aerospace Cluster	Switzerland	Zurich	150	190000	16.6 billion CHF 2.5 % of GDP
Torino Piemonte Aerospace	Italy	Turin	85	47274	14 billion euros

10 Annex 3: UK Aerospace sector

10.1 Overview

10.1.1 Aerospace

The annual ADS Industry Facts and Figures guide provides an indication of the UK aerospace, defence, security and space sectors' contribution to the economy in 2021, as shown in Figure 9-1. The Aerospace, Defence, Security and Space Group (ADS) notes that it has over 1,100+ member companies (including over 1,000 SMEs), supporting around 1,000,000 jobs (direct and indirect) across the country.

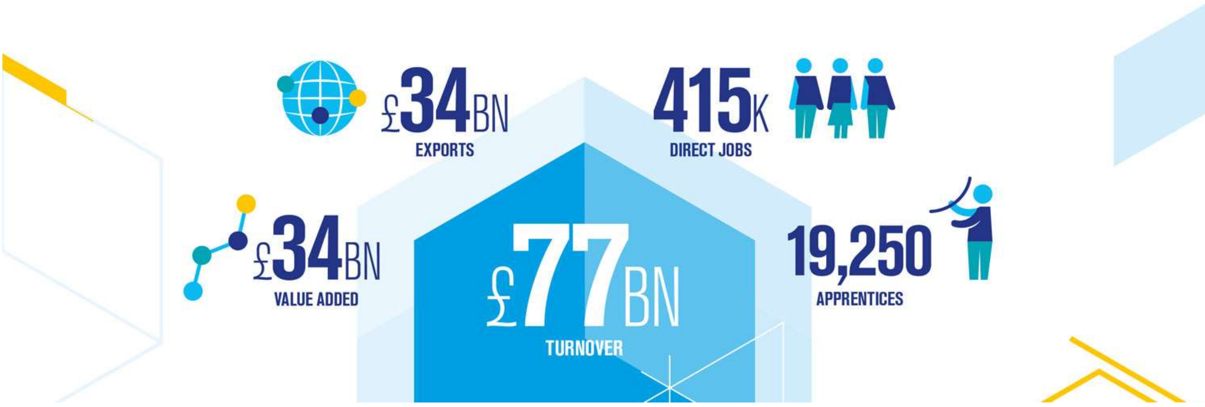

Figure 9-1: Contribution of UK aerospace, defence, security and space sectors to the economy in 2020[100]

The UK aerospace sector is considered by the government to be "hugely important to the UK economy"[101], providing direct employment of over 120,000 highly skilled jobs that pay about 40% above the national average. The sector has an annual turnover of around £77bn, half of which comes from exports to the rest of the world. It is a driver of economic growth and prosperity across the UK, given that most of the jobs (92%) are located outside London and the south east – see Figure 9-2.

Given the economic importance of the sector, it has been the focus of an Aerospace Sector Deal launched on 6 December 2018) under the UK Industrial Strategy. The deal is aimed at helping industry move towards greater electrification, accelerating progress towards reduced environmental impacts, and has involved significant levels of co-funding by the government (e.g. a co-funded £3.9 billion for strategic research and development activities over the period up to 2026)[102]. To date, this co-funded programme has invested £2.6 billion, across all parts of the UK.

It is anticipated that the UK aerospace sector will continue to grow into the future, due to the global demand for large passenger aircraft, as discussed further below.

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100 https://www.adsgroup.org.uk/wp-content/uploads/sites/21/2022/06/ADS-FF2022-Twit-header-72.jpg

101 BEIS, Aerospace Sector Report, undated.

102 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/763781/aerospace-sector-deal-web.pdf

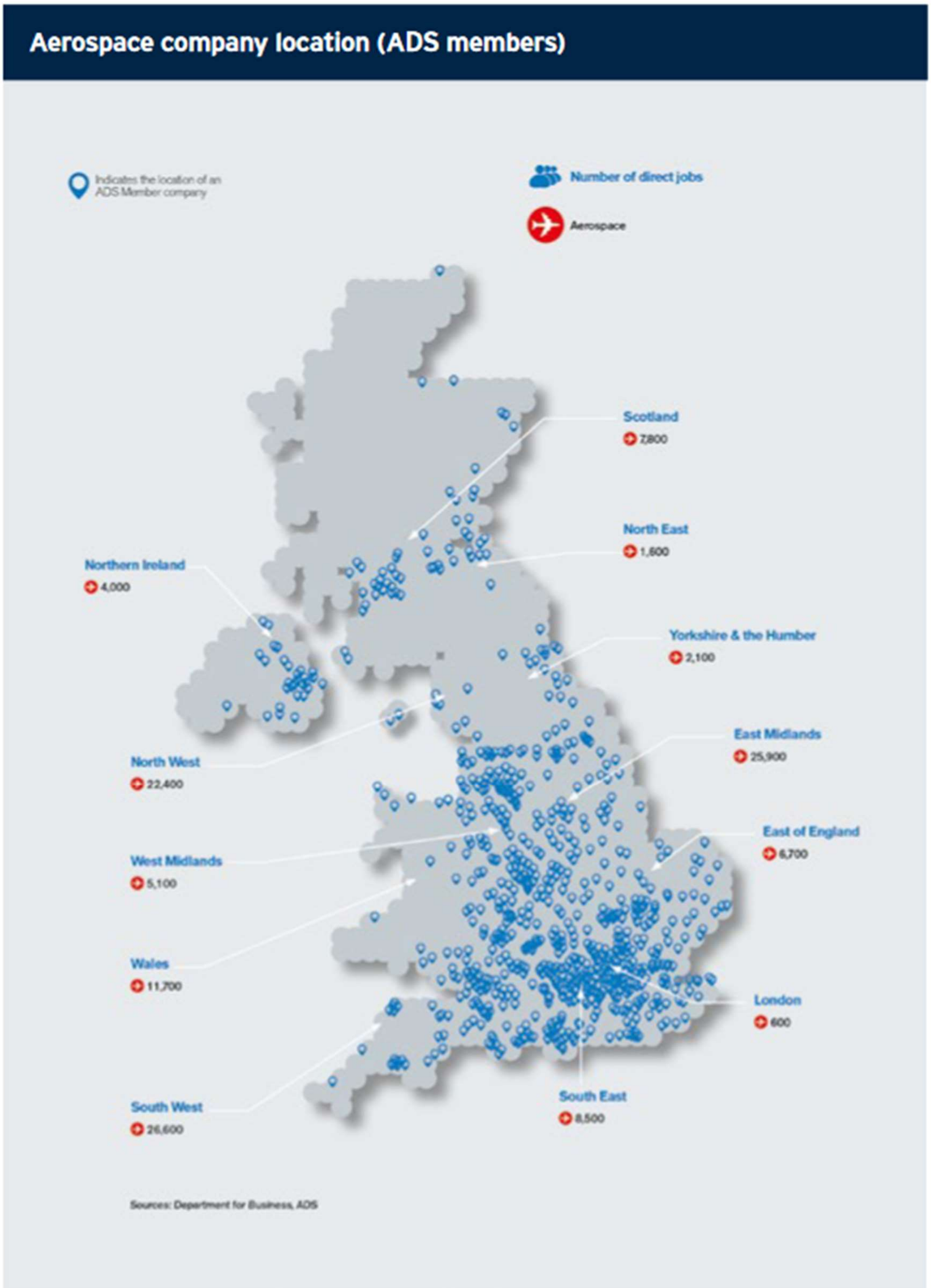

Figure 9-2: Location of aerospace manufacturing sites and associated jobs in the UK[103]

The National Aerospace Technology Exploitation Programme was created in 2017 to provide research and technology (R&T) funding with the aim of improving the competitiveness of the UK aerospace

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[103] Sources: ONS, BEIS, ADS Industrial Trends Survey 2020

industry, as well as other supporting measures under the Industrial Strategy. The Government's investment in R&T is through the Aerospace Technologies Institute and is programmed at £1.95 billion in expenditure between 2013-2026.

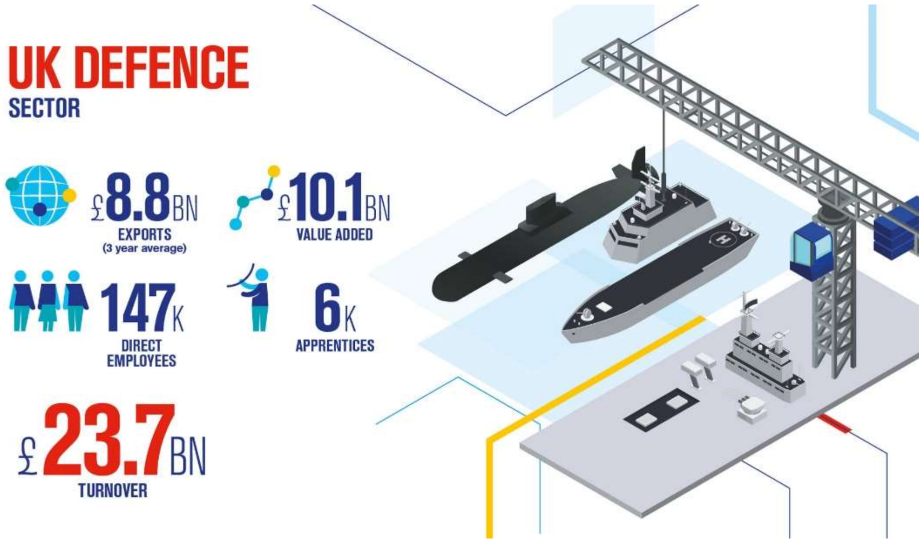
This will help in maintaining the current expected market development in the UK, which would see a 2.3% per year growth in real terms, leading to direct added value of just over £14 billion in 2035 (compared to £9 billion in 2016). In 2016, the UK aerospace sector employed around 112,500 people, with each direct job in the aerospace industry creating at least one additional job within the aerospace supply chain. This gives around 225,000 people directly and indirectly employed by the aerospace sector in high-value design and high value manufacturing jobs. By maintaining its current direction of growth, the sector is expected to create up to a further 45,000 positions by 2035.

The value of the sectors is also significant in wider economic terms. Investment in aerospace research and technology leads to wider impacts beyond the sector. Every £100 million spent on R&T by the government crowds-in around £300 million of additional private sector investment. Furthermore, every £100 million invested benefits not only UK aerospace GVA by £20 million per year, but also the wider economy by £60 million per year through technology spillovers. These include automotive, marine, oil and gas, nuclear, electronics, composites, metals and other UK industrial sectors. In total, the return on government investment in the sector is estimated as delivering an additional £57 billion of gross value added for the UK aerospace sector and a further £57 billion to the wider UK economy between 2015 and 2035.

10.1.2 Defence

With respect to defence, the UK is the second largest defence exporter in the world, with its contribution to employment, turnover, and exports illustrated in Figure 9-3[104]. Again the importance of the sector to UK exports and value added, as well as employment is clear from Figure 9-3.

Figure 9-3: UK defence sector contribution to the economy in 2021



[104] Sources: https://www.adsgroup.org.uk/industry-issues/facts-figures/facts-figures-2022/