ANALYSIS OF ALTERNATIVES

and

SOCIO-ECONOMIC ANALYSIS

Complete version

Legal name of applicant(s):	Boeing Distribution (UK) Inc. (CT, SC) Henkel Ltd (CT) MacDermid Performance Solutions UK Ltd (CT) Wesco Aircraft EMEA Ltd (CT)
Submitted by:	Wesco Aircraft EMEA Ltd on behalf of the Aerospace and Defence Chromates Reauthorisation Consortium
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Substance:	- Chromium trioxide - Sodium chromate
Use title:	Anodise sealing using chromium trioxide and/or sodium chromate in aerospace and defence industry and its supply chains
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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

CAGR – Compound Annual Growth Rate

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

GVA – Gross Value Added

HvE – Humans via the Environment

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

Term	Description
	satisfied the specific requirements. These are usually defined in the Certification requirements.
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.

Term	Description
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.
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.

Term	Description
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.
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 Applicants, 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 8 February 2023 the information is not publicly available and, in accordance with the due measures of protection that we have implemented, a member of the public should not be able to obtain access to this information without our consent or that of the third party whose commercial interests are at stake.

Signature: Date: 8 February 2023

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08/02/2023

SES Simple electronic signature
Signed on Skribble.com

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 successes and levels of use have decreased significantly, the specific use of hexavalent chromium compounds in anodise sealing[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 Review Report covered multiple surface treatments and different individual chromates. This combined AoA/SEA covers only one of the currently authorised types of surface treatment – anodise sealing – 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.

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

[1] Review Reports 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

1) Anodise sealing using chromium trioxide, potassium dichromate, sodium chromate and/or sodium dichromate in aerospace and defence industry and its supply chain

The "applied for use" involves the continued use of chromium trioxide (CT), sodium dichromate (SD), potassium dichromate (PD) and sodium chromate (SC) across the EEA and the UK in anodise sealing for a further 12-year review period. These four chromates were included in 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, PD, SC and SD 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/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 anodise sealing due to the fact that different chromates may be used within the same facility.

The potential for double counting is significant given that approximately 125 sites in the EEA and 35 sites in Great Britain are anticipated as undertaking anodise sealing. 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 quantities of each of the four chromates, with some sites using more than one chromate in anodise sealing activities, 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 anodise sealing (substances and formulations)

	Chromium trioxide	Sodium dichromate	Potassium dichromate	Sodium chromate
EEA	Up to 2.5 t/y	Up to 10 t/y	Up to 12 t/y	Up to 2 t/y
UK	Up to 0.5 t/y	Up to 6 t/y	Up to 6 t/y	Up to 0.5 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 (DtB) manufacturers) selling products used in civil aviation, military aircraft, ground and sea-based defence systems, and aeroderivatives have been searching for alternatives to the use of the chromates in anodise sealing as a specific use. At the current time, the remaining uses form a part of an overall system providing the following key functions:

- Corrosion resistance; and
- Active corrosion inhibition.

Other factors which are taken into account when assessing proposed candidates include maintaining the layer thickness and adhesion to subsequent layers provided by the anodic treatment.

For aluminium, in particular, sealing is an important step employed in the anodising process, principally to impart corrosion resistance and corrosion inhibition to the anodised aluminium by ensuring that the pores of the porous oxide layer are sealed.

The OEMs and DtB manufacturers that are the design owners for A&D final products (aircraft, helicopters, military jets, missile systems, tanks, etc.) have conducted a full analysis of their requirements into the future, taking into account progress of R&D, testing, qualification, validation, 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 anodise sealing 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 been able to identify technically feasible alternatives for all components and products that will meet performance requirements and will require 12 years or more to gain certification and to then implement current test candidates. A further group of companies are constrained by military and/or 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 in order 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 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, potassium dichromate, sodium chromate and sodium dichromate in anodise sealing 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. This applies not only to MROs involved in servicing civilian aircraft but also military MROs servicing military equipment.

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, refer to **Figure 1-1**. The potential need for more than 12 years has been identified by some OEMs due to their inability to identify any 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.

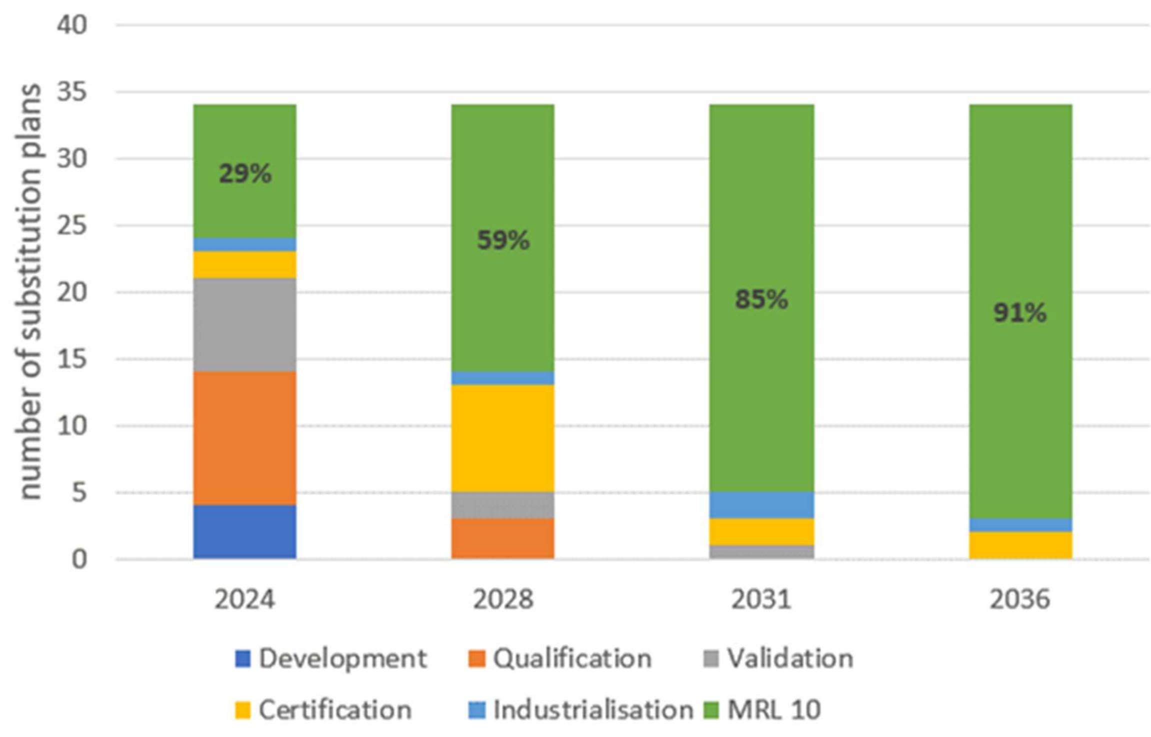


Figure 1-1: Expected progression of substitution plans for the use of Cr(VI) in anodise sealing by year
The vertical axis refers to number of substitution plans (some members have multiple substitution plans for anodise sealing). The percentage value shown on each of the green bars indicates the proportion of substitution plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which manufacturing is in full rate production/deployment and it is therefore where it is expected that Cr(VI) will be fully substituted under the relevant plan.
Source: RPA analysis, ADCR members

1.3 Socio-economic benefits from continued use

The continued use of the four chromates in anodise sealing 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 and emergency services. It will also ensure the continued functioning of the A&D supply chains within 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 substances and formulators of the mixture used in anodise sealing will continue to earn profits from sales to the A&D sector;

- 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 €2,000 – 4,600 million for the EEA and €200 – 700 million for the UK, over a 2-year period (starting in 2025, PV discounted at 4%). These figures exclude the potential 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 continued use scenario for these companies are calculated at between €200 – 800 million for the EEA and €30 – 300 million for the UK over a 2-year period (starting in 2025, PV discounted at 4%);

- MRO companies which provide maintenance and repair services to both civil aviation and/or military forces, would not be forced to move some operations outside the EEA/UK, and would avoid the consequent profit losses equating to between €100 – 1,000 million for the EEA and €40 – 300 million for the UK over a 2-year period (starting in 2025, PV discounted at 4%). Such relocation of strategically important activities would run contrary to the EU's New Industrial Strategy;

- 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 anodise sealing and linked treatment, manufacturing and assembly activities are estimated at €6,900 million in the EEA and €900 million in the UK. These benefits are associated with the protection of around 62,300 jobs in the EEA and around 10,400 jobs in the UK;

- Critically, civil aviation and emergency services will benefit from the continued flight safety and mission readiness 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 economic development, as well as R&D and technological innovation, while alternatives are qualified, certified and industrialised.

The loss to the A&D companies and to society are expected to be much larger than the losses calculated in the non-use scenario. This is because the non-use scenario does not account for the cost associated with, for example, disruption, relocation in the supply chain.

[3] Two different approaches have been used to calculate economic impacts to produce lower and upper bound estimates. Profit losses are discounted over 2 years at 4% per annum.

1.4 Residual risk to human health from continued use

The parent authorisations placed conditions on the continued use of the chromates in surface treatments, including in anodise sealing. 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.

Significant technical achievements have also 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 125 EEA sites where chromate-based anodise sealing is anticipated as taking place, an estimated total of 2,900 workers may be exposed to Cr(VI); and for the 35 UK sites where anodise sealing takes place the estimated figure is 800.

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 anodise sealing is considered to take place, an estimated 40,100 people in the EEA and around 33,300 people in the UK[4] are calculated as potentially being exposed to Cr(VI) due to chromate-based anodise sealing activities.

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: 0.80 statistical fatal cancers and 0.22 non-fatal cancers over the 12-year review period, at a total social cost of €1.16 million
- UK: 0.37 fatal cancers and 0.10 non-fatal cancers over the 12-year review period at a total social cost of €547,000

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 total residual risks to human health are as follows for the EEA and UK respectively (based on 2 years for economic losses and 12 years for health risks @ 4%):

- EEA: 8,731 to 1 for the lower bound of profit losses and unemployment costs or 10,725 to 1 for the upper bound profit losses and unemployment costs, where economic impacts are assessed over 2 years and residual risks over 12 years;

[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.

- UK: 2,594 to 1 for the lower bound of profit losses and unemployment costs or 3,466 to 1 for the upper bound profit losses and unemployment costs, where economic impacts are assessed over 2 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 sodium chromate in anodise sealing, 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;

- 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 cost of flights for passengers, or cargo shippers, 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;

- The avoided negative environmental impact associated with prematurely obsoleted final products which creates excess waste in the disposal of components, and increased scrappage in the manufacture of the replacements; 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:

- The sector has reduced the volume of chromates used in anodise sealing, and the quantities used in this surface treatment are expected to start reducing significantly year on year until use is phased-out by the majority of the companies in 2036.

- 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.

- 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 anodise sealing.

- As indicated in the Substitution Plan, companies are progressing towards the certification and implementation of substitutes where this is already indicated as possible. Those uses that continue to take place are those where the components or the final products face the more demanding performance requirements and development of proposed candidates is ongoing.

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 components 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 still 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 represent a shift away from the need for the chromates in anodise sealing, 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 have to be met to ensure airworthiness and safety**. These requirements mandate the need for testing, qualification and certification of components using the alternatives, with this having to be carried out on all components and then formally implemented through changes to design drawings and Maintenance Manuals. In some cases, this requires retesting of entire pieces of equipment 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 owners could not afford to undertake action across the range and numbers of components that still require the qualification, certification and industrialisation of alternatives. These activities themselves are costing the companies hundreds of millions of Euros across all uses of Cr(VI).

- **The strict regulatory requirements that must be met generate additional, complex requalification, recertification and 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 anodise sealing, 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 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 performance as the chromates. They will not be able to qualify and certify a proposed or test candidate for some components within a seven-year time frame. It is also of note that anodise sealing 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 MROs to move completely away from the use of the chromates in anodise sealing 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 OEM/MoDs ensure that substitution has been successful in practice. In this respect, **it is important to note that the use of the chromates is required 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**.

- **An Authorisation of appropriate length is critical to the continued operation of A&D 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 sodium chromate in anodise sealing 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 chromates in anodise sealing 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 EEA and UK A&D sector must ensure not only that it meets regulatory requirements in the EEA and UK, but also that it meets requirements in other jurisdictions to ensure that its final products can be exported and used globally.

[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)

2 Aims and Scope of the Analysis

2.1 Introduction

2.1.1 The A&D Chromates Reauthorisation Consortium

This combined AoA/SEA covers all of the soluble chromates for the specific use of anodise sealing as a post-treatment after anodising of metallic surfaces, in particular aluminium and its alloys, by the ADCR consortium members and companies in their supply chain. The ADCR has adopted a narrower scope for the use definition, to provide a more meaningful and specific description of use than the initial "parent" applications (see Section 2.2), which covered a wide range of surface treatments and substrates.

Anodise sealing is usually the final step in the anodising process. Anodise sealing can be performed with chromium trioxide (CT), potassium dichromate (PD), sodium chromate (SC) and/or sodium dichromate (SD) and is always carried out after the main process of anodising. It is mainly used to improve the resistance to corrosion of the treated metallic surface. After anodising, the surfaces of substrates are naturally porous and the unsealed coating cannot provide sufficient corrosion resistance without further treatment to close the micropores of the anodised surface.

The use of the chromates in anodise sealing is limited to those situations where it plays a critical (and currently irreplaceable) role in ensuring the protection of aluminium and other alloys to meet 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 their use 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 must also comply with numerous other 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 was collected from companies covering over 260 A&D sites in the EEA and UK, with data for 58 of those sites that that are anticipated to undertake anodise sealing used in developing 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 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 anodise sealing activities carried out within the EEA and UK, as it is fundamental to preventing corrosion of critical A&D components and final products. It forms part of an overall surface treatment system, which may include both pre- and post-treatments, aimed at ensuring the compulsory airworthiness requirements of aircraft and safety of military equipment.

Although the A&D sector has been successful in implementing alternatives for some components with less demanding requirements, the aim of this application is to enable the continued use of the chromates in anodise sealing beyond the end of the existing review period which expires in September 2024, 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 by anodise sealing 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 to chromates in anodise sealing. 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 the 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 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, downstream supply chains and, crucially, for the EEA and UK more 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 four chromates and risks to human health from the carcinogenic and repro-toxic effects that may result from exposures to the chromates.

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

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 anodise sealing.

- Chromium trioxide (includes "Acids generated from chromium trioxide and their oligomers", when used in aqueous solutions) EC 215-607-8 CAS 1333-82-0
- Potassium dichromate EC 231-906-6 CAS 7778-50-9
- Sodium dichromate EC 234-190-3 CAS 10588-01-9
- Sodium chromate EC 231-889-5 CAS 7775-11-3

The chromates shown 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 (CT) has been included in Annex XIV of REACH (Entry No. 16) due to its carcinogenic (Cat. 1A) and mutagenic (Cat. 1B) properties. As CT is mainly used in aqueous solution in anodise sealing, this combined AoA/SEA also covers the acids generated from CT and their oligomers. Sodium dichromate (SD; Entry No. 18), potassium dichromate (PD; Entry No. 19), and sodium chromate (SC; Entry No. 22) 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).

These chromates were granted authorisations for use in anodise sealing 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 the 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 via the ADCR dossiers.

Table 2-1: Overview of Initial Parent Applications for Authorisation

Application ID/authorisation number	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	Various applicants (CTAC consortium)	Surface treatment for applications in the aeronautics and aerospace industries, unrelated to functional chrome plating or functional chrome plating with decorative character
0032-05 REACH/20/18/21, REACH/20/18/23, REACH/20/18/25	Chromium trioxide	1333-82-0	215-607-8	Various applicants (CTAC consortium)	Surface treatment (except passivation of tin-plated steel (ETP)) for applications in various industry sectors namely architectural, automotive, metal manufacturing and finishing, and general engineering (unrelated to functional chrome plating or functional chrome plating with decorative character)
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)	Use of potassium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites, sealings of anodic films
0098-01 REACH/19/31/0 18UKREACH/19/31/0	Potassium dichromate	7778-50-9	231-906-6	HAAS GROUP INTERNATIONAL SP. Z.O.O (GCCA consortium)	Use of potassium dichromate for sealing after anodizing applications by aerospace companies and their suppliers
0099-02 REACH/19/32/2, REACH/19/32/3 20UKREACH/19/32/3	Sodium chromate	7775-11-3	231-889-5	Various applicants (GCCA consortium)	Use of sodium chromate for sealing after anodizing, chemical conversion coating, pickling and etching applications by aerospace companies and their suppliers

0043-02 REACH/20/5/3, REACH/20/5/5 24UKREACH/20/5/3	Sodium dichromate	10588-01-9	234-190-3	Various applicants (CCST consortium)	Use of sodium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites and sealings of anodic films
0097-01 REACH/20/14/0 35UKREACH/20/14/0	Sodium dichromate	10588-01-9	234-190-3	HAAS GROUP INTERNATIONAL SP. Z.O.O (GCCA consortium)	Use of sodium dichromate for sealing after anodizing applications by aerospace companies and their suppliers

2.3 Scope of the analysis

2.3.1 Brief overview of uses

2.3.1.1 Process description

Anodise sealing by the aerospace and defence industry and its supply chain in the EEA and the UK involves the use of chromium trioxide (CT), potassium dichromate (PD), sodium chromate (SC) and/or sodium dichromate (SD).

Anodise sealing in the aerospace and defence supply chains is carried out exclusively in industrial settings. Sealing is an important step employed in the anodisation process, principally to improve the corrosion resistance and corrosion protection of the anodised surface by ensuring that the pores of the porous oxide layer are sealed.

Aluminium and magnesium and their respective alloys can be processed by anodising. It should be noted however that the majority of the treated substrates are aluminium alloys. Examples of different types of anodise treatments referred to in this document include:

- Chromic acid anodise (CAA)
- Sulphuric acid anodise (SAA)
- Thin film sulphuric acid anodise (TFSAA)
- Tartaric sulphuric acid anodise (TSA)
- Tartaric sulphuric acid anodise long cycle (TSA LC)
- Boric sulphuric acid anodise (BSAA)

Anodise sealing is a chemical process which is mostly carried out by immersion of components in treatment baths. Typically, the treatment baths for anodise sealing 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 the present use. The immersion tanks can be placed individually or within a line of several immersion tanks. Usually anodising baths and anodise sealing baths are located in the same line. Most of the time, at least one rinsing tank with water is positioned after an immersion tank, for rinsing the anodise sealing solution from the component(s).

If the components that have been anodised using a swab/electrode (brush anodising) need to be sealed, they undergo a subsequent immersion anodise sealing process.

Figure 2-1: Treatment baths for anodise sealing

2.3.1.2 Choice of chromate

The chromates that can be used for anodise sealing are CT, SD, PD, SC or a mixture thereof. The four chromates do not differ in terms of functionality for anodise sealing. The reason why either one or the other is used, in most cases, is due to the particular chromate being defined in the specification of the customer for a particular component or application: such a specification by the customer often has a historical or empirical background.

When no specification is given by the client, the choice of the chromate by the site is often based on the practical reasons, e.g., because the site prefers to use one of the four chromates for other processes as well (economic feasibility), or the handling of one of the four is preferred.

2.3.1.3 Relationship to other uses

Anodise sealing is usually the final step in the anodising process and is always carried out after the main process of anodising (which can involve CT or be Cr(VI) free).

Figure 2-2: Schematic presentation of treatment steps

For those customers' specifications where sealing is not performed after anodising, primer application (with or without Cr(VI)) or Cr(VI)-free impregnation with petroleum jelly can be performed instead.

Referring to **Figure 2-2**, the pre-treatments and anodising process can involve the use of chromates or may be Cr(VI)-free. Inorganic finish stripping can also be required in case of defective finishing or as part of rework processes. Details of the pre-treatment processes of deoxidising/etching/pickling/desmutting using the chromates are described in the combined AoA/SEA for pre-treatments. Further details on the inorganic finish stripping process and the anodising process are described in their respective combined AoA/SEAs.

Please see the other ADCR combined AoA/SEA (as applicable) for further details on the availability of alternatives and the socio-economic impacts of a refused re-authorisation. It is important to recognise though that as these "uses" form part of a process flow, the benefits from the continued use of chromates in anodise sealing also reflect, to a degree, the continued use in the other processes.

2.3.2 Temporal scope

Because of the lack of viable and qualified alternatives for the use of CT, SD, PD and SC in anodise sealing for aerospace components, it is anticipated that it will take ADCR members and their supply chains between four and 12 years to develop, qualify, certify, and industrialise alternatives; the longest timeframes are required by MROs and companies acting as suppliers of defence products. 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>
<tr><th colspan="4">Table 2-2: Temporal boundaries in the analysis</th></tr>
<tr><th colspan="2">Present value year</th><td colspan="2">2021</td></tr>
<tr><th colspan="2">Start of discounting year</th><td colspan="2">2024</td></tr>
<tr><th colspan="2">Impact baseline year</th><td colspan="2">2024</td></tr>
<tr><th>Scenario</th><th>Impact type</th><th>Impact temporal boundary</th><th>Notes</th></tr>
<tr><td>"Applied for Use"</td><td>Adverse impacts on human health</td><td>12 years, following a 20 year time lag</td><td>Based on the length of requested review period</td></tr>
<tr><td rowspan="4">"Non-use"</td><td>Loss of profit along the supply chain</td><td>2 years assessed; 12 years relevant as will move out of EEA/UK</td><td>Based on ECHA guidance and the length of requested review period</td></tr>
<tr><td>Impacts on growth and GDP</td><td>12 years</td><td>Based on the length of requested review period</td></tr>
<tr><td>Disruption to EU society due to impacts on civil, emergency and military aviation, as well as defence equipment</td><td>12 years</td><td>Based on the length of requested review period</td></tr>
<tr><td>Loss of employment</td><td>1 to over 3 years</td><td>Average period of unemployment in the EEA (Dubourg, 2016)</td></tr>
</table>

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, Design-to-Build (DtB) and MROs operating in the EEA and UK. These 24 companies operate across multiple sites in the EEA, as well as in the UK and more globally. It is the leading OEMs and DtB companies that act as design owners and establish the detailed performance criteria that must be met by individual components and final products in order to ensure that airworthiness and military requirements are met. The consortium also includes 21 small and medium sized companies. As stakeholders using chromates within the A&D sector their information and knowledge supplements the aims of the consortium to ensure its success in re-authorising the continued use of the chromates. These companies are involved in BtP, DtB and MRO activities, sometimes acting as a combination of these.

With respect to anodise sealing, over two thirds of the larger ADCR members (17 of 24) support the use of chromates in anodise sealing; 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 anodise sealing to ensure it is available to their suppliers as well as for their own use. The most supported substance by members is sodium dichromate (12 members) followed by chromium trioxide and potassium dichromate (9 members) in the EEA.

Nearly half of the larger ADCR members (11 of 24) support the use of chromates in the UK with most members supporting potassium dichromate and sodium dichromate (8 members). As for EU REACH, the larger members are supporting both their use and use by their UK suppliers.

Table 2-3: Number of ADCR members supporting each substance for use in anodise sealing for their own activities or for their supply chain

	Chromium trioxide	Potassium dichromate	Sodium dichromate	Sodium chromate
EEA	9	9	12	5
UK	5	8	8	4

2.3.3.2 Suppliers of chromate substances and mixtures

The types of Cr(VI) products used in anodise sealing are listed in the table below. In broad terms, all the chromates are used as pure substance with sodium dichromate also used in a mixture form. Five generic chromate products have been identified as being used in anodise sealing; these are listed in **Table 2-4**.

Table 2-4: Products used in anodise sealing	
Product A	Solid Chromium Trioxide (flakes or powder), pure substance (100%
Product B	Solid Potassium Dichromate (flakes or powder), pure substance (100%)
Product C	Solid Sodium Chromate (flakes or powder), pure substance (100%)
Product D	Solid Sodium Dichromate (flakes or powder), pure substance (100%)
Product E	Aqueous solution of Sodium Dichromate as purchased (50-75.5% SD (w/w))

All the chromates are imported into the EEA/UK, with formulation of the sodium dichromate mixture taking place in the EEA. They are delivered to the downstream user either directly or via distributors. Some distributors operate across many EU countries while others operate nationally.

2.3.3.3 Downstream users of the chromates for anodise sealing

Anodise sealing within the A&D 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) – companies which design and build components;
- Build-to-Print (BtP) – companies that undertake specific processes, dictated by their customers, involving chromates on components; and
- Maintenance, Repairs and Overhaul (MRO) – companies that service aircraft, space and defence equipment.

It is 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 components they designed and manufactured which are already in use. Similarly, a company may fall into different categories depending on the customer and the component/final product.

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

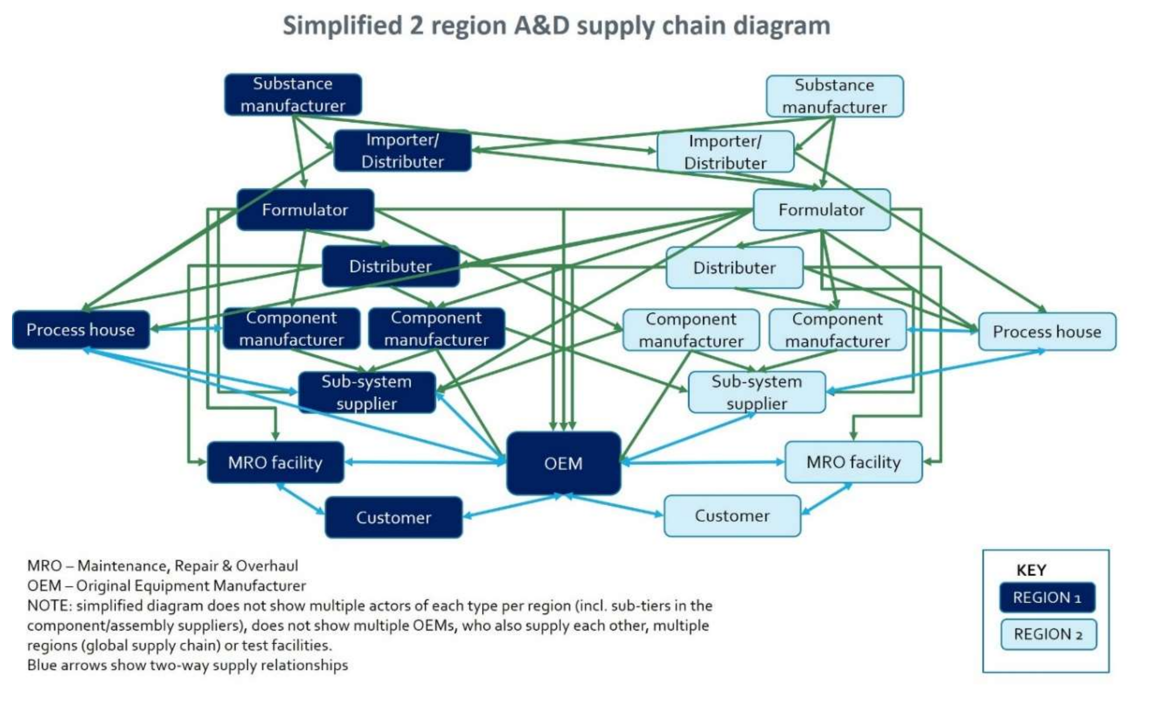


Figure 2-3: Complexity of supply chain roles and relationships within the A&D sector Two-way supply relationship are indicated by the double headed arrows

The assessment provided in this combined AoA/SEA is based on the distribution of companies by role given in **Table 2-5**, where this includes ADCR members, and their suppliers, involved in anodise sealing. It is important to note that these companies operate across multiple sites within the EEA and/or UK, with the total number of sites covered by the data provided also reported below. Note that the number of OEMs providing data for this SEA is smaller than the number of ADCR OEM members supporting this use, as some rely on operators within their supply chain to undertake such activities rather than carrying out anodise sealing themselves.

It is important to note the number of BtP companies and associated sites that provided data on anodise sealing activities. This has implications for the level of effort required by design owners (OEMs and DtB companies) in implementing an alternative throughout their value chains.

Table 2-5: Distribution by role of SEA questionnaire respondents providing information on anodise sealing

Role	Number of companies EEA & UK	Number of sites EEA & UK
OEMs	7	15
Design-to-Build	3	6
Build-to-Print	21	27
MRO mainly (civilian and/or military)	8	11
Total	39	59

2.3.3.4 OEMs, DtB and BtP Manufacturers

While the OEMs do undertake anodise sealing, it is clear that anodise sealing 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 aerospace, defence or space product, as well as the materials and processes to be used in manufacturing and maintenance. They may also undertake anodise sealing themselves, as part of their own manufacturing activities. OEMs, as design owners, 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. 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 formulations to be used to meet the performance requirements set by their customers. The components are then used by DtBs or OEMs in the final production of aircraft and defence and space 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 DtBs and BtPs tend to be located relatively close to their customers, which sometimes results in the development of clusters across the EEA and within the UK.

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 Cr(VI)-based anodise sealing as a portion 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.

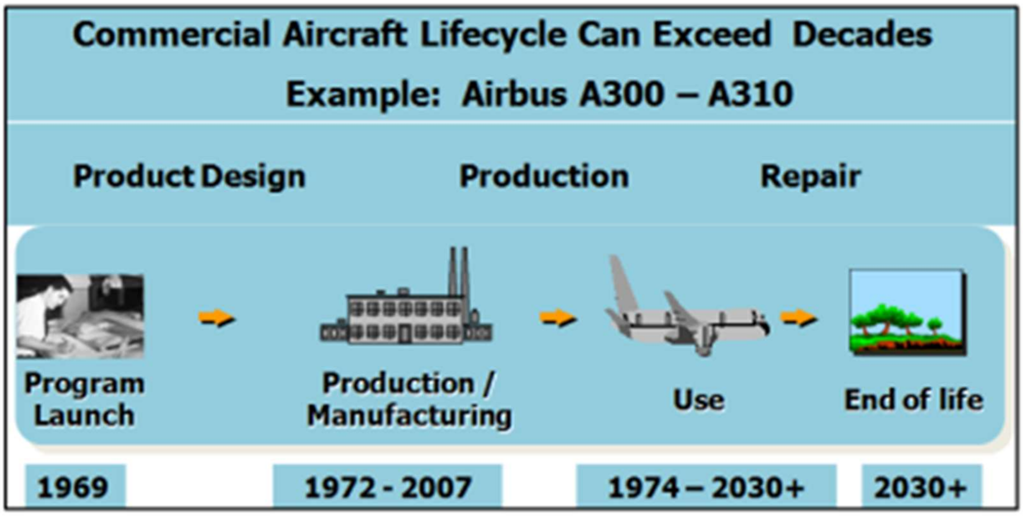


Figure 2-4: Commercial Aircraft Service Life, from ECHA & EASA (2014)[10]

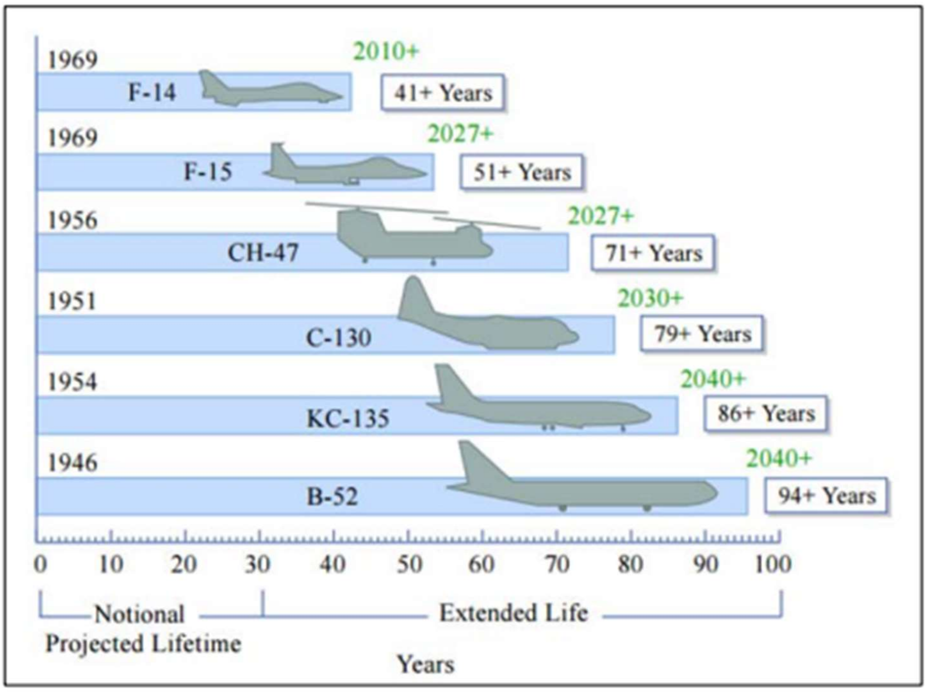


Figure 2-5: Life cycles of defence aircraft, from A Haggerty (2004)[11]

Even if new designs/components – coming onto the market in the short to medium term – might succeed in dispensing with the need for sealing of anodised components with Cr(VI), products

[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...

already placed on the market still need to be maintained and repaired using Cr(VI)-based anodise sealing until suitable alternatives are validated 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 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.

As a result, MROs (and MoDs) face on-going requirements to undertake anodise sealing in strict adherence to the requirements of qualified repair and maintenance schemes to ensure continued safe operation of the final A&D products. There will be an overlap between those companies undertaking work as MROs and those also involved as Design-to-Build suppliers.

2.3.3.6 Estimated number of downstream user sites

Based on the information provided by the companies, work involving anodise sealing for ADCR members is undertaken at numerous sites across the EEA with an average of ten sites per OEM/DtB company – although some of the larger companies have over 20 active sites (either their own or their suppliers).

Furthermore, there are countries – France, Germany, Italy and Poland - where several OEMs and DtB companies have major facilities. As such, there is likely to be some overlap since some BtP and DtB companies will carry out anodise sealing on components supplied to more than one OEM or DtB company in their area. Taking this into account, the estimated number of sites in the EEA has been taken as 125.

For the UK, based on the information provided by the OEMs and DtB companies, as well as considering relevant data, anodise sealing for ADCR members is undertaken at approximately 35 sites across the UK.

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 462 notifications relating to the various REACH Authorisations listed above, covering 608 sites across the EU-27 (and Norway). The distribution of notifications by substance and authorisation is summarised in **Table 2–6**. It is important to note that some sites may draw on more than one Authorisation for use of the same substance. 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. Note that Authorisations 20/18/21-25 relate to aeroderivative uses of chromium trioxide for surface treatment, but these uses will occur at the same sites as notifying for A&D uses and would therefore result in double-counting.

Table 2–6: Number of sites using chromates for surface treatment, including anodise sealing as notified to ECHA as of 31 December 2021

Substance	Authorisation	Authorised Use	Notifications	EU Sites
Chromium trioxide	20/18/14-20	Surface treatment of metals	263	357
Potassium dichromate	20/3/1	Surface treatment of metals	15	18
	19/31/0	Sealing after anodising	4	7
	20/2/1	Surface treatment of metals	53	61
Sodium dichromate	20/5/3-5	Surface treatment of metals	61	84
	20/14/0	Sealing after anodising	1	7
	20/4/1	Surface treatment of metals	58	67
Sodium chromate	20/18/14-20	Surface Treatment for aerospace	7	7
Total			462	608

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

There are more sites than notifications, reflecting the fact that some notifications cover more than one site[12]. However, several of the authorisation's cover 'surface treatment' which covers more treatments than just anodise sealing. As such, the number of sites undertaking anodise sealing will be far fewer than the indicated 608. Furthermore, some sites will be using more than one of the chromates for anodise sealing lowering the figure even further. Indeed, some ADCR members may use multiple chromates at an individual site for anodise sealing.

There is no comparable publicly available data for the UK, so estimates for the UK rely on information from the ADCR members and its SEA Expert Group. HSE did not provide data on the number of notifications made under UK REACH in time for incorporation into this assessment.

With these points in mind, the estimated 125 EEA sites to be covered by this combined AoA/SEA and by the ADCR applicants is believed to be consistent with the ECHA data on Article 66 downstream user notifications.

2.3.3.7 Geographic distribution

Based on the data provided by members and responses to consultation (SEA questionnaire), it is anticipated that the geographical distribution of sites is similar to that for other uses with the activities concentrated in France, Germany, Italy, Spain, and Poland. There are also sites in a number of other EEA countries, including e.g., the Czech Republic.

Table 2-7: Number of sites assumed to be undertaking anodise sealing based on distribution of sites notified to ECHA as of 31 December 2021, ADCR member data and SEA responses

Country	# Sites
Italy	30

[12] Article 66 reporting is by legal entity, which can have multiple sites using a chromate for anodise sealing. 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.

Poland	24
France	20
Germany	11
Spain, Romania, Belgium, Czech Republic, Netherlands (6 each)	32
Hungary, Portugal, Bulgaria, Malta (2 Each)	8
Total EU (plus Norway) sites	**125**
Total UK	**35**

2.3.3.8 Customers

The final actors within this supply chain are the customers of A&D final products treated via anodise sealing.

With respect to civil aviation, the global air transport sector employs over 10 million people to deliver some 120,000 flights and 10 million passengers a day in a normal year. In 2017, airlines worldwide carried around 4.1 billion passengers. They transported 56 million tonnes of freight on 37 million commercial flights. Every day, aeroplanes transport over 10 million passengers and around US$ 18 billion (€16 billion, £14 billion) worth of goods. Across the wider supply chain, assessment of subsequent impacts and jobs in tourism made possible by air transport, 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 1 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 anodise sealing.

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 products. 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

[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)

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 notification 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; and

- 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 of the chromates used in anodise sealing.

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 authorisations sought 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 7 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.

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 that Design-to-Build suppliers have 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 58 sites operated by the ADCR OEMs and their DtB and BtP suppliers was provided in response to these questionnaires. The information provided by the companies forms the basis for the SEA component of this document.

2.4.3.3 Maintenance, Repair and Overhaul suppliers

For consistency purposes, MROs were asked to also complete the BtP or DtB questionnaires. Again, these were supplied directly to MROs or were distributed by ADCR members to 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 Substance ID and Overview of the key functions and usage

The definition of anodise sealing, as agreed by ADCR members, is:

> *"After the anodising step, sealing with a solution comprising chromium trioxide, sodium dichromate, potassium dichromate, sodium chromate, sodium dichromate or a mixture thereof. During the sealing, chromate oxide and hydroxides precipitate in the pores of the previously anodised oxide layer and are hydrated. By this process, the pores are closed and an adequate corrosion resistance is provided to the surface."*

As indicated in Section 2, the chromates 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
Sodium chromate	EC 231-889-5	CAS 7775-11-3

3.1.1.1 Process steps and overview of key functions

As illustrated in section 2.3.1.3, there are various steps in the surface treatment process, which can be classified into pre-treatment processes, main treatments and post-treatment processes. The use of chromates for sealing after anodising in the post-treatment step is crucial to ensure the quality of the product and to meet the requirements of the industry. However, further Cr(VI) compounds might also be used within the whole process chain (i.e., the pre-treatment and main process step) that are not subject to this AoA. As such, although single process steps can be assessed individually, they cannot be seen as standalone processes but as part of a whole process chain (GCCA, 2016).

Anodising is an electrolytic oxidation process where the surface of a metal is converted into an oxide which has desirable functional properties. The oxide layer that is formed partly grows into the substrate and partly grows onto the surface (CTAC, 2015). It is typically performed in an acidic solution which may contain, for example, boric-sulphuric acid, sulphuric acid, phosphoric acid, tartaric-sulphuric acid, or chromic acid.

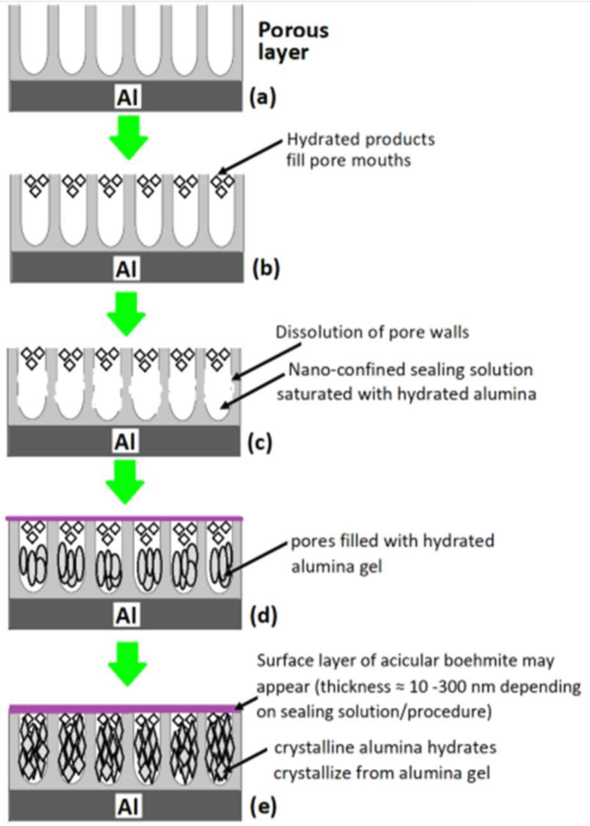
Aluminium and magnesium, and their respective alloys, can be processed by anodising, however aluminium represents the very large majority of the treated substrates. The component to be treated forms the anode of an electrical circuit, whilst the respective cathode is inert. The electric current can be varied which leads to oxidation of the base metal at the anode with the formation of aluminium oxides on the surface.

The surface of a substrate after anodising is made up of a large number of microscopic hexagonal cells, each with a central core (Hao and Cheng, 2000). The outer layer of the anodised surface is therefore naturally porous and may allow corrosive chemicals to penetrate and come into contact with the underlying substrate. Consequently, the micropores of the surface must be closed through a sealing post-treatment step to deliver adequate corrosion resistance and active corrosion inhibition, delivered by Cr(VI), required for certain aerospace components. During the sealing process, chromate oxide/hydroxide precipitate in the pores of the previously anodised oxide layer and are hydrated under carefully controlled conditions. By this process, the pores are closed, and an adequate corrosion resistance is provided to the surface (GCCA, 2016). The thickness and quality of the anodise coating (porosity, pore microstructure etc.) depends on pre-treatments and processing conditions and must be carefully controlled.

The key functions of the chromates in anodise sealing are therefore:

- Corrosion resistance; and
- Active corrosion inhibition.

The anodic oxide structure, formed on aluminium after anodising, is comprised of two layers; a thicker and porous outer layer (measured in µm) and a much thinner but compact inner layer - the barrier layer (measured in nm). A surface view of an anodised aluminium substrate prior to sealing exhibits tubular shaped pores more or less normal to the interface, with pore diameter reported in the range of 10 to 20 nm for a sulphuric acid (17.5% v/v at 19 ± 1 °C) anodised 99.99% aluminium sample. The pore size is predominantly dependent on the electrolyte used and independent of anodisation voltage, the pore wall thickness and the barrier layer thickness are primarily functions of anodisation voltage and are less affected by the electrolyte used (Ofoegbu, Fernandes and Pereira, 2020).



Structure of the anodized layer on aluminum prior to sealing and changes that occur during sealing; (**a**) anodized aluminum prior to sealing, (**b**) pore mouths filled with hydrated products, (**c**) dissolution of pore walls, (**d**) precipitation of hydrated alumina gel in pores and emergence of surface layer of acicular boehmite, and (**e**) crystallization of crystalline alumina from alumina gel.

Figure 3-1: Structure of anodised layer on aluminium during sealing process (Ofoegbu, Fernandes and Pereira, 2020)

Figure 3-1 details the changes in structure of an anodised layer on aluminium during the sealing process. As stated above, endowing enhanced and adequate corrosion resistance of the anodised layer is a key function of the sealing treatment which is the subject of this combined AoA/SEA, therefore the pores must be filled with a substance which provides corrosion protection. Adding Cr(VI) to the sealing process delivers active corrosion inhibition functionality as illustrated in **Figure 3-2**.

The hydration process (in the course of sealing after anodising) is pH dependent, but in all cases, the chromate is absorbed to the anodised aluminium surface. Depending on the pH, Cr(VI)-based sealing forms either aluminium oxychromate (equation 1) (at pH lower than 6) or aluminium dioxychromate (equation 2) in the coating micropores (CCST, 2015)

Equation **1**

$AlOOH + HCrO_4^- \text{-->} AlOHCrO_4 + OH^-$

Equation **2**

$(AlO(OH))_2 + HCrO_4^- \text{-->} (AlO)_2CrO_4 + OH^- + H_2O$

The final step closes the pores by contact with hot water and locks in the chromate according to equation (3):

Equation 3

$Al_2O_3 + H_2O \rightarrow 2\ AlO(OH)$

The hydrated aluminium oxide (boehmite) has a larger volume than aluminium oxide, therefore the pores are closed.

Cr(VI) has two-fold corrosion inhibition properties. Firstly, as described above, it combines with the naturally occurring aluminium oxide to form a mixed oxide layer that prevents oxygen from contacting the aluminium and thus provides a corrosion inhibition layer. Secondly, should the chromium oxide layer be damaged (e.g., scratched sufficiently deeply to reveal bare aluminium) then, after the initial creation of a thin aluminium oxide layer, the Cr(VI) ion, in its hydrated form, diffuses into the aluminium oxide converting it to chromium oxide thus re-establishing a corrosion inhibiting layer, albeit a layer that is less effective than before. The areas close to the damage will become depleted in Cr(VI) thus reducing the corrosion protection offered in the immediate area. However, the diffusion mechanism operates continuously allowing further diffusion of Cr(VI) ions from more distant areas into the depleted area. This dynamic process represents the "self-healing" mechanism that to date, appears to be unique to Cr(VI) (CCST, 2015).

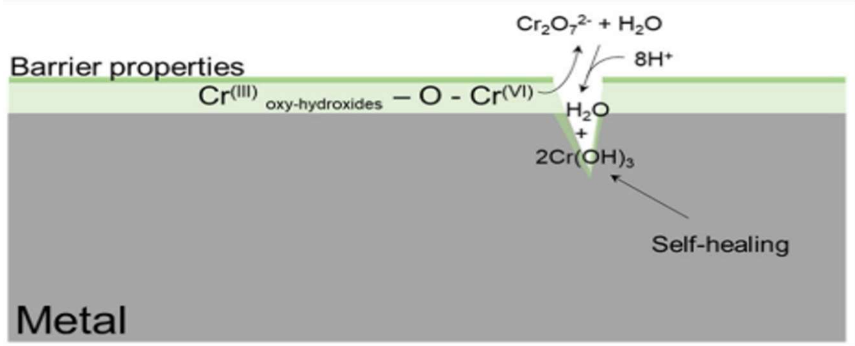


Figure 3-2: Self-healing mechanism afforded by Cr(VI) on metal substrates (Gharbi *et al.*, 2018)

Sealing is often performed in a hot aqueous chromate solution (typically > 95°C but below the solution's boiling point) typically using either sodium dichromate, potassium dichromate, chromium trioxide, or sodium chromate. For some applications, hot water or salts of other metals are used for sealing, however a hot water seal alone does not provide sufficient corrosion protection. Chromium trioxide conversion coating solutions can also be used for the purpose of sealing after anodising (CTAC, 2015).

3.1.1.2 Usage

Components that may be treated with the Annex XIV substance

As detailed above, anodise sealing, 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 (radar domes)
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, 2017)			

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 in key functions, since some or all the following consequences may occur:

- 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 components;

- 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 aircraft 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 components

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; and
- D-checks include major structural inspections with attention to fatigue damage, corrosion, etc. which 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(VI)-free system would lead to a significant reduction in the maintenance interval, potentially doubling the frequency of the checks described above (GCCA, 2017).

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 on 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

[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

of Cr(VI) is essential as the treatments on some A&D components cannot be inspected, repaired, or replaced during the life of 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 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 3-3**).

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 can be 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

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

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.

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 standards, 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.

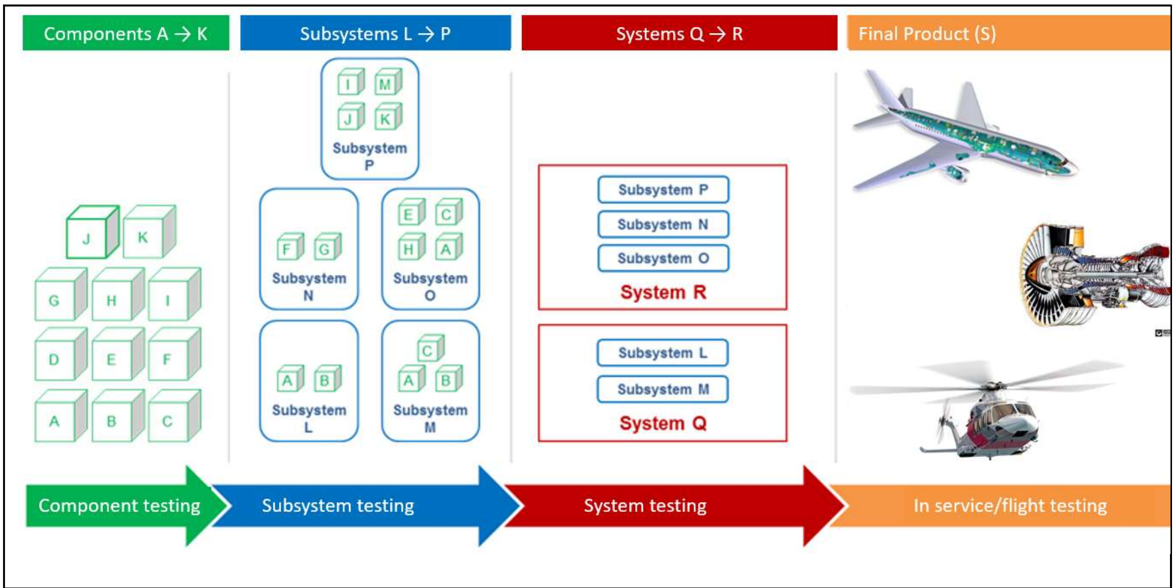


Figure 3-3: Assessment requirements in the implementation of alternatives
Source: Adapted from GCCA white paper

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.

Table 3-2: Technology Readiness Levels as defined by US Department of Defence		
TRL	**Definition**	**Description**
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 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 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	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.

Table 3-3: Manufacturing Readiness Levels as defined by US Department of Defence		
MRL	Definition	Description
	in place to begin Full Rate Production	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 the 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 3-4**, 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.

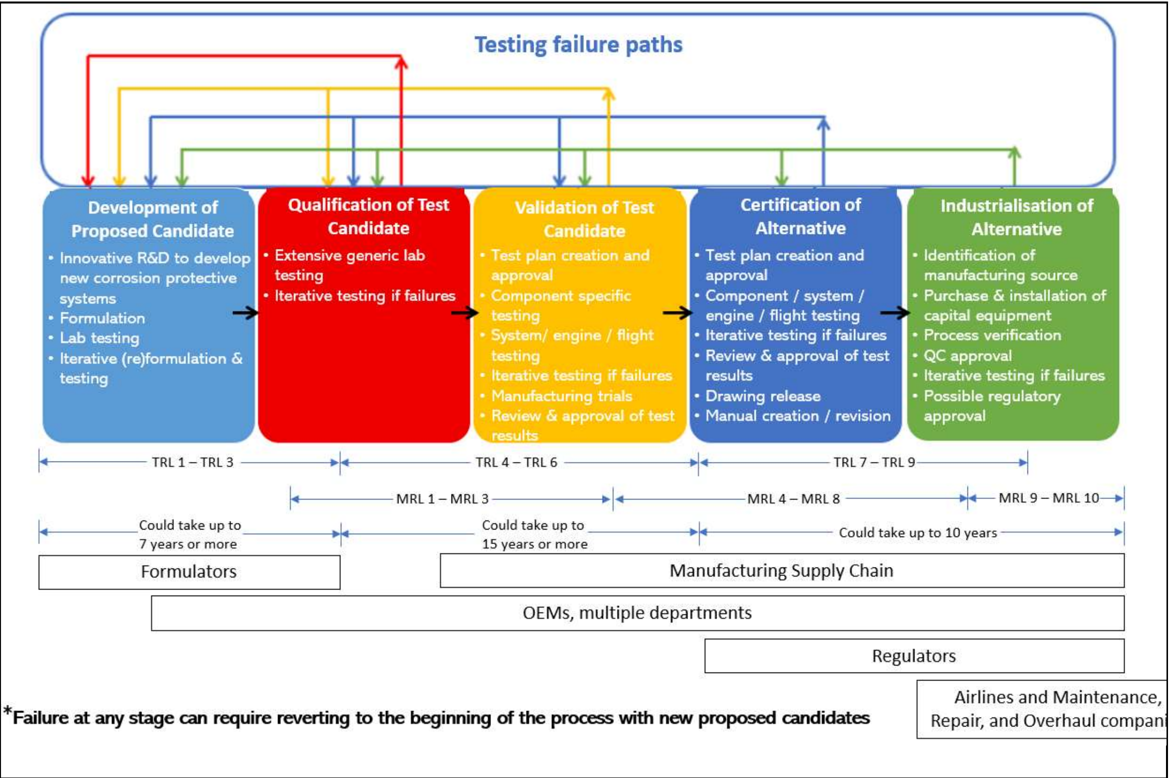


Figure 3-4: Schematic showing the key phases of the substitution process.
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note 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 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 3-4** above).

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.

[18] GCCA

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 3-5** 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 standards/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:

> "*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.*"

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

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

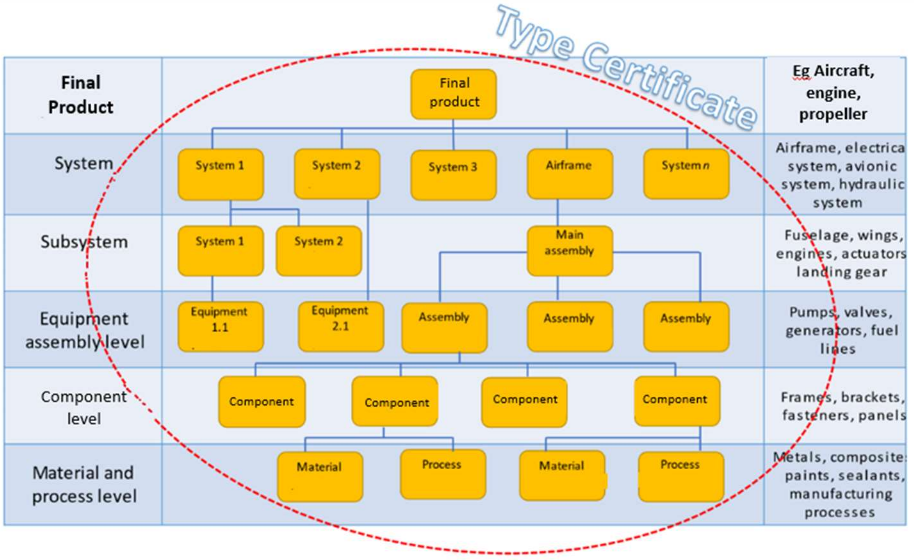


Figure 3-5: System hierarchy of a final product showing the interconnection of each level in the system hierarchy, and how changes at a lower level have impacts on higher levels.
Source: ADCR member

After the alternative is certified, design drawings and part 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 programme, 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 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 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 programme, 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, a simplified example of the process, described above and leading to industrialisation of the alternative, is illustrated in **Figure 3-6** below.

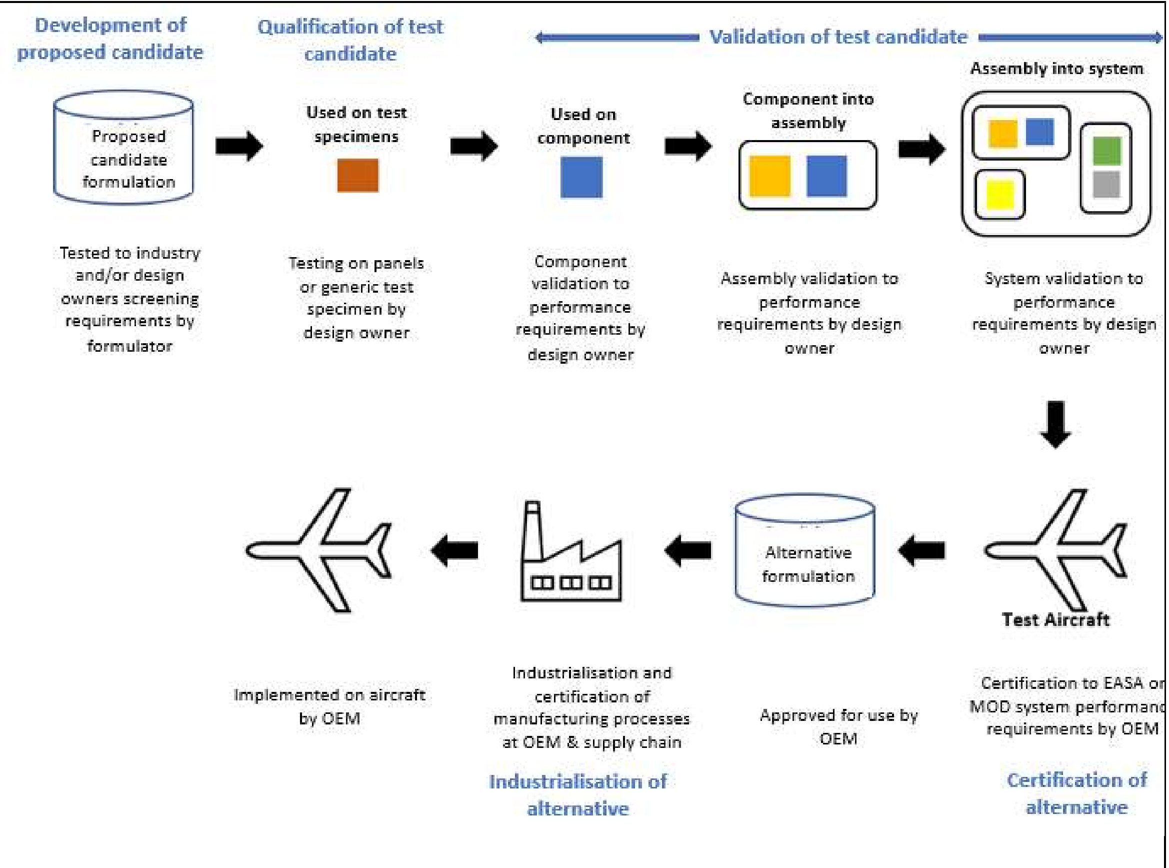


Figure 3-6: Process to Certify a Formulation for use on Aircraft.
Formulations used in production have completed this process. New or reformulations must follow same process for use in production.
Source: ADCR member

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 anodise sealing

3.2.1.1 Introduction

The development of technical feasibility criteria for proposed candidates to replace the use of Cr(VI) in anodise sealing has been based on a combination of assessment of the parent AfAs, consultation with ADCR consortium members, and non-exhaustive reviews of available scientific literature and patents within the field.

Using detailed written questionnaires (disseminated throughout 2021 and 2022) the ADCR consortium members were asked to thoroughly describe the technical feasibility criteria and associated performance requirements that Cr(VI) imparts in this use, and that any test candidates (substances and technologies) would also need to impart in order to deliver the functions attributed to anodise sealing.

In parallel, scientific literature describing specificities of anodise sealing and the assessment of the technical feasibility of specific alternatives was collected and analysed (with the assistance of the ADCR consortium members) and incorporated into the analysis.

The technical feasibility criteria that shall be used in the assessment of selected alternatives are as follows:

- Corrosion resistance;
- Layer thickness;
- Chemical resistance;
- Adhesion promotion (Adhesion of subsequent layer); and
- Impact on fatigue life.

As noted above, this combined AoA/SP and SEA covers the use of multiple chromates for anodise sealing; chromium trioxide (includes “acids generated from chromium trioxide and their oligomers"), sodium dichromate, potassium dichromate and sodium chromate.

In the context of technical feasibility, it is important to note that the mode of action for each of the key functions clearly describes the contribution of the Cr(VI) species in the delivery of anodise sealing. By extension, the donor chromate substance containing Cr(VI) is responsible for delivering the functions attributed to Cr(VI) within the over-arching use. As such the discussion of technical feasibility and the functions imparted by anodise sealing encompasses the mode of action by which Cr(VI) is involved in the delivery of the key functions.

When considering corrosion resistance, a function imparted by anodise sealing with Cr(VI), the mode of action of Cr(VI) makes use of the chemical process by which the Cr(VI) is reduced to Cr(III) and the formation of the physical chromium oxide barrier layer. Mode of action is important to consider when analysing test candidates; how the chemistry of Cr(VI) contributes to a particular function, what are the benefits from using Cr(VI), whether these benefits are replicated by another substance or process and, if not, what the implications are on the performance requirements of the anodic seal.

The discussion below explains the relevance and importance of each of the technical feasibility criteria in more detail, capturing key performance requirements of the criteria in the context of the overall sealing process.

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, 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 'anodise sealing'. 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 and support to the documents controlled by the manufacturer and/or design owner of the component. As such, these documents are typically classified as confidential business information.

In the context of the 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, inferior performance characteristics, 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, it 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 3-7**. 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 3-7: 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 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.

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 sealing process and it is not possible to consider one criterion independently of the others when assessing proposed candidates. The individual criteria collectively constitute part of a system delivering the use anodise sealing with a degree of dependency on one another.

There are several types of anodise coatings which are selected based on their suitability for the particular component (substrate, fatigue requirements, tolerance related thickness requirements, whether they are painted). The performance of Cr(VI)-free sealing solutions varies not only with the sealing process parameters but also with the anodise process and any pre-treatments. The substitution of a treatment system of which sealing is just a single part requires a complex approach.

The requirements for anodise sealing (for unpainted corrosion resistance) and for paint adhesion (which is frequently required to provide additional corrosion protection) are contradictory. Excellent paint adhesion is produced by mechanical interlocking of the paint primer layer with the pores in the anodised layer. The naturally porous surface containing many cavities, which is created by anodising, supports this adhesion of paint to the substrate, however by sealing the pores, the adhesion is decreased. Extensive testing is required to verify that both the corrosion resistance and paint adhesion requirements are met on the substrate which has been anodised and sealed.

As better adhesion to subsequent coatings is obtained without sealing, where painting of a sealed surface is required, a chromated primer is often applied after the Cr(VI) sealing process to improve adhesion of the paint. Combining a Cr(VI)-free alternative to anodise sealing, with a Cr(VI)-free primer (without any reduction in adhesion) remains an ongoing challenge to the A&D industry.

Each process change, including the introduction of alternatives, requires an extensive suite of documentation changes to meet certification and approval requirements. Therefore, it is often more time and cost efficient to implement Cr(VI)-free test candidates for all affected uses at the same time to ensure a stable treatment system. This unified approach minimises the risk of failure of the treatment system from implementing incompatible Cr(VI)-free test candidates for different types of anodise (e.g., TSA vs. SAA) at different times. When anodise sealing is required, it is often necessary to approve test candidates for both the anodising and anodise sealing treatments together to ensure both are compatible with one another.

A further consideration is alignment with development of other Cr(VI)-free processes used alongside anodise sealing or for repairing sealed anodic coatings, for example chemical conversion coating. Almost all anodised components are subject to 'touch-up' with a conversion coating, as the area of the component used as the contact point will not be immersed in the anodic coating. Similarly the 'touch-up' with a conversion coating will often be used in the repair of a damaged anodic layer. Parallel development is necessary as a Cr(VI)-free repair process is required to support the introduction of the Cr(VI)-free use. Subjecting all changes across the system to rigorous certification requirements in parallel maximises the opportunity for implementation of the Cr(VI)-free system within a shorter timeframe. Where a solution is implemented for anodise sealing, compatibility with the alternative chemical conversion coating must be ensured.

The link with chemical conversion coating is particularly pertinent here. For many A&D companies who require anodise sealing as part of their process, the number of sealed components is relatively small, particularly when compared to the number which require chemical conversion coating. Due to the financial implications of sourcing formulations in low quantities, and the space required to implement two processes, for most members it will be a key requirement that the same alternative can be used as both a chemical conversion coating and anodise sealing solution.

The GCCA application for authorisation (GCCA, 2017) 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 are listed below[21]:

- Hardware[22] base alloy(s);
- Contact or mating surfaces with other components;
- Exposure to fluids;
- Structural stress and strain; and
- External environment.

[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

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

- Exposure to chemicals e.g., de-icer, 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 component and the performance requirements which any alternative delivering the surface treatment 'system' must meet. Due to the complexity of these assemblies and the variety of environments encountered in service, a single alternative may not provide a universal solution to delivery of all technical criteria under all scenarios of use.

3.2.1.3 Technical feasibility criterion 1: Corrosion resistance

The A&D industry has very demanding requirements for corrosion resistance, particularly for unpainted components, which cannot be met by unsealed anodising. As discussed in section 3.1.1.1, the anodising process creates a porous oxide layer. The porous structure provides excellent adhesion for subsequent paint layers, but the pores also provide open entrances for corrosive media to access and oxidise the substrate if they are not sealed. During the sealing process, the open pores on the surface of the anodised component will be closed and blocked. Chromates infiltrated in the pores or present in spot locations in the barrier layer act as active corrosion inhibitors and contribute to the corrosion performance. In general, it is even more challenging to achieve corrosion resistance on thinner/lower weight anodised coatings (such as thin film sulphuric acid anodise) without the use of Cr(VI) sealing.

The nature of the substrate is important when it comes to the corrosion protection which sealing is required to provide. For example, fatigue sensitive components often require the use of high strength, low weight aluminium alloys. These typically contain copper and/or iron as alloying elements, which renders them more susceptible to the reactions leading to corrosion, and therefore a higher level of corrosion resistance is required from the sealed anodised layer.

Any proposed candidate for the sealing process must meet the requirements of the design owner, for the particular component to which it is to be applied, in terms of number of pits per unit of surface area over a given length of time, in the neutral salt spray test (which may be conducted according to ASTM B117 or other similar test methods). If the proposed candidate passes these initial screening tests, more stringent bespoke tests are employed for the test candidate.

3.2.1.4 Technical feasibility criterion 2: Layer thickness

For components with narrow geometric tolerances, and those that are sensitive to fatigue strength loss, the thickness of the sealed anodic layer cannot cause the component to exceed the dimensional tolerances on the design plan. As the sealing process takes place mostly within the porous oxide structure of the anodic layer, the thickness the Cr(VI) seal will add to the treated component will be negligible (<1µm). For close tolerance components particularly, any alternative sealing process should similarly only minimally alter the layer thickness of the previously anodised component to ensure redesign is not required and that the fatigue strength of the substrate is not adversely impacted.

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

3.2.1.5 Technical feasibility criterion 3: Chemical resistance

In addition to environmental exposures (such as sea water, acid rain, and volcanic ash), sealed anodised layers may be exposed to various other media. These include fuel, hydraulic fluids, engine and gearbox oil, engine corrosion inhibiting fluid, corrosion preventive compounds, de-icing fluids, and cleaning compounds. MIL-STD-810 Method 504 provides a list of common fluids used in chemical resistance testing and is an example of a method which may be used to assess chemical resistance.

The method by which Cr(VI) enhances corrosion resistance, by filling the pores present on the anodised surface as described above, should also act to provide chemical resistance. With any proposed candidate for the replacement of Cr(VI), it must be ensured that resistance to chemicals is retained.

3.2.1.6 Technical feasibility criterion 4: Adhesion promotion (Adhesion of subsequent layer)

Cr(VI), when used in the anodise sealing process, does not have any effect on promoting adhesion. As described above, the effect is in fact the opposite. Sealing reduces the porous surface of the anodised layer and decreases the surface area onto which primers, paints or adhesives could otherwise adhere. For this reason, for some A&D companies anodise sealing is limited to those components which will remain unpainted. Other members indicated however that, despite the reduced adhesion, a sealed anodic coating is still preferable for painted components to ensure the component will continue to be adequately protected from corrosion in the event of the corrosion resistant paint peeling off.

For a proposed candidate, adhesion is generally tested by a method such as ASTM D3359 or ISO 2409, and members reported that it would be essential for painted components that any new sealing technique provides equivalent performance to the existing Cr(VI) seal.

3.2.1.7 Technical feasibility criterion 5: Impact on fatigue life

The anodise process selected for a particular component is often based on the individual characteristics of the component rather than its corrosion resistance. A prime example is fatigue sensitive components in which one of the key requirements is the maximum allowable anodise coating weight, which is a function of the alloy in use and fatigue requirements for the component. The established limits of coating weight or thickness must be strictly met when assessing a proposed candidate to replace Cr(VI) in the sealing process.

Fatigue can also be affected by a number of other factors, including temperature. If a proposed candidate for the replacement of Cr(VI) in anodise sealing requires thermal treatments at temperatures greater than those used in the incumbent process, this could lead to cracking of the anodise layer through thermal strain, and a negative impact on fatigue life.

3.3 Market analysis of downstream uses

The market analysis of downstream uses is provided in section 4.2.

3.4 Efforts made to identify alternatives

3.4.1 Research and Development

3.4.1.1 Past Research

Regarding 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), this should be set against the diversity of applications of aluminium across the sector. Aerospace and Defence sector finished products include fixed wing aircraft, rotary wing, powered lift aircraft, land-based equipment, military ordnance, and spacecraft. Examples of finished products within the scope of the ADCR are shown in **Figure 3-8**. Consequently, the industry requires a diverse range of metal alloys to fulfil all performance requirements that these various applications demand. Considering these factors, combined with the strict safety and certification requirements as described in Section 3.1.2, the pace of research and development will not be uniform across the sector.

Figure 3-8: Examples of finished products in A&D sector
Rheinmetall – Systems & Products, n.d.; Royal Navy, 2021

As highlighted throughout, 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 plus aircraft in service. The demanding nature of service environments in the aerospace and defence sector, and potential for serious consequences if only one component should fail, dictate that very stringent measures are adopted and enforced when developing and qualifying Cr(VI)-free test candidates.

Various R&D activities were reported within applications for authorisation relating to this combined AoA/SEA for the use 'anodise sealing'. Proposed candidates for the replacement of Cr(VI) in anodise sealing are shown in **Table 3-4**. This list comprises all the alternatives that were reported in the parent AfAs. Note that not all proposed candidates reported in the parent AfAs have been the focus of research and progression by the members.

Table 3-4: Cr(VI)-free proposed candidates reported in parent AfAs[24]

Proposed candidate	Implementation status (TRL level) reported in parent AfA	AfA ID
Cr(III)-based surface treatments	Implemented for limited, less demanding aerospace applications only. Additional substitution activities reported to be between TRL 2-4.	0032-04 0032-05 0043-02 0044-02 0097-01 0098-01 0099-02
Silane/siloxane and Sol-gel coating	Concluded not to be technically feasible as an alternative to Cr(VI)-based sealings.	0032-04 0032-05 0043-02 0044-02 0099-02
Water-based post-treatments	Neither hot water sealing as a stand-alone nor hot water sealing plus additives were identified as able to fulfil the high corrosion prevention requirements, which are essential for numerous aerospace companies, especially for structural parts.	0032-04 0043-02 0044-02 0099-02
Molybdates and molybdenum-based processes	Concluded not to be technically feasible as an alternative to Cr(VI)-based sealings.	0032-04 0043-02 0044-02
Manganese-based processes	Concluded not to be technically feasible as an alternative to Cr(VI)-based sealings.	0032-04 0043-02 0044-02 0099-02
Organometallics (Zr- and Ti-based products)	At a very early stage of development (TRL 2).	0097-01 0098-01 0099-02
Cold nickel sealing[(a)]	May be technically suitable to fulfil the corrosion and adhesion requirements for the military aerospace sector, but	0043-02 0044-02

24 Adopted opinions and previous consultations on applications for authorisation - ECHA (europa.eu)

Table 3-4: Cr(VI)-free proposed candidates reported in parent AfAs[24]		
Proposed candidate	**Implementation status (TRL level) reported in parent AfA**	**AfA ID**
	the alternative is neither qualified for the military aerospace sector nor for the civil aerospace sector.	
Nickel acetate[(a)]	Implemented alternative in narrowly defined aerospace applications. Not technically feasible as a general alternative.	0097-01 0098-01
Nickel fluoride[(a)]	Not technically feasible as a general alternative.	0097-01 0098-01
[(a)]Represents a regrettable substitution candidate due to classification of nickel salts as cat. 1A carcinogens.		

Within the period since the parent authorisations were granted, further R&D has been conducted by members on some of the proposed candidates shown in **Table 3-4** above.

Cr(III)-based surface treatments: Of those proposed candidates reported in the parent AfA, Cr(III)-based surface treatments represent those into which the most R&D has been conducted within the period since the parent authorisations were granted. One member reported that a Cr(III) solution has been industrialised for components treated with SAA, where a greater layer thickness is permissible. Most members reported that Cr(III) alone does not meet the requirement for corrosion protection in the neutral salt spray test when used following their chosen anodising process, however when an organometallic substance (zirconium) is added to the Cr(III) solution, and a second step is added to the process, the treatment has progressed to being a viable test candidate for most members.

A number of different Cr(III) formulations have been progressed, with a second treatment step involving either hot-water sealing (with or without additives) or a solution containing a rare-earth element. Further discussion of these test candidates is to be found in section 3.5.

Silane/siloxane and sol-gel coatings: One member reported that sol-gel coatings continue to be investigated by some formulators, and that they had progressed to TRL 3, demonstrating proof-of-concept. Whilst further R&D has been conducted by design owners on sol-gel coatings as an alternative to the standalone use of chemical conversion coating, no members reported any further progression for their use as an anodise sealing post-treatment due to the insufficient level of corrosion resistance previously identified and reported in the parent AfAs. It was further reported that, following the Cr(VI)-free process tartaric-sulphuric acid anodising (TSA), compatibility between the unsealed anodise layer and sol-gel is difficult to achieve.

Water-based post-treatments: Although not stated in the parent AfAs, a number of members reported that hot water sealing is an established alternative which has reached TRL 9 and is approved by various OEMs, however, importantly this is only for those components where corrosion resistance and adhesion to a subsequent layer are **not** a requirement. Multiple members reported having investigated hot water sealing as a post-treatment following sulphuric acid anodising (SAA) in the period since the parent authorisations were granted, however all reported that on aluminium alloys it was unable to meet the requirements of the neutral salt-spray test for corrosion resistance. The process therefore did not progress beyond TRL 2 for those components where corrosion resistance is a key performance requirement.

To further highlight the significant efforts being made by the aerospace and defence sector to substitute chromates, ongoing and past 'R&D collaborations' are identified below. It is noted that collaborations are mentioned within the parent AfAs associated with the ADCR consortium Review Reports, e.g., the Global Chromates Consortium for Aerospace (GCCA), Chromium Trioxide Authorisation Consortium (CTAC) and Chromium VI Compounds for Surface Treatment (CCST). This review focuses upon collaborations which include research into the development of alternatives for anodise sealing.

A summary of the collaborations relevant to anodise sealing is provided below.

Please note that for many projects only limited information is publicly available due in part to maintaining intellectual property rights 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 (total funding £1.06 million). Phase one and two included testing of the two-step Cr(III)-based solution described above;

- **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). The report summarises an extensive variety of research initiatives and the organisations, including ADCR members, involved in past and ongoing development of Cr(VI)-free technologies. Noblis identifies TCP (trivalent chrome passivate) as being capable of sealing sulphuric acid anodising layers, although acknowledges that this process has not yet been qualified. The report also states that some European organisations are reformulating sol-gel for anodise sealing, however had not yet finished testing. No information is provided on which European organisations participated in the testing programme (Noblis, 2016);

- **International Aerospace Environmental Group (IAEG) Replacement Technologies Working Group (WG2),** formed in 2011 provides a global framework for aerospace and defence manufacturers, including a number of companies within the ADCR, to collaborate on widely applicable, non-competitive alternative technologies. Interested member companies have worked on information exchange/survey projects on anodise sealing as well as passivation of corrosion resistant steel, functional chrome plate and corrosion inhibiting primers (GCCA, 2017).

3.4.2 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.

3.4.3 Data Searches

3.4.3.1 High level patent review

A patent search was performed with the aim of identifying examples of potential technologies related to anodise sealing. The search was performed using Espacenet[25], 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).

By way of example, the search term "Anodised (anodized) sealing chromate" was filtered via the main group classification filter C23 (description below):

- 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

This search returned 104 results. These 104 patents were screened by reading of the abstracts, and discussion with ADCR members, and those identified as potentially relevant to this AoA are presented in **Table 3-5** below.

Table 3-5: Patent search technology summary

Title	Patent publication reference	Summary
Post-treatment for anodised aluminum	US2002117236A1	The composition comprises an acidic aqueous solution having a pH ranging from about 2.5 to 4.5 containing effective amounts of trivalent chromium salts, alkali metal hexafluorozirconates, an alkali metal fluoro-compound e.g., fluoroborates and/or fluorosilicates, and effective amounts of water soluble thickeners and surfactants.
Non-chromium coatings for aluminum	US2007095436A1	The process comprises pre- or post-treating said aluminium with an acidic aqueous solution comprising, per litre of solution, from about 0.1 to 22 grams of at least one fluorometallate, about 0.1 gram up to the solubility limit of a water soluble cationic or divalent zinc compound and, optionally, effective amounts of water-soluble thickeners and/or surfactants.
Systems and methods for treating a metal substrate	WO2018031986A1	A system that includes a sealing composition having a pH of 9.5 to 12.5 and comprising a lithium metal cation and an aqueous composition for contacting a surface of the metal substrate following contacting with the sealing composition.

[25] Espacenet Patent Office (2022): Available at Espacenet – patent search accessed 24 August 2022

Table 3-5: Patent search technology summary		
Title	**Patent publication reference**	**Summary**
Sealed anodic coatings	KR101871702B1	The crystalline sealed anodised coating impregnates the pores of a metal or metal substrate with metal precursor species, converts the metal precursor species into metal hydroxide, heat treatment to heat and remove moisture, and metal oxide solids of metal hydroxide products. It can be manufactured by enhancing the phase transformation of the furnace and bonding with the metastable metal oxide material in the pore structure of the metal or metal alloy substrate, and hot water sealing.
Conversion coating and anodizing sealer with no chromium	US2010314004A1	Aqueous acidic coating solutions containing a water-soluble divalent zinc compound, a complex fluoride compound, and an organic inhibitor for improving the corrosion resistance and adhesive bonding characteristics of aluminium, aluminium alloys, anodic coatings, and sacrificial coatings, are disclosed. Suitable organic inhibitors include oximes, such as salicylaldoxime, and/or quinolines, particularly 8-hydroxyquinoline, and mixtures thereof.
Anodization method for corrosion protection of aluminium alloy elements used in aircraft structure	JP2020056097A	Dipping the element in a bath in which a solution of chromium, with an oxidation number of +3, and zirconium ions and fluorides are present, in order to carry out a first sealing step; and subjecting the element to final washing and dipping in a tank of boiling water, and then drying the element.
Silane/rare-earth composite protective film on aluminum or aluminum alloy surface and preparation method thereof	CN102677039A	The preparation method comprises the following steps: sequentially immersing pre-treated aluminium or aluminium alloy in a treatment fluid A and a treatment fluid B, and curing at 60-140°C to obtain the composite protective film, wherein the treatment fluid A is prepared by mixing gamma-aminopropyltriethoxysilane, anhydrous alcohol and distilled water, regulating the pH value to 10-13 and finally hydrolyzing; and the treatment fluid B is prepared by mixing chlorinated rare earth salt, a hydrogen peroxide solution, sodium hydroxide and distilled water and regulating the pH value to 4-5. The treated silane/rare-earth composite protective film on an aluminium or aluminium alloy surface is uniform golden yellow on the surface and has excellent corrosion resistance.
Methods and compositions for coating aluminium substrates	US2009280258A1	The first solution can include a zinc metal salt, a sugar acid or alkali metal salt thereof, and an alkali metal hydroxide. The method can also include contacting the aluminium substrate with a second solution. The second solution can include a molybdate salt, an alkanolamine, and a fluorine acid.
(EPO, 2020)		

As with all patents, those listed in **Table 3-5** introduce concepts and developments that may be advantageous within a given field in the fullness of time. However, it should be remembered that patents are granted for 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.

Of those technologies identified, some (US2002117236A1, and JP2020056097A) represent solutions similar to those already being progressed by the A&D industry, whilst others (US2007095436A1, KR101871702B1, US2010314004A1, CN102677039A, and US2009280258A1) are similar to other proposed candidates which were identified in the parent AfAs. Commentary on these is provided in section 3.4.1.1 above. The patent with publication reference WO2018031986A1 does represent a novel technology not described previously, however as there are viable solutions which have already been progressed to test candidate status, members have not investigated this patent further.

3.4.3.2 High-level literature review

A non-exhaustive technical literature review was carried out using Science Direct (Journals and Books)[26] on-line service using the keyword search term 'Anodized sealing chromate aluminium'[27]. The purpose of this search was to identify examples of alternatives to Cr(VI) for anodise sealing that have been investigated in the academic field or within other industry sectors. Although it is acknowledged that technical requirements for anodise sealing 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 high-level literature review compliments the parallel non-exhaustive patent search. The results returned from the search are summarised in **Table 3-6.** Of the 149 research articles and 23 review articles found in the search, an expanded review is presented below for 14 of the research articles and for 3 of the review papers that was deemed to be of most relevance, these articles are summarised in **Table 3-7.**

Table 3-6: Literature search for Anodized sealing chromate aluminium in Science Direct

Search term	Time period	Research articles	Review articles
Anodized sealing chromate aluminium	2008 - 2020	149	23

Table 3-7: Expanded review of selected scientific publications

Ref.	Article Title
1	Wang et al (2019), "Studies on the sealing processes of corrosion resistant coatings formed on 2024 aluminium alloy with tartaric-sulfuric anodizing" Surface and Coatings Technology Volume 360, 25 February 2019, Pages 369-375
2	Yu et al (2020), "Studies on the corrosion performance of an effective and novel sealing anodic oxide coating"

[26] ScienceDirect.com | Science, health and medical journals, full text articles and books.

[27] Literature search conducted October 2020

Table 3-7: Expanded review of selected scientific publications	
Ref.	**Article Title**
	Journal of Alloys and Compounds Volume 817, 15 March 2020, 153257
3	Yoganandan et al (2016), "Electrochemical and long term corrosion behaviour of Mn and Mo oxyanions sealed anodic oxide surface developed on aerospace aluminum alloy (AA2024)" Surface and Coatings Technology Volume 288, 25 February 2016, Pages 115-125
4	Manavbasi et al (2013), "Alkaline Corrosion-Resistant Sealant for Anodised Aluminum Alloys" Metal Finishing Volume 111, Issue 6, November–December 2013, Pages 12-15
5	Yoganandan & Balaraju (2014), "Synergistic effect of V and Mn oxyanions for the corrosion protection of anodised aerospace aluminum alloy" Surface and Coatings Technology Volume 252, 15 August 2014, Pages 35-47
6	Castro et al (2020), "Integrated self-healing coating system for outstanding corrosion protection of AA2024"[28] Surface and Coatings Technology Volume 387, 15 April 2020, 125521
7	Karanika et al (2018), "Development of new environmentally friendly anticorrosive surface treatments for new Al-Li alloys protection within the frame of Clean Sky2" Procedia Structural Integrity Volume 10, 2018, Pages 66-72
8	Costenaro et al (2017), "Corrosion resistance of 2524 Al alloy anodised in tartaric-sulphuric acid at different voltages and protected with a TEOS-GPTMS hybrid sol-gel coating" Surface and Coatings Technology Volume 324, 15 September 2017, Pages 438-450
9	Wojciechowski et al (2106), "Anti-corrosive properties of silane coatings deposited on anodised aluminium"[29] Electrochimica Acta Volume 220, 1 December 2016, Pages 1-10
10	Mason et al (2011), "Alternatives to dichromate sealer in anodizing operations" Metal Finishing Volume 109, Issues 4–5, June 2011, Pages 25-32
11	Hu et al (2015), "Effect of sealing on the morphology of anodised aluminium oxide" Corrosion Science, 97(October 2017), 17–24. https://doi.org/10.1016/j.corsci.2015.03.021
12	The effects of different sealing techniques for anodic film of Al-12.7Si-0.7Mg alloys

[28] Available at Integrated self-healing coating system for outstanding corrosion protection of AA2024 - ScienceDirect accessed 27 July 2021

[29] Abstract available at Anti-corrosive properties of silane coatings deposited on anodised aluminium - ScienceDirect accessed 27 July 2021

Table 3-7: Expanded review of selected scientific publications	
Ref.	**Article Title**
	International Journal of Electrochemical Science, 11(6), 5234–5244. https://doi.org/10.20964/2016.06.85
13	Nazeer & Madkour (2018), "Potential use of smart coatings for corrosion protection of metals and alloys: A review" Journal of Molecular Liquids Volume 253, March 2018, Pages 11-22
14	Cui et al (2020), "A comprehensive review on smart anti-corrosive coatings" Progress in Organic Coatings Volume 148, November 2020, 105821
15	Ofoegbu (2020), "The Sealing Step in Aluminum Anodizing: A Focus on Sustainable Strategies for Enhancing Both Energy Efficiency and Corrosion Resistance" Coatings 2020, 10, 226; doi:10.3390/coatings10030226 https://www.mdpi.com/2079-6412/10/3/226/htm
(Elsevier B.V., 2020)	

The technologies described in the above literature sources are all either assessed as alternative anodise sealing technologies in the parent applications for authorisation (and have been further described in section 3.4.1.1 above) or have been investigated as proposed candidates for the replacement of Cr(VI) in chemical conversion coating and rejected in favour of the test candidates which will be discussed in section 3.4.5. They have therefore not been investigated for use in anodise sealing alone.

Ofoegbu, Fernandes and Pereira (2020) provides a systematic literature review of articles published in the past 30 years on anodise sealing, in the context of increased demands for environmental sustainability and energy efficiency. The nano-porous structure of the anodic film and its influence on improving the quality of the anodic seal is investigated. A summary of technologies is presented in **Table 3-8.**

In addition, perspective is provided on plausible approaches and important factors to be considered in developing sealing procedures that can minimise the energy input and environmental impact of the sealing step and ensure a more sustainable aluminium anodisation process/industry.

Table 3-8: Summary from recent reports of alternative sealing methods for anodised aluminium alloys
Reproduced from table 1 in (Ofoegbu, Fernandes and Pereira, 2020)

Name	Classification	Bath operating conditions	Major findings
H_2O sealing	Hot sealing	Distilled water, 100°C, 30 min.	Pores were filled with boehmite (γ-AlO(OH)) after H_2O sealing Corrosion potential after H_2O sealing was lower than that of the anodised but unsealed sample.
H_2O sealing	High temperature sealing	Anodised samples were immersed for 30 mins in deionized water at 96°C, to which 1 g/L of sodium sulphate had been added to increase the conductivity and thus to enable reliable in-situ electrochemical impedance spectroscopy (EIS) measurements. pH of sealing bath was adjusted to 6 by addition of a few drops of 10 g/L sulphuric acid solution.	The porous skeleton of the anodic layer suffers only little attack during hot water sealing. Improved corrosion protection after hot water sealing is attributed to enhanced barrier effect. Surface morphology of the anodised layer is not substantially different from that observed prior to hot water sealing (i.e., as anodised). EIS spectra after hot water sealing manifest a second time constant in the medium frequency region of the spectra, attributed to precipitation and solidification of the sealing products as this second time constant appeared only after cooling and was absent when the measurements were performed (in-situ) in hot conditions.
Nickel fluoride (NiF_2) sealing	Cold sealing	Anodised samples were sealed in 2.5 g/L NiF2 at 25°C for 30 minutes.	After NiF2 sealing the pores were filled with aluminium hydroxide (Al(OH)3),nickel hydroxide (Ni(OH)2) and aluminium fluoride (AlF3). Improved wear resistance compared to H2O and Cr2O3 sealing, as measured by decreased volumetric wear loss (2.014×10−9 m3 (N/m) after NiF2 sealing.
Nickel fluoride sealing	Cold and low temperature sealing	Nickel fluoride sealing under 3 different bath conditions: (a) 5 g/dm3 NiF2.4H2O, pH 6, 25°C for 15 mins; (b) 5 g/dm3 NiF2.4H2O, pH 6, 30°C for 15 mins; (c) 5 g/dm3 NiF2.4H2O, pH 6, 40°C for 15 mins.	Proposed a mechanism for nickel fluoride sealing and the ageing effect common with nickel sealed anodised aluminium alloys. Authors averred that increasing temperature adversely affected nickel absorption. Determined that nickel (16.3 at.%) and fluorine contents are maximum at the top surface (oxide-air interface) of the anodised layer and reduces with increasing depth into the film (towards the oxide-metal interface). The authors suggested that in nickel fluoride cold sealing, nickel ions exert catalytic effects on the hydration process with the presence of fluoride creating suitable pH condition for accelerated hydration of aluminium.

Table 3-8: Summary from recent reports of alternative sealing methods for anodised aluminium alloys
Reproduced from table 1 in (Ofoegbu, Fernandes and Pereira, 2020)

Name	Classification	Bath operating conditions	Major findings
Nickel acetate ($C_4H_{14}NiO_8$) sealing	High temperature sealing	Anodised samples were immersed for 30 min in nickel acetate solution (with Ni concentration = 1.4–1.8 g/L, pH = 5.5–6.0, temperature = 85–95°C).	Blocking of the porous layer of anodic film achieved by co-deposition of boehmite and nickel hydroxide Ni(OH)2 considered to catalyse boehmite formation. Corrosion resistance of nickel acetate sealed samples attributed to synergistic effect of boehmite and Ni(OH)2 precipitation.
Nickel acetate ($C_4H_{14}NiO_8$) sealing	Low temperature and high temperature sealing	Anodised aluminium samples were sealed in 3 different acetate solutions: hot 5 g/L nickel acetate (90°C), cold 5 g/L nickel acetate (at room temperature), and cold saturated nickel acetate (180 g/L) at room temperature for 30 min, respectively.	Hot nickel acetate sealed samples outperformed those sealed by other sealing methods. Hot nickel acetate sealing leads to both filling of the pores and formation of deposits on the air-oxide interface. Significant differences in the structure of the anodised layer after sealing by cold nickel acetate and hot water respectively is deemed to imply that sealing occurs by different mechanisms. Concluded that both nickel acetate and high temperatures are necessary for superior corrosion protection of sealed anodic layers.
Nickel acetate ($C_4H_{14}NiO_8$) sealing	Two-Step Sealing (Low-High temperature sealing)	Immersion of anodised samples in nickel acetatesolutioncontaining2g/L of nickel metal for 2 min and then 2 min immersion in boiling deionized water	The anodised layer from sulphate anodising baths is comprised mainly of aluminium and oxygen, but also displays an homogeneous sulphur content of about 3 at.% at all depths and indicative of the incorporation of sulphates from the electrolyte. In hot water and nickel sealing a short sealing time of 4 mins is sufficient to induce formation of a top layer over the anodic oxide film. Sealing with formulations containing nickel salt leads to incorporation of nickel within the anodic film. In nickel sealed samples, nickel is mainly located in the upper part of the coating (up to 8 at. %) and forms a superficial overlayer of thickness≈20 nm. Lower sulphur content of the first µm of the oxide after sealing was deemed to indicate that hydrolysis of sulphates occurs during the sealing process, and thus explains the formation of sulphur-containing precipitates. Energy Dispersive X-ray Spectroscopy (EDS) analysis in transmission electron microscopy (TEM) images of nickel sealed samples indicated that in the pores, some nickel precipitates can contain up to 15 to 20 at.% of nickel which was deemed to be indicative of precipitation of nickel hydroxy-sulphate compounds (comprised of nickel, oxygen and sulphur).

Table 3-8: Summary from recent reports of alternative sealing methods for anodised aluminium alloys
Reproduced from table 1 in (Ofoegbu, Fernandes and Pereira, 2020)

Name	Classification	Bath operating conditions	Major findings
Nickel acetate ($C_4H_{14}NiO_8$) sealing	Low and High temperature sealing (respectively)	Anodised aluminium samples were sealed using conventional hot nickel acetate sealing (HNAS) and cold nickel acetate sealing (CNAS). HNAS conditions: Immersion for 60 min in hot 8 g/L nickel acetate solution. CNAS conditions: Immersion in cold saturated nickel acetate solution for 30 min	Cold nickel acetate sealing (CNAS) yielded better results compared to hot nickel sealing (HNAS) and hot water sealing, which was deemed to be indicative of faster kinetics of nickel hydrolysis at room temperature. CNAS mechanism was proposed to occur by incorporation of Ni2+ ions into the oxide film which causes co-precipitation of nickel and aluminium hydroxide(s) precipitate at the pore mouth due to a local pH shift (towards more alkaline pH). pH excursions near the pore mouth promote partial pore sealing of the top surface of the anodic oxide while the bottom of the pores remain unsealed
Sodium acetate ($C_2H_3NaO_2$) sealing	High temperature sealing	Anodised aluminium samples were sealed in boiling de-ionized water in the absence and presence of 0.5 g/L of acetate anion (added as either its sodium or ammonium salt) for vary time durations (0, 2, 5. 10, 20 or 45 min).	The accelerative effect of acetate on sealing process is demonstrated. The important ability of acetate to shorten the sealing time without compromising sealing quality was highlighted. Hardness of the anodised layer was shown increase more rapidly in the presence of acetate. Authors concluded that sealing increased the hardness of anodised materials. Ageing phenomenon in sealed and partially sealed anodised aluminium alloys was attributed to the fact that the most kinetically favoured hydrates are the first hydrates formed during the sealing and aging processes and since they might not be the most stable, they slowly transform to more stable forms.
Cerium acetate ($C_6H_9CeO_6$) sealing under pulsed electric field	Low temperature sealing	Immersion of anodised aluminium samples in Ce3(NO3)3 solution (Ce3+ concentration = 1.5 g/L, pH≈6–7) for 60 min under a bidirectional electric pulse at room temperature (20°C). Pulse frequency = 50Hz, Pulse voltage = 0.8 V, Pulse ratio = 1:1, Negative duty cycle = 60%, Positive duty cycle = 35%.	A new method of sealing aluminium anodic films with a cerium salt sealing by pulse electrodeposition of rare metal on anodic film was reported. Corrosion resistance of anodic film sealed with this method are claimed to be superior to those obtained by sealing with boiling water and potassium dichromate. A mechanism was proposed for sealing mechanism of Ce salt sealing of anodised aluminium alloy under bidirectional pulse electric field.
cerium nitrate ($Ce(NO_3)_3$) sealing (with application of pulse power)	Low temperature sealing	Immersion of anodised aluminium samples in Ce3(NO3)3 solution (Ce3+ concentration = 1.5 g/L, pH≈5–6) for 60 min under a bidirectional electric pulse at room temperature (20◦C). Pulse frequency	Cerium salt sealing by this method resulted in superior long term corrosion resistance of anodised aluminium in NaCl solution compared to potassium dichromate sealing

Table 3-8: Summary from recent reports of alternative sealing methods for anodised aluminium alloys
Reproduced from table 1 in (Ofoegbu, Fernandes and Pereira, 2020)

Name	Classification	Bath operating conditions	Major findings
		= 50 Hz, Pulse voltage = 0.8 V, Pulse ratio = 1:1, Negative duty cycle = 60%, Positive duty cycle = 35%.	
Cerium nitrate ($Ce(NO_3)_3$) sealing	Low temperature sealing	Anodised aluminium samples were immersed in a cerium(III) nitrate solution at 37◦C containing 0.015M hydrated (Ce(NO3)3) and 0.029M H2O2 for 30 min. (H2O2 was added to enhance the deposition rate by accelerating oxidation of Ce3+ ions to Ce4+).	Highlighted the distinctive feature of cerium sealing; precipitation of cerium products which acting as inhibitor reservoirs together with pre-existing oxide(s) enhance the corrosion resistance of sealed samples. Barrier properties of hot water sealed, and cerium nitrate sealed samples were superior to chromate sealed samples leading to the conclusion the good corrosion resistance of chromate sealed samples is due to the inhibitive effect of residual hexa-chromate ions. The competitiveness of cerium bitrate sealing as a plausible environmentally friendly replacement for chromate sealing was highlighted.
Cerium nitrate ($Ce(NO_3)_3$) sealing	Low temperature sealing	Anodised aluminium samples were immersed in a cerium(III) nitrate solution at 37°C containing 0.015M hydrated Ce(NO3)3 and 0.029 M H2O2 for 30 mins. (H2O2 was added to enhance the deposition rate by accelerating oxidation of Ce3+ ions to Ce4+).	Oxide morphology was found to exert significant effect when sealing is performed in hot water or cerium-based solution but not in chromate solution. Impedance spectra acquired during cerium sealing indicated no variation in capacitance which was taken to be indicative of little or no attack of the barrier layer by the sealing solution
cerium chloride ($CeCl_3$) sealing	Low and mid temperature sealing	Sealing was carried out on anodised aluminium samples (of anodised layer 3–5 µm) by immersion in 0.5M CeCl3 solutions at temperatures25°C and 60°C for varied time durations (1–48 h).	CeCl3 sealing yielded more uniform and compact surface structure and morphology of anodic films. The products of cold and hot CeCl3 sealing are comprised of Al(OH)3, Ce(OH)3, and Ce2O3. These products co-precipitate inside the pores of the anodic films thus blocking the pores and imparting a higher corrosion resistance compared to films sealed in boiling water. It was demonstrated that depending on sealing conditions up to 2.69 to 10.4 wt.% of cerium can be mobilized inside the pores of the anodic oxide layer.
Ce-Mo sealing	Mid temperature Sealing	Samples were first immersed in 10 mmol/L Ce(NO3)3 solution at 40°C with pH = 6.8–6.9 for 2 h, then into 5 mmol/L CeCl3 solution (pH = 4.5–4.8, 40°C) for 2 h, and finally a potentiostatic polarization	Method involved chemical treatments in cerium solutions and subsequent electrochemical treatment in a molybdate solution. Resulted in uniform and compact surface structure and morphology in sealed anodic films. Ce and Mo are shown to exist throughout the anodic film with peak concentrations at the surface of the anodic layer, but whereas Ce concentration decreased with depth, Mo concentration increased with

Table 3-8: Summary from recent reports of alternative sealing methods for anodised aluminium alloys Reproduced from table 1 in (Ofoegbu, Fernandes and Pereira, 2020)

Name	Classification	Bath operating conditions	Major findings
		at +500mV vs SCE in 0.1 mol/L Na2MoO4 at pH = 8.5 solution for 2 hours.	depth. Improved corrosion resistance of anodic films in both acidic and basic solutions. However, Ce-Mo sealing involved long cumulative sealing times ≥6 hours and three solutions.
Sodium silicate (Na_2SiO_3) sealing	High temperature sealing	Immersion of anodised samples in 20% by vol. sodium silicate solution of pH≈11, temperature = 85–95°C for immersion time = 10–15 minutes.	Silicate sealing mechanism suggested to be by a physical plugging action occasioned by the growth of aluminium silicate within the pores, as silicates are known to inhibit sealing of anodic layers in hot water sealing by inhibiting boehmite formation/precipitation. Sodium silicate sealing does not negatively affect abrasion resistance of sealed anodic coatings as the sealing product is the harder sodium silicate in contrast to the softer boehmite formed during hot water sealing (compared to alumina formed during anodisation).
Sodium silicate (Na_2SiO_3) sealing	High temperature sealing	Na2SiO3 acidified to pH = 10 by addition of silicic acid (Si(OH)4 (total silicon concentration≈5.10−3 M). 95°C for 4 minutes.	Presence of silicate prevents formation of hydroxide sheets or blocking nanometer layer. Release of aluminium ions is inhibited by the silicate adsorption. Inhibition of release of Al ions is attributed to stability of the bond between silicate and aluminium cations.
Cerium nitrate and yttrium sulphate ($Ce(NO_3)_3$ + $Y_2(SO_4)_3$) sealing	Hot temperature sealing	Sample used were (anodised Al 2024, Al 6061, and Al 7075 alloys). Sealing in cerium salts [cerium acetate (C6H9CeO6), cerium nitrate (Ce(NO3)3), cerium (III) sulphate (Ce2(SO4)3), and cerium (IV) sulphate Ce(SO4)2], and Yttrium salts [yttrium acetate (C6H9O6Y), yttrium chloride (YCl3), and yttrium sulphate (Y2(SO4)3)] and combinations and selected sequences of boiling solution of these salts at different concentration, pH and sealing times.	Sealing in cerium nitrate and yttrium sulphate solutions yielded corrosion resistance similar to that of chromate-sealed anodised Al alloys. Generally, the best results for all three anodised alloys were obtained by sealing in cerium nitrate and yttrium sulphate solutions.
Sol–gel sealing	Two-Step Sealing (Low-High temperature sealing)	Sol–gel films based on Tetraethylorthosilicate (TEOS) and Phenyltriethoxysilane (PhTEOS) used for sealing. Dip cycle was 20 minute immersion in the sol–gel solution and then withdrawal at a rate of 10	Sol gel sealing negatively affected hydration process. Acid catalysed sol–gel systems displayed better corrosion resistance compared to base catalysed silanes. Sol–gel sealers from organically modified silanes displayed much better corrosion resistance compared to purely inorganic systems.

Table 3-8: Summary from recent reports of alternative sealing methods for anodised aluminium alloys
Reproduced from table 1 in (Ofoegbu, Fernandes and Pereira, 2020)

Name	Classification	Bath operating conditions	Major findings
		mm/min. Samples then cured in an oven at 110°C for 16 hours.	
Sol–gel sealing	Two-Step Sealing (Low-High temperature sealing)	Sol–gel solution was tetraethoxysilane (TEOS) (and 3-glycidyloxypropyl-trimethoxysilane (GPTMS) in a mixture of ethanol and distilled water. pH was adjusted to 2.3–2.5 by adding acetic acid and left to hydrolyze for 2 hours at room temperature. Dip cycle: immersion time of 2 minutes and withdrawal rate fixed at 100 mm/minute. Curing at 150°C for 1 hour.	Complete pore filling by sol-gel solution from the bottom up to the top. Dependency of pore filling on the thickness of the porous layer.
Sol–gel sealing	Two-Step Sealing (Low-Very High temperature sealing)	Anodised Al samples of anodised layer thickness µm were dipped into Al2O3 sol at a dip and withdrawal speed of 11.7 cm/minute. Sealing is concluded by heating sample to 270°C and holding for 15 min (heating and cooling rates were 10°C/min). The molar ratio of alkoxide (aluminium butoxide) to water was varied in the range 100 to 200.	Demonstrated that anodised aluminium substrate can be sealed with sol-gel coating. Resistance to atmospheric corrosion after sol-gel sealing claimed to be comparable with values from hydrothermal sealing and even superior. Highlighted that major disadvantages of sol-gel sealing are the higher cost process and decreased hardness and abrasion resistance.
Graphene oxide modified sol-gel sealing	Two-Step Sealing (Low-High temperature sealing)	3-Glycidyloxypropyl)-trimethoxysilane (GPTMS) (an organosiloxane) and Zirconium (IV) tetra-propoxide (TPOZ) (a Zirconium alkoxide sol) + graphene oxide (GO) 0, 0.05, 0.1, 0.5 and 1 mg/mL, respectively of sol mixture. Mixed sols were sealed and kept on stirring for 2 h at room temperature Dipping cycle: Immersion of pre-treated samples into mixed sols for 5 min, withdrawal at the 100 mm/min and curing at room temperature for 15 min. (Dip cycle repeated twice) Samples cured at 60°C for 60 mins, 90°C for 30 min and 100°C for 15 min respectively.	Improved corrosion resistance of sol-gel film with addition of graphene oxide (GO) and the optimal concentration = 0.5 mg/mL.

Table 3-8: Summary from recent reports of alternative sealing methods for anodised aluminium alloys
Reproduced from table 1 in (Ofoegbu, Fernandes and Pereira, 2020)

Name	Classification	Bath operating conditions	Major findings
Graphene oxide filled sol-gel sealing	Two-Step Sealing (Low-High temperature sealing)	3-Glycidyloxypropyl-trimethoxysilane (GPTMS) (an organosiloxane) and Zirconium (IV) tetra-propoxide (TPOZ) (a Zirconium alkoxide sol) + graphene oxide (GO) 0.5 mg/mL of sol mixture. Mixture kept stirred for 2 h at room temperature. Dipping cycle: Samples immersed in GO-filled sol for 5 min which, then withdrawn at the rate of 80 mm/min, cured at room temperature for 10 min. Dipping cycle was repeated thrice and then samples were cured at 110°C for 2h.	Sealing with GO/sol-gel yielded better corrosion resistance. Sealing with sol-gel only yielded better paint adhesion. GO/sol-gel sealing led to filling of pores and formation of a thin and uniform GO/sol-gel film about 1 µm was on sample surface.
Sodium aluminate ($NaAlO_2$) sealing	High temperature sealing	0.2 M NaAlO2 solution, pH 7 to 13 (adjusted with sulphuric acid), temperature 20–100°C, time 1–10 min.	Demonstrated a new eco-friendly sealing method based on NaAlO2 for anodised porous aluminium. NaAlO2 sealing resulted in superior corrosion resistance properties, high Vickers hardness, and low mass loss of the oxide in a sealing quality test compared to other sealing methods. Optimal conditions for NaAlO2 sealing of anodised aluminium are; temperature 85°C, pH 7, and sealing time 5 min.
Sodium aluminate ($NaAlO_2$) sealing	Hot sealing	0.2 mol/L NaAlO2 solution at pH 7 for 5 min at 85°C.	Better corrosion resistance of NaAlO2 sealed samples compared to hydrothermally sealed samples. Better corrosion resistance from NaAlO2 sealing attributed to formation of more AlOOH.
Lithium hydroxide (LiOH) sealing	Low temperature sealing	Sealing of 13 µm thick anodic films on high-purity (99.99%) aluminium sheets in 0.24 mol/dm3 lithium hydroxide solution at 25°C for 1–2 min.	Room temperature and short duration (1–2 min) sealing of anodic films with corrosion resistance acclaimed to be superior to that of hot water sealed samples. Platelet-like hydroxide layer thicker and larger size than those observed in hot water hydration sealing (200–300 nm) found on the top surface of the anodised layer. Sealing attributed to platelet-like precipitates composed of LiH(AlO2)2·5H2O and hydrated alumina formed on the surface and in the pores of the anodised layer. Proposed a mechanism for sealing in lithium hydroxide solution in which the pore wall of an anodic film is dissolved, prior to precipitation of platelet-like lithium and aluminium hydroxides in the pores.

Table 3-8: Summary from recent reports of alternative sealing methods for anodised aluminium alloys Reproduced from table 1 in (Ofoegbu, Fernandes and Pereira, 2020)

Name	Classification	Bath operating conditions	Major findings
Non-chromate Lithium and Fluoride ions sealing	Two-Step Sealing (Low-High temperature sealing)	First step; 0.15 to 1.5 min contact per micrometer of anodising layer thickness with an aqueous solution comprised of 0.1 to 3g/L of lithium ions and 0.1 to 5g/L of fluoride ions, at temperature of 15 to 35°C. and a pH value of 5.0 to 6.5. Final Sealing in a hot sealing bath at 80 to 100°C at a pH value of 5.8 to 8.2 and immersion time of 0.25 to 1.5 minutes per micrometer (preferably between 0.75 and 1.25 min), per micrometer of anodised layer.	Two step sealing of anodised metals without using any heavy metals but lithium and fluoride-containing solutions. In spite of the additional pre-sealing step, overall treatment time is reduced resulting in enhanced productivity.
Triethanolamine ($C_6H_{15}NO_3$) sealing	Mid temperature sealing	2 ml/L TEA solution, 50°C	TEA alters mechanism of sealing, exerts a catalytic effect on sealing process attributed to higher pH of TEA solution and its chemical structure. Presence of alcohol and amine groups in the same organic molecule is reported to exert synergistic effects on sealing process.
Layered Double Hydroxide (LDH) sealing	Two-Step Sealing (High-Low temperature sealing	Sealing on an anodic layer thickness of 3 µm. Parental LDH structures synthesized by immersion of anodised Al samples bath mixture of LiNO3 (0.1 M) and NaNO3 (0.6 M) for 30 min with stirring at 420 and the pH and temperature of the bath varied in the range of pH 9–12 and 25–95°C respectively. Inhibitors (vanadate anion species (LDH-VOx)) were loaded on prepared LDHs by immersion for 30 min in 0.1 M NaVO3 solution (pH 8.4) at 50°C with stirring at 200 rpm to achieve complete anion-exchange.	Low-temperature sealing of anodised AA2024 based on hierarchically organized Li–Al-layered double hydroxide (LDH) structures LDH sealing at room temperature (pH 11/25°C). Corrosion protection of Li–Al-LDH-OH/CO3 grown at room temperature comparable to that offered by hot water sealing (≥95°C). Multi-scale (macro to nano scale) hierarchical organization of in-situ formed LDH nano-flakes across the depth of pores.
LDH sealing	Two-Step Sealing (High-Mid temperature sealing	Sealing on 3 µm TSA anodised layer. Formation of parental LDH structures with nitrate anion (LDH-NO3) by immersion of anodised sample stirring in a solution comprised of Zn(NO3)2.6H2O (0.01 mol) and NH4NO3 (0.06 mol) dissolved in deionized water (100 ml), adjusted to 6.5 by slow addition of 1% ammonia, at 95°C for 30 min. LDH-vanadate sealing	Sealing anodised Al alloy using in situ grown LDH to provide combined passive/active corrosion protection.

Table 3-8: Summary from recent reports of alternative sealing methods for anodised aluminium alloys
Reproduced from table 1 in (Ofoegbu, Fernandes and Pereira, 2020)

Name	Classification	Bath operating conditions	Major findings
		achieved via anion-exchange reaction from the anodised aluminium samples with parental LDH-nitrate structure by immersion in reaction 0.1 M NaVO3 solution (pH 8.4) at 50°C for 30 and 60 min.	
2-MBT ethanol solution sealing	Two-Step Sealing (Low-High temperature sealing	Post -anodisation treatment of anodised aluminium in ethanol solution of 2-MBT(C6H4NSCSH), with and without subsequent hydrothermal sealing. Step I: Immersion for 30 min in 5% wt. ethanol 2-MBT solution. Step II: Sealing in deionized hot water containing 1g/L sodium sulphate (adjusted to pH 6 with sulphuric acid) at a temperature of 96°C for 30 min.	Better corrosion resistance from aluminium alloy samples post-treated in 2-MBT (2-Mercaptobenzothiazole) and then sealed in hot compared to samples sealed in hot water only. Improved corrosion resistance of samples post-treated in 2-MBT and then sealed attributed to incorporation of inhibitor (2-MBT) into the sealing products. Comparable corrosion resistance in samples treated in 2-MBT, with and without hot water sealing.
Organic acid sealing [Phytic acid ($C_6H_{18}O_{24}P_6$)] sealing	Mid to High sealing	Phytic acid (C6H18O24P6) concentration 1-3 wt.%, pH 1.5–4 (adjusted by addition of trietanolamine), temperature 60–90°C and time 5–20 min.	Phytic acid (C6H18O24P6) sealing of anodised aluminium resulted in superior corrosion resistance, compared to sealing by boiling water and dilute CrO3 solution. Superiority of phytic acid sealed samples was attributed to a synergistic effect; the observation that PA sealing resulted in both filling of the pores and formation of a PA conversion film of thickness 3–4 µm on immersion of anodised aluminium samples for 15 mins in 2.5 wt.% PA solution at 90°C (pH≈1.5).
Organic acid sealing [Stearic acid ($C_{18}H_{36}O_2$) sealing]	High temperature sealing	Sealing in varying concentrations of stearic acid-isopropyl alcohol solution (from 30 wt.% to 100 wt.%). Sealing time ranged from 20–90 mins Sealing temperature ranged from 60–100°C.	Optimal parameters for stearic acid sealing treatment: pure stearic acid, sealing time of 45 min at 95°C. Hydrothermal and stearic acid sealing exhibited better surface morphology with respect to flatness and uniformity, and best the sealing effects.
Alkaline Earth Metal Salts sealing (magnesium acetate and calcium acetate)	High temperature sealing	Optimized bath parameters: 10 g/L mixed salts comprised of (Ca(CH3COO)2·H2O, C4H6O4Mg·4H2O), 16 g/L complexant (C6H15NO3), 0.5 g/L surfactant (C24H32O7S2Na2), 2 g/L pH buffer (CH3COONH4), pH =7 and temp = 85°C.	Sealing quality superior to that from nickel acetate sealing. Sealing quality evaluation based on anti-staining adsorption and weight loss tests.

Table 3-8: Summary from recent reports of alternative sealing methods for anodised aluminium alloys
Reproduced from table 1 in (Ofoegbu, Fernandes and Pereira, 2020)

Name	Classification	Bath operating conditions	Major findings
Trivalent Chromium Sealing	Two-Step Sealing (High-High temperature sealing	Bath parameters: 5 g/L $Cr_4(SO_4)_5(OH)_2$ (26 percent Cr_2O_3 and 23 to 24 percent Na_2SO_4), + 20 mL/L 0.5 N NaOH + 0.4 g/L Na_2SiF_6. Immerse anodised samples in boiling bath with composition above for 2 min, remove and rinse for 2 min in 10 mL/L H_2O_2 (30%). Replace sample in boiling bath for 5 mins, remove and rinse again for 2 min in 10 mL/L H_2O_2 (30%).	Trivalent chromium sealing proposed as an alternative to dichromate sealing. Trivalent chromium sealed aluminium alloys present excellent adhesion to epoxy paints. Trivalent chromium sealing of Sulphuric-acid-anodised aluminium (2024-T3) provided corrosion resistance comparable to that of dichromate sealing. Trivalent chromium sealing of chromic-acid-anodised panels resulted in improved corrosion resistance compared to sealing same panels in bichromate baths.

The review summarised in **Table 3-8** encompasses some novel solutions not previously investigated for their technical/economic feasibility by members or identified in other data searches. These include:

- Sealing with sodium compounds (e.g., sodium acetate, sodium silicate, sodium aluminate);
- Triethanolamine solution;
- Lithium hydroxide sealing;
- Sealing with 2-Mercaptobenzothiazole (2-MBT) ethanol solution;
- Layered double hydroxide sealing; and
- Organic acid sealing.

Members provided the below commentary on these processes:

Lithium hydroxide sealing: The thickness of the anodic film described is likely to be too high for fatigue critical components, therefore it has not been determined if the technology could be applied to the thinner films used for these components.

Sealing with 2-MBT ethanol solution: 2-MBT is known to detrimentally impact polysulphide sealants, which are widely used in the A&D sector, by attacking di-sulphide bridges. It is unlikely therefore that such a solution could be used.

It should be noted that the publication of novel methods in scientific literature does not equate to these solutions being under consideration as proposed candidates by the A&D sector. Whilst the methods described may offer some insights into innovative chemistries, process methods, deposit morphologies, and analysis methods, these solutions must be investigated by formulators and presented to industrial end users as viable proposed candidates, with the potential to meet customer requirements, before they can be progressed as test candidates. Proposed candidates based on these technologies have not been presented, which may be because initial investigations by formulators have concluded that they would not meet customer requirements or could be because test candidates are already available for which substitution plans are being progressed. If qualification, certification, or industrialisation of the test candidates currently being progressed were to fail for particular components, or anodising processes, formulators and downstream users may look to develop proposed candidates based on these novel methods.

3.4.4 Identification of alternatives

As noted above in Section 3.2.1, the technical feasibility criteria for anodise sealing are:

- Corrosion resistance;
- Layer thickness;
- Chemical resistance;
- Adhesion promotion (Adhesion of subsequent layer); and
- Impact on fatigue life.

In support of initial screening, testing, also referred to as Critical to Quality (CTQ) tests, is conducted to assess performance of proposed candidates in the laboratory environment for each of the criteria. Corrosion resistance may be measured according to confidential internal specifications or publicly available standards, for example MIL-A-8625, BS EN 2101, EN 4704, or ASTM B117. Chemical resistance may be measured using ISO 2812-1. This standard provides a method for the determination of individual or multi-layer coating systems resistance to the effects of liquids, other than water, or paste-like products. ISO 2409 measures adhesion by 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.

Other examples of standards used in the evaluation of technical feasibility criteria and performance are given in Annex 1.

Performance requirements extend beyond the key functions. Essential attributes or performance requirements of the use must be considered in addition to key functions to ensure substitution with an alternative does not lead to unintended consequences which could impact safety and/or reliability of a component. For this reason, the delivery of the key functionalities cannot be considered in isolation; due regard must be paid to additional performance requirements associated with the successful delivery of the use.

Proposed candidates for the replacement of Cr(VI) in anodise sealing are shown in **Table 3-9** below. This list comprises all the alternatives that were reported in the parent AfAs, as well as any further proposed candidates identified during consultation. Note, those solutions identified following review of the data searches undertaken and presented above are not included in this table as at present they have not been presented as proposed candidates by the formulating companies and performance has not been assessed. The proposed candidates listed are assessed against the technical feasibility criteria identified above.

Table 3-9: Proposed candidates for the replacement of Cr(VI) in anodise sealing

Proposed candidate	Corrosion resistance	Layer thickness	Chemical resistance	Adhesion of subsequent layer	Impact on fatigue life
Cr(III)-based surface treatments		N/R	N/R	N/R	N/R
Cr(III)-/Zr based surface treatments					
Silane/siloxane and Sol-gel coating			N/R	N/R	N/R
Water-based post-treatments		N/R			
Molybdates and molybdenum-based processes		N/R	N/R	N/R	N/R
Manganese-based processes		N/R	N/R	N/R	N/R
Organometallics (Zr- and Ti-based products)		N/R	N/R	N/R	N/R
Cold nickel sealing[(a)]		N/R	N/R	N/R	N/R
Nickel acetate[(a)]		N/R	N/R		N/R
Nickel fluoride[(a)]		N/R	N/R	N/R	N/R

Green = Meets performance requirements for all anodising processes/components/substrates for which Cr(VI) is currently used; Yellow = Meets performance requirements for some anodising processes/components/substrates for which Cr(VI) is currently used; Red = Does not meet performance requirements for any anodising processes/components/substrates for which Cr(VI) is currently used; N/R = Not reported

[(a)]Represents a regrettable substitution candidate due to classification of nickel salts as cat. 1A carcinogens.

As well as representing the result of assessing the proposed candidates against the technical feasibility criteria given, **Table 3-9** also acts to further highlight the time it takes to develop substitutes which may be considered suitable test candidates. When compared to the treatments listed in **Table 3-4** it can be seen that none of the alternatives presented in the parent AfA have proven to be universally suitable test candidates, when the key requirements for an alternative are subject to bespoke testing, and that potential test candidates for the components where use of Cr(VI) is ongoing have only been identified through iterative development of these treatments.

3.4.5 Shortlist of alternatives

Focusing on the overriding need to maintain performance requirements critical to airworthiness, safety, and reliability, proposed candidates must demonstrate performance as good as, or better than, the incumbent Cr(VI) surface treatment. If performance requirements do not meet or exceed initial generic quality control screening thresholds, the proposed candidate will not advance to test candidate status where it is subject to bespoke Breadboard[30] level testing.

Note that it is a minimum requirement to pass initial screening tests within the laboratory environment. Design owners often apply more stringent internal performance requirements, as discussed in Section 3.2.1, which may add complexity to the testing regime and additional time to the approval process. In addition, achieving pass thresholds at the laboratory scale does not mean that the component or design will perform as intended in its operating environment. More advanced, often bespoke, testing is required to assess the viability of a test candidate against the technical feasibility criteria. Testing regimes that serve to replicate environmental in-service operating conditions are developed over decades of experience using Cr(VI). This knowledge has aided the development of test methodology aimed at laboratory scale test panels at one end of the spectrum to multi-climate chambers for simulated environment testing capable of housing airframe sections or complete working engines at the other. However, even these elaborate testing facilities cannot always replicate nature. There can still be differences between what is observed in the laboratory environment and what is experienced in the field especially over the longer term of the operational life of the component/complete assembly. Although rigorous, exacting, and designed to give the best and most realistic information possible, there remains the chance that these complex and detailed test regimes will not fully replicate all exposure scenarios and failure modes encountered in the operational environment.

An additional factor to consider is that service life of equipment can be extended by ten or more years beyond its designed service life. This, together with the potential for laboratory testing not to replicate all potential operational environments, emphasises the need for the test candidates' performance to be at least as good as Cr(VI).

Based on an assessment of technical feasibility and potential to be suitable alternatives to Cr(VI), the only proposed candidate which can be progressed to test candidate status is **Cr(III)/Zr-based treatments**. Within this group, there are two shortlisted alternatives:

- 2-step Cr(III)/Zr-based treatment including hot water sealing; and
- 2-step Cr(III)/Zr-based treatment including rare-earth elements.

[30] 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.

These are discussed in more detail in Section 3.5.

3.5 Assessment of shortlisted alternatives

3.5.1 Introduction

To achieve certification or approval by the relevant authority and/or design owner each component must meet the performance and safety requirements provided by the incumbent Cr(VI) based treatment.

Approval of the test candidate must include a complete understanding of the influence of the adjacent treatments to anodise sealing within the process flow. This is to understand the influence of all processes representing the surface treatment 'system' including pre-treatments and anodising. Evaluation of the technical feasibility of the test candidate for anodise sealing should consider its behaviour in combination with other supporting treatments within the 'system'. Any change in these system variables may lead to irregular or unacceptable performance of the test candidate delivering the seal and consequently impact or delay approval of the alternative 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.

When assessing the suitability of an alternative reference is made to the European Commission note dated 27 May 2020 which clearly defines the criteria by which an alternative may be judged as suitable[31] In order to be considered as suitable in the European Union (EU) the alternative should demonstrate the following:

- Risk reduction: the alternative should be safer;
- The alternative 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?

[31] 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

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[32], the test candidate cannot be deemed 'available'.

All civil aircraft operating in the EU are subject to Airworthiness Directives issued by 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 Regulation, such as (EU) 2018/1139[33]. 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'.

3.5.2 Test candidate 1: 2-step Cr(III)/Zr-based treatment including hot water sealing

3.5.2.1 Introduction

In the original applications, it was reported that extensive R&D was ongoing on Cr(III)-based sealing after anodising within the aerospace sector. Tests showed varying corrosion protection results, depending on the anodising process used.

Cr(VI)-free sealing with a Cr(III)-based conversion coating solution was shown to meet requirements for corrosion resistance in salt spray testing in the laboratory, however unacceptable results were achieved in industrial conditions.

Additional tests were carried out with various Cr(III) salts. Cr(III) alone was not sufficient for adequate corrosion protection and needed a pH stabiliser, however better results were achieved when using a nickel-based mixture containing Cr(III). Corrosion performance varied depending on the anodising process used. The required corrosion protection was achieved when sealing on chromic acid anodising, however when applied on Cr(VI)-free thin film sulphuric acid anodising (TFSAA) or tartaric-sulphuric acid anodising, corrosion protection did not meet the requirements of the industry.

Overall, it was concluded that Cr(III) sealing after anodising was a promising alternative, however corrosion resistance was limited as a certain level of porosity was retained after applying the seal. The parent AfA therefore also described a two-step process, in which a second sealing step is used to close the remaining pores. One example was given in which the second step was a hot water sealing process, although there was only limited information presented on the progression of this alternative.

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

[33] 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)

It was stated that complete implementation of Cr(III) into the supply chain for all anodise sealing processes could not be expected for at least 12 to 15 years.

In the period since the initial application for authorisation, members reported that Cr(III) solutions containing zirconium (Zr) have provided improved performance in this two-step process. The zirconium enables the deposition of chromium in the pores by acting as a reaction partner.

3.5.2.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of 2-step Cr(III)/Zr-based treatments including hot water sealing

It was reported by multiple members that a Cr(III)/Zr based solution produced by one formulator, followed by a hot water seal, fulfilled all the requirements for sealing of tartaric sulphuric-acid anodising (TSA), and therefore had progressed to test candidate status. For one member this test candidate was now at TRL 5 as a post-treatment for TSA. Another member reported they had progressed this test candidate to TRL 5 in 2017, again as a post-treatment for TSA, however after several industrial test campaigns, it was found that the test candidate was unable to meet performance requirements for corrosion resistance under industrial conditions. Over the past 3-4 years, significant efforts have been undertaken to optimise the process to allow progression to TRL 6, however these are yet to create a process sufficiently stable to provide the required corrosion resistance.

For one member the formulation was meeting corrosion performance and adhesion requirements and progression to TRL 7 is ongoing to increase robustness and repeatability of the process in a production environment. Quality inspection remains a considerable challenge in this substitution as the seal is colourless. Other members reported that for them, this same proposed candidate formulation was unable to progress beyond TRL3 because it could not provide the required corrosion protection on the aluminium alloys tested.

A second formulation based on a similar technology was reported as being progressed by other members, however for one member it was unable to produce sufficiently robust adhesion for all substrates and failed at TRL 4. This member reported that the proposed candidate also did not meet the technical requirements for corrosion resistance for all components, however the addition of additives to the hot water sealing process was being investigated to try and fulfil these requirements. It was felt that with the correct additives, the process could potentially be a viable test candidate for other types of anodising, in addition to TSA.

For one member this formulation is already certified as a sealing post-treatment for their Cr(VI)-free anodising processes. This test candidate has reached TRL 6 when used after sulphuric acid anodising (SAA), and TRL 8 when used after TSA LC (long cycle). For TSA LC, full equivalence with the design requirements of this member had been demonstrated, and the process is now certified, although not yet fully industrialised. For SAA the Cr(VI)-free sealing process is not yet qualified due to a lack of repeatability and robustness.

Economic feasibility of 2-step Cr(III)/Zr-based treatments including hot water sealing

A challenge with this test candidate is the overall increase in the infrastructure and operating costs. Member companies reported the requirement for at least one additional tank, which will result in the need for investments in new equipment. The cost of a new tank installation will vary depending on location, size, etc. thus estimates are likely to vary significantly across companies and across sites. No figures can be provided as an estimate at this stage.

The operational costs will increase due to the following impacts:

- **Increases in processing times**: The introduction of a two-step industrial process which will lead to an increase in production times and hence reductions in production rates (potentially with consequent impacts on turnover);

- **Waste Disposal costs**: Potential increases in the volume of waste and therefore disposal costs than current levels.

The inclusion of additional tanks into the process also creates additional costs linked to monitoring, maintenance and replenishment of raw materials.

Health and safety considerations related to the use of 2-step Cr(III)/Zr-based treatments including hot water sealing

For the purposes of understanding the risks associated with the test candidates for Cr(III)/Zr-based treatments including hot water sealing, the key identifiers and summary of hazard properties for two representative formulations used in the first step are given in **Table 3-10** below

Table 3-10: Summary of composition and hazard properties of two representative formulations, which are test candidates for first step of 2-step Cr(III)/Zr-based treatments prior to hot water sealing

Formulation	Substance	EC Number	CAS number	Concentration	CLP classification
Test candidate 1	Ammonium nitrate[a]	229-347-8	6484-52-2	5 - ≤10%	Oxi. Sol. 1; H271
	Chromium (III) sulphate[a]	233-253-2	10101-53-8	1- ≤3%	Skin Corr. 1B; H314 Acute Tox. 4; H302 Acute Tox. 4; H312 Acute Tox. 4; H332
	Ammonium hexafluorozirconate[b]	240-970-4	16919-31-6	5 - ≤10%	Acute Tox. 3; H301 Skin Irrit. 2; H315 Eye Dam. 1; H318 Skin Sens. 1; H317 STOT RE 1; H372
Test candidate 2	Ammonium nitrate[a]	229-347-8	6484-52-2	5 - ≤10%	Oxi. Sol. 1; H271
	Chromium hydroxide sulphate[b]	235-595-8	12336-95-7	1- ≤3%	Skin Irrit. 2; H315 Eye Irrit. 2; H319 Skin Sens. 1; H317 Aquatic Chronic 3; H412
	Ammonium hexafluorozirconate[b]	240-970-4	16919-31-6	5 - ≤10%	Acute Tox. 3; H301 Skin Irrit. 2; H315 Eye Dam. 1; H318 Skin Sens. 1; H317 STOT RE 1; H372

[a]Classified in accordance with suppliers Safety Data Sheet
[b]Classified in accordance with disseminated REACH Registration dossier

Based on the above, the test candidates would represent a less hazardous alternative to the current process using Cr(VI), a non-threshold carcinogen. Those members who have undertaken risk assessments of the process using the test candidate have universally identified a reduction in risk, with adequate control available for the risks which do exist.

Availability of 2-step Cr(III)/Zr-based treatments including hot water sealing

Each of the test candidates which members have been progressing for this process rely on commercially available solutions, and sufficient stock is believed to be available on the market to allow industrialisation. At least one additional tank is required for the process, however the equipment required is not unique to the process, and again should be available.

The biggest issue impacting availability is qualification of the test candidate for use on all relevant A&D components, and qualification of the supply chain required to support the process. This ultimately prevents the test candidate from being an alternative generally available to the A&D sector. One major concern in qualifying a supply chain is that trivalent chromium anodise seals do not meet the customers' requirements as consistently as hexavalent chromium anodise seals. This limits the number of suppliers willing to perform this process due to risk of failing to pass the corrosion test requirements for all production series.

Suitability of 2-step Cr(III)/Zr-based treatments including hot water sealing

The use of Cr(III)/Zr-based treatments with a hot water seal represents a reduction in risk to human health and the environment during processing, when compared to the incumbent process, and has been demonstrated to be technically feasible following certain anodising processes, although there is still an open question as to whether it can fulfil the requirements for thin film sulphuric acid anodising (TFSAA).

It relies on commercially available formulations and uses standard equipment, however there is an increase in costs due to the requirement for at least one additional bath. The process is not yet generally available to the A&D sector due to the requirement for its use to be certified on all relevant components and processes. One member has already certified the process for use following TSA LC and is currently working to qualify the process as a sealing post-treatment for SAA. For a number of other members, the formulations which may be used in this process remain test candidates, however progression beyond TRL 6 is currently on hold due to the identification of more promising test candidates based on an alternative second step (as described in section 3.5.3 below).

3.5.3 Test candidate 2: 2-step Cr(III)/Zr-based treatment including rare earth elements

3.5.3.1 Introduction

As described in section 3.5.2.1 above, in the parent AfA it was concluded that Cr(III) sealing after anodising was a promising alternative, however, to achieve the necessary corrosion resistance, the addition of zirconium to the solution, and a second step after immersion in the Cr(III) solution to close remaining pores was required. Two examples of a second step were described – one using hot water as described above, and a second using rare earth elements. This two-step process was stated to be at TRL 4, however the process was patent protected by a single company in the aerospace sector, so there was uncertainty as to whether it could provide an industry-wide solution.

In the period since the initial applications were submitted, a supplier has obtained world-wide distribution rights to this patent-protected technology, therefore the formulations required for this process are available, and have been tested by, ADCR members. This treatment uses a Cr(III)/Zr solution in the first step, and a Lanthanum solution in the second step. In addition to the inclusion of rare-earth elements, this second step also requires the use of hydrogen peroxide.

3.5.3.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of 2-step Cr(III)/Zr-based treatments including rare-earth elements

Several members have been progressing this technology alongside the alternative process involving hot water sealing, and almost all have reported this to be the more promising technology. They have therefore paused the progression of the other test candidates in order to divert more resources to the qualification and certification of these formulations.

It was reported that for TFSAA and SAA this was a viable test candidate, and in fact it has already been certified by one company for use on certain components. One member, that is transitioning from a chromic acid anodising process to SAA on more than 1000 components, has selected 20 of these components to also qualify this test candidate for sealing. For these components, TRL 6 was completed in 2019 with the demonstration of performance equal to or better than the legacy process using sodium dichromate for corrosion resistance, adhesion, and layer thickness. The substitution process is currently at TRL 7-9 for the 20 components which are a focus of the project. The next step will be industrialisation and the extension of the solution to the remainder of the 1000 plus components relevant to the member.

For another member, this test candidate reached TRL 3 in 2021 as a post-treatment for TSA. An industrial test campaign has been completed and showed poor reproducibility of the process under industrial conditions. Based on root-cause analysis a new industrial test campaign is planned, which may lead to a delay in reaching TRL 6, initially expected by the end of 2023. For two further members TRL 6 has already been achieved.

For many members, the process of industrialising Cr(VI)-free anodise sealing, and Cr(VI)-free anodising, are taking place in parallel. Whilst this ensures the implemented alternative is more likely to work as part of the entire system, it also means that one substitution is adversely impacted by a setback in another. For one member, who was working on TRL 4-6 actions with this test candidate, a change in the anodising method moved the process back to below TRL 4. It is anticipated that with this new system, TRL 6 will be reached by mid-2024, however until the data from the suite of assessment requirements associated with TRL 4 testing is available, it is difficult to estimate the requirements and timescale for industrialisation.

Economic feasibility of 2-step Cr(III)/Zr-based treatments including rare-earth elements

A challenge with this test candidate is the overall increase in the infrastructure and operating costs. Member companies reported the requirement for an additional tank, which will result in the need for investments in new equipment. The cost of a new tank installation will vary depending on location, size, etc. thus estimates are likely to vary significantly across companies and across sites. No figures can be provided as an estimate at this stage.

The operational costs will increase due to the following impacts:

- **Increases in processing times**: Moving to Cr(III)-based alternatives will require the introduction of a two-step industrial process which will lead to an increase in production times and hence reductions in production rates (potentially with consequent impacts on turnover);

- **Raw Material costs**: The overall cost of raw materials will rise since the two-step process requires more raw materials for anodise sealing. Also, as a patented technology from a single source, the user is less able to mitigate the impact of price increases. In addition to the direct purchasing costs, the need to hold stock of the additional raw materials and potential requirement for additional warehousing is also a consideration;

- **Energy Costs**: Energy costs are expected to rise due to the requirement for cooling and ventilation of the hydrogen peroxide solution;

- **Waste Disposal costs**: Potential increases in the volume of waste and therefore disposal costs than current levels.

The inclusion of additional tanks into the process also creates additional costs linked to monitoring, maintenance and replenishment of raw materials.

Given the above, a switch to this test candidate may require additional time for the optimisation of production capabilities to avoid incurring unaffordable losses that could result in the closure of some operations.

Health and safety considerations related to the use of 2-step Cr(III)/Zr-based treatments including rare-earth elements

For the purposes of understanding the risks associated with the test candidate for Cr(III)-based treatments including rare earth elements, the key identifiers and summary of hazard properties for the formulations used in each step are given in **Table 3-11** below.

Table 3-11: Summary of composition and hazard properties of test candidate for 2-step Cr(III)/Zr-based treatments including rare-earth elements

Formulation	Substance	EC Number	CAS number	Concentration	CLP classification
Step 1	Dipotassium hexfluorozirconate[(a)]	240-985-6	16923-95-8	1 - <3%	Acute tox. 3; H301 Eye Dam. 1; H318
Step 2	Lanthanum nitrate hexahydrate[(a)]	-	10277-43-7	1- <3%	Ox. Sol. 2; H272 Eye Dam. 1; H318 Skin Irrit. 2; H315 STOT SE 3; H335 Aquatic Acute 1; H400 Aquatic Chronic 1; H410
	Hydrogen peroxide solution[(b)]	231-765-0	7722-84-1	35%	Ox. Liq. 1; H271 Acute Tox. 4; H302 Skin Corr. 1A; H314 Acute Tox. 4; H332

[(a)]Classified in accordance with suppliers Safety Data Sheet
[(b)]Classified in accordance with Annex VI of Regulation 1272/2008 (CLP)

Based on the above, the test candidates would represent a less hazardous alternative to the current process using Cr(VI), a non-threshold carcinogen. The analysis of bath status and composition for this test candidate cannot yet be full automated, and therefore there is the potential for increased exposure during this task, however those members who have undertaken risk assessments of the process using the test candidate have universally identified a reduction in risk, with adequate control available for the risks which do exist.

Availability of 2-step Cr(III)/Zr-based treatments including rare-earth elements

Although this test candidate is commercially available, there is only a single supply source, which could impact the implementation of the alternative at scale across multiple A&D organisations. Additionally, a supply of high purity hydrogen peroxide is critical to the implementation of this test candidate. The supplier specifies the use of 35% hydrogen peroxide in the process, and the recent pandemic demonstrated a lack of resilience in the supply chains currently available for the sourcing of this solution.

In addition to the above, the process using the test candidate requires unique equipment, which although available on the market, requires complex analytics, not fully automated, to determine the bath status and composition. This may prevent some existing component suppliers from implementing the process and there is a concern that the supply chain may not have the required capacity to allow industrialisation of the process.

As with the other shortlisted alternative, the biggest issue impacting availability is qualification of the test candidate for use on all relevant A&D components, and qualification of the supply chain required to support the process. This ultimately prevents the test candidate from being an alternative generally available to the A&D sector. One major concern in qualifying a supply chain is that trivalent chromium anodise seals are not as reproducible as hexavalent chromium anodise seals. This limits the number of suppliers willing to perform this process due to risk of failing series production corrosion test requirements.

Suitability of 2-step Cr(III)/Zr-based treatments including rare-earth elements

The 2-step process including rare-earth elements in the second step represents a technically feasible test candidate for all anodising processes after which it has been tested, however it is not yet generally available to the A&D sector due to the requirement for its use to be certified on all relevant components. Reproducibility and bath stability still need to be demonstrated on an industrial level following some treatments, whilst there is currently also only limited industrial experience in managing the baths required for the process. The bath required for the second step will contain hydrogen peroxide that will degrade over time and regular replenishment is required to maintain performance.

The use of this combination of formulations reduces the risk associated with the existing process and represents the most suitable test candidate for most members, however as a patented technology with a single supply source, there is concern that availability could limit its implementation at scale across the A&D sector.

3.6 Conclusions on shortlisted alternatives

Table 3-12 summarises the current development status of the test candidates to replace Cr(VI) for anodise sealing. A qualitative assessment (low, moderate, or high) has been provided for each of the criteria: technical feasibility, economic feasibility, risk reduction, availability, and suitability. The qualitative assessment is provided as a high-level summary and is based on the detailed discussions in the preceding sections.

Table 3-12: Current development status of test candidates

Alternative	Technical feasibility	Economic feasibility	Risk reduction	Availability	Suitability
Cr(III)/Zr-based treatments including hot water sealing	Moderate	Moderate	High	High	Moderate
Cr(III)/Zr-based treatments including rare-earth elements	High	Moderate	High	Low	Moderate

Although both of the test candidates require a two-step process, rather than the current single step, both represent technically feasible test candidates, which have been industrialised for some components. Due to the complexity of the substitution process with the A&D sector, described in section 3.1.2 however, neither can be implemented for all components and final products prior to the end of the existing review period.

It should also be considered that this process forms part of an overall 'system' which currently utilises formulations containing Cr(VI) at multiple stages. Cr(VI)-free alternatives for anodise sealing are, in some cases, being tested alongside anodising processes which themselves are not yet industrialised. Additionally due to the relatively low quantities of solution required for sealing compared to the much more widespread process of chemical conversion coating, it must be ensured that the test candidates introduced as alternatives for anodise sealing are also industrialised for use as a chemical conversion coating.

Additionally, MRO is affected. Some members need to validate methods to remove sealed anodic film, and to validate repairs to sealed anodic film. Furthermore, there is a need to demonstrate compatibility between components made using the current methods and components made using the new method(s). This must also be considered when assessing the time required to implement the test candidate as an alternative.

3.7 The substitution plan

3.7.1 Introduction

3.7.1.1 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 control, 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 anodise sealing. 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.

3.7.1.2 Substitution plans within individual members

Each ADCR member has a substitution plan to remove Cr(VI) in anodise sealing that is uniquely reflective of their individual situation. Additionally, an individual member often has multiple substitution plans for anodise sealing, 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 component, type of alternative and type of anodic process. These different substitution plans are progressed simultaneously although they typically have differences in timing of milestones and anticipated achievement of each TRL/MRL level, based on various factors such as the technical difficulty of introducing the alternative and prioritisation of certain types of component.

3.7.1.3 Interplay with pre-treatments and post-treatments

Development of substitution plans for alternatives to Cr(VI) for anodise sealing are fundamentally related to and impacted by its compatibility with the anodic process used prior to sealing. In the cases where members have not yet been able to introduce Cr(VI)-free anodising, they plan to develop the Cr(VI)-free anodic treatment in parallel with the Cr(VI)-free sealing process. The progression and success of the development of alternatives to Cr(VI) in anodise sealing depends on the successful progression of anodising alternatives. In most cases, a member will target substitution of Cr(VI) from both the anodic treatment and the sealing process at the same time.

Additionally, for some members, the test candidates which are the subject of these substitution plans will be the same test candidate that member is looking to industrialise as a Cr(VI)-free alternative for chemical conversion coating. This is due to the relatively low volumes of the test candidates which will be used for anodise sealing, and therefore the difficulty of presenting a suitable business case for introducing an alternative which can be applied only to this use. Once again, therefore, the progression of the test candidate is dependent on its continued progression as a viable alternative for the chemical conversion coating process. Any unexpected technical failures in the progression of the test candidate as a substitute in chemical conversion coating may impact the planned timing of the substitution plan for anodise sealing.

3.7.2 Substitution plans for ADCR members in anodise sealing

3.7.2.1 Substitution plans

Two, 2-step Cr(III)/Zr-based treatments have been progressed by members to replace Cr(VI) in anodise sealing.

The expected progression of ADCR members' substitution plans to replace Cr(VI) in anodise sealing is shown in **Figure 3-9** below. The progressive stages of the substitution plan (development, qualification, validation etc.) are shown in the diagram and 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 and is therefore where Cr(VI) use is expected to be eliminated due to replacement with an alternative.

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 anodise sealing 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 34 distinct substitution plans for Cr(VI) in anodise sealing, covering different plans across different members, and multiple plans within individual members. These data have been aggregated to present the expected progress of the substitution of Cr(VI) from anodise sealing for the ADCR consortium as a whole.

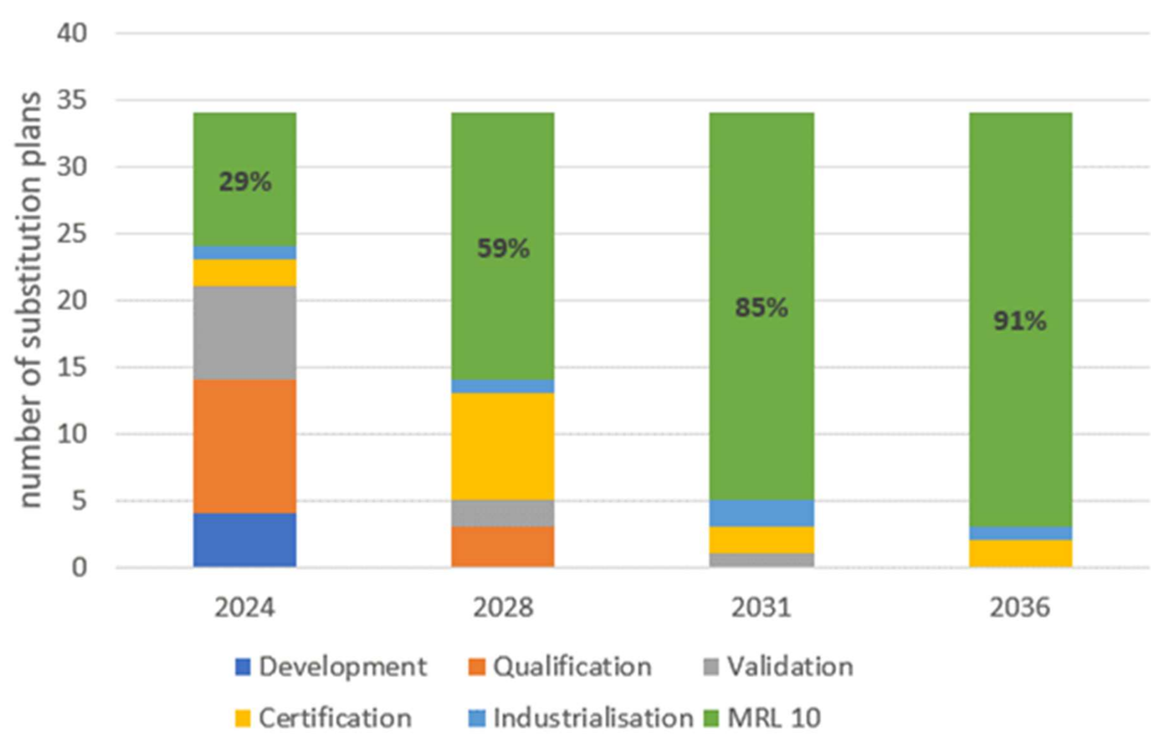


Figure 3-9: Expected progression of substitution plans for the use of Cr(VI) in anodise sealing, by year. The vertical axis refers to number of substitution plans (some members have multiple substitution plans for anodise sealing). The percentage value shown on each of the green bars indicates the proportion of substitution plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which manufacturing is in full rate production/deployment and it is therefore where it is expected that Cr(VI) will be fully substituted under the relevant plan.

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, types of anodic process, types of substrates, types of components); 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, and there are uncertainties due to, for example, unexpected technical failures which may only reveal themselves at more advanced stages of testing. 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 3-9.** 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 anodise sealing, 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 anodic process, types of component, and type of alternative being developed.

The principal issue associated with Cr(III) surface treatments, their inability to sufficiently enhance corrosion resistance, has been overcome with the development of 2-step processes which members are able to progress beyond TRL 3 for multiple component types, and following multiple different types of anodic process. Challenges still remain however which limit members' progression of the substitution plans beyond the stages indicted in **Figure 3-9**. Technical challenges include ensuring the reproducibility and bath stability associated with the process, as well as the logistical issues presented to organisations who need to add additional equipment to support the processes. 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. There are also interlinked and interdependent workstreams where for example substitution plans for anodise sealing cannot be implemented until those for anodising have also been implemented.

The potential need for more than 12 years has been identified by some OEMs due to their inability to identify any technically feasible alternatives to date. This is illustrated by the near equivalence between the number of substitution plans at the development phase in 2024, and the number where it is anticipated MRL 10 will not be reached by 2036. For proposed candidates which have not yet progressed beyond TRL 3, predicting the length of time until industrialisation will be completed can be a particularly difficult task because, as has been illustrated with those test candidates being progressed by other members, iterative re-formulations of a proposed candidate are not uncommon. Each of these re-formulations results in the timeline for this substitution plan being reset. A proportion of those substitution plans which are not anticipated to progress to MRL 10 until 2036 or beyond are also impacted by the needs of MROs and MoDs for continued use in the maintenance and repair of in-service (legacy) final A&D products.

The timeframes associated with the activities presented in **Figure 3-9** result from the requirements of the substitution process which are presented in section 3.1.2. To be noted also 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.

3.7.2.2 Requested Review Period

It can be seen in **Figure 3-9** that despite ongoing and concerted efforts of the members to develop alternatives to Cr(VI) in anodise sealing, it has not proved possible to replace Cr(VI) by the end of the review periods granted in the parent authorisations (which end in 2024). 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, a proportion are not expected to have achieved MRL 10 and are expected to be at the validation, certification or industrialisation stage. For these substitution plans 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 anodise sealing**.

4 Continued Use Scenario

4.1 Introduction

Section 3 provided an analysis with respect to the technical feasibility, economic feasibility, risk reduction, availability, and suitability of alternatives. The assessment highlights the importance of Cr(VI) for corrosion protection (resistance and inhibition) by anodise sealing. Although some of the companies supporting this use have industrialised alternatives (e.g., hot water sealing) for some components this is not across all components or products.

Until alternatives which are compatible with all the relevant anodising processes and which deliver an equivalent level of functionality are, qualified, validated and certified for the production of individual components and products, use of the chromates in anodise sealing will continue to be required; their use is essential to meeting airworthiness and other safety requirements. Therefore there are no alternatives which can be considered “generally available” in the context of A&D.

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 anodise sealing, implementation itself may take several years (e.g., 6-8 within the larger value chains).

Even then, issues may remain with legacy spare parts and 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.

As demonstrated by the substitution plan, MRL10 is expected to be achieved for some components and final products by 2024, but in other cases is not expected to be reached until 2028, 2031 or 2036. Even in 2036, there are some cases where substitution plans are not expected to have reached MRL10. As a result, the aerospace and defence industry and its supply chains require at least a further 12 years to complete substitution across all components and final products.

The Continued Use Scenario can be summarised as follows:

Continued use of Cr(VI) in anodise sealing 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

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 anodise sealing, including projected tonnages over the requested review period; 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 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 as per stringent airworthiness requirements and industrialised by members and their supply chains. The continual re-visiting of supply chain requirements has allowed the narrowing of the substance-use combinations requiring re-authorisation compared to the original applications for authorisation.

Furthermore, the scope of this combined AoA/SEA is driven by A&D qualification, validation, and certification requirements, which can only be met using the substances that provide the required performance as mandated by airworthiness authorities. This constrains OEMs and DtBs, and hence their suppliers and MRO facilities (civilian and military), to the use of Cr(VI) in anodise sealing until alternatives can be qualified and certified across all relevant components.

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[34]). As noted by the European Commission, the industry is "characterised by an extended supply chain and a fabric of dynamic small- and medium- sized enterprises throughout the EU, some of them world leaders in their domain"[35]. **Figure 4-1** provides details of turnover and employment for the industry in 2020, based on the A&D

[34] Further information on the UK is provided in Annex 3.

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

Industries Association of Europe (ASD) publication "2021 Facts & Figures".[36] These figures are lower than the comparable figures for 2019, at around 405,000 jobs and €130 billion in revenues[37], with these leading to exports amounting to around €109 billion.

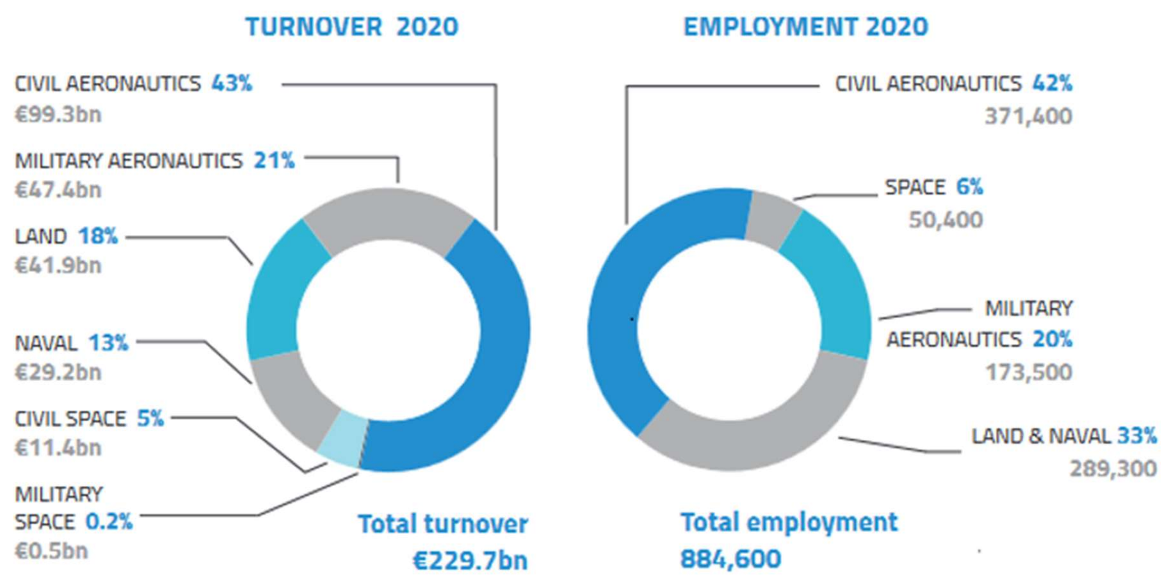


Figure 4-1: Turnover and Employment for the European A&D Industry in 2020 (snip taken from ASD, 2021)

Note: The employment graphic contains an error with the shaded size of the contributions by Space and Land & Naval swapped. See also the corresponding chart for 2019, available at https://www.asd-europe.org/sites/default/files/atoms/files/ASD_FactsFigures_2020.pdf

As can be seen from **Figure 4-1**, civil and military aeronautics alone accounted for 64% of turnover and 62% of employment 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:

36 ASD, 2021: Facts & Figures, available at: https://www.asd-europe.org/facts-figures

37 https://ec.europa.eu/defence-industry-space/eu-aeronautics-industry_en

- Aircraft and other 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 (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 of existing aircraft and equipment, as well as for models that are still in production for 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 have to be ready to demonstrate fully developed technologies, or they risk losing contracts that may have a lasting effect on business.[38]

- 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 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 anodise sealing proving a difficult task for some products (and in particular some military final products).

- 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 anodise sealing

4.2.3.1 Profile of downstream users

As noted in Section 2, anodise sealing is a common use of the chromates within the aerospace sector. As a treatment, it is carried out in-house by some of the OEMs, as well as being carried out by BtP suppliers, DtB suppliers and MROs.

Anodise sealing is therefore 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 its alloys but may also be carried out on other substrates such as magnesium and its alloys. Examples of the types of components treated by anodise sealing include:

- fuselage skins and bulkheads;
- wing skins, panels and covers;
- stabilisers;
- wheels and landing gear links; and
- Gearbox and engine inlet cases.

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

SEA questionnaire responses were provided by 39 A&D companies undertaking anodise sealing with these companies operating across 38 sites in the EEA and 21 sites in the UK (59 in total).

Table 4-1 provides an indication of numbers of respondents by role in the supply chain and by size of company. As might be expected, respondents to the SEA survey tended to be medium and larger sized companies within their sectors of activity (with the exception of responses from Build-to-Print suppliers in the UK). The number of responses covering MROs is also low compared to what might be expected.

Table 4-1: Numbers of SEA respondents undertaking Anodise sealing

Role	Number of companies/sites undertaking Anodise sealing *		Company Size[39]	
	EEA	UK	EEA	UK
Build-to-Print	10/12	11/14	2 small 6 med 2 large	7 small 3 med 1 large
Design-to-Build	3/5	1/1	1 medium 2 large	0 medium 1 large
MRO only	8/9	1/2	1 small 1 medium 6 large	0 small 0 medium 1 large
OEM	6/12	2/4	7 large	2 large
Total	27/38	15/21		
Note; Some of the OEMs have sites in both the EEA and UK. In total, 39 companies provided a response, but some reported for the purposes of both EEA and UK REACH. There is therefore overlap in the number of companies but there is no overlap in the figures given for the number of sites.				

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).

4.2.3.2 Economic characteristics

Table 4-2 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, DtP or MRO company. Companies may have indicated more than one NACE code as being relevant to their activities, with the result that the number of relevant NACE code counts is higher than the number of SEA responses relevant to anodise sealing 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 number of employees, and average personnel costs per employee.

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

Table 4-2: Economic characteristics of "typical" companies by NACE in sectors involved in Anodise sealing (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	24	20.88	54,000	35,500	15.5%
C2540 - Manufacture of weapons and ammunition	2	306.44	70,000	42,500	12.3%
C2594 - Manufacture of fasteners and screw machine products	2	57.20	65,000	43,200	9.7%
C2599 - Manufacture of other fabricated metal products n.e.c.	5	57.20	65,000	43,200	9.7%
C265 - Manufacture of instruments and appliances for measuring, testing and navigation;	1	159.30	84,000	57,500	11.1%
C2732 - Manufacture of other electronic and electric wires and cables	1	34.39	76,000	51,700	4.8%
C2815 - Manufacture of bearings, gears, gearing and driving elements	5	284.64	72,000	44,500	7.9%
C3030 - Manufacture of air and spacecraft and related machinery	10	1,214.65	98,000	76,400	11.2%
C3040 - Manufacture of military fighting vehicles	5	1,214.65	99,000	64,800	9.8%
C3316 - Repair and maintenance of aircraft and spacecraft	13	71.33	85,000	56,400	8.4%
Other	2	4,828.3	NA	NA	NA
Total count	70				
Note: The count total is by number of NACE code identifications by company and not by sites, with 37 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 anodise sealing and taking into account the size distribution of the companies[40] 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[41] (GOS) 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 11% which is an average across the various NACE codes weighted by the number of companies declaring each NACE code.

As can be seen from **Table 4-3**, the 59 sites for which data were collected via the SEA questionnaire represent an estimated €22,700 million in turnover and €2,400 million in GOS as a proxy for profits. Across all 160 sites expected to be undertaking anodising in the EEA and UK, these figures rise to around €54,400 million in turnover and €5,700 million in GOS.

Table 4-3: Key turnover and profit data for market undertaking anodise sealing (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 11%) € million
38 EEA Sites	16,548	1,738
21 UK sites	6,175	648
Extrapolation to all sites involved in chromate-based anodise sealing in the EEA or UK		
125 EEA sites	45,989	4,828
35 UK sites	8,373	879

Source: Based on SEA questionnaire responses, combined with Eurostat data
Note: See Section 2.3.3.6 for basis of extrapolation to the 160 sites in the EEA and UK combined

4.2.3.3 Economic importance of anodise sealing to revenues

Anodise sealing will only account for a percentage of the calculated revenues, GVA and jobs associated with the results given in **Table 4-3**. To understand its importance to the activities of individual companies, a series of questions were asked regarding other processes carried out, production costs, and the share of revenues generated from the use of chromates in anodise sealing.

As the supply chains covered by this SEA vary from manufacturers of small components to producers of much larger components (e.g., components for landing gear versus doors and/or skirts), the responses vary significantly across companies. Of key importance is that for the design owners anodise sealing continues to be a critical surface treatment, the loss of which would result in loss of a

[40] 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 take 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.

[41] 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).

significant level of turnover due to the inability to meet airworthiness requirements, even though as a process it accounts for only a very small percentage of production costs.

Given the importance of anodise sealing in enhancing corrosion resistance, it is a vital portion of the value stream. The combination of pre-treatment, anodising, anodise sealing and inorganic finish stripping (to repair defects) using the chromates can also be important with respect to production costs and turnover. **Table 4–4** sets out the number of companies that indicated that they also carry out other treatments. This includes both Cr(VI)-based and non-Cr(VI) based treatments as part of a certified system.

The pre-treatments and inorganic finish stripping may also be relevant to other "uses"; however, they are a common part of the anodise sealing process flow. Similarly, not all anodising will be followed by Cr(VI)-based sealing, and not all Cr(VI)-based anodise sealing will be preceded by chromic acid anodising (CAA). As already stated, the need for CAA as oppose to other anodic processes will depend on the EASA certifications in place and the extent to which a feasible alternative has been identified, qualified and certified and has gone through industrialisation.

Table 4–4: Company responses on undertaking other relevant treatments

Role	Number of companies also undertaking pre-treatments		Number of companies undertaking anodising		Number of companies also undertaking inorganic finish stripping	
	Cr(VI) based	Non-Cr(VI) based	Cr(VI) based	Non-Cr(VI) based	Cr(VI) based	Non-Cr(VI) based
Build-to-Print	12	11	17	12	8	4
Design-to-Build	2	1	3	1	2	1
MRO only	5	2	7	2	3	2
OEMs	4	3	5	1	5	2
Total	23	17	32	16	18	9

Given the importance of anodise sealing in protecting substrates, 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, anodising, anodise sealing and inorganic finish stripping combined. Corrosion resistance is generally a non-negotiable requirement for a contract. Loss of the ability to provide an adequately performing product, would result in the loss of the ability to sell the entire product, not just the portion associated with anodise sealing production costs.

As a result, the combination of these activities has been taken as the relevant process flow for assessing the economic impacts, regardless of whether pre-treatments, anodising, anodise sealing and inorganic finish stripping are Cr(VI) or non-Cr(VI) based, as it is the series of processes, and the profits and employment linked to them as an overall activity, that is relevant for this SEA.

It is relevant to consider the extent to which the production costs at different companies/sites relate to these four activities. Responses to the SEA questionnaire reveal the following:

- Pre-treatments account for an average of 15% of production costs for BtPs, 46% for DtBs, 8% for OEMs and just over 20% for MROs;

- Anodising accounts for an average of 26% of production costs for the majority of BtPs and over 73% for DtBs, meanwhile for OEMs the figure is significantly less with production costs at 9%;
- Inorganic finish stripping also accounts for an average of 22% of production costs for BtPs, 45% for DtBs, 8% for OEMs, and less than 5% for MROs;
- The production costs for anodise sealing itself were identified as accounting for 16% for BtPs, 55% for DtBs, 6% for OEMs and 5% for MROs.

Even where anodise sealing and the other relevant treatments account for only a low percentage of total production costs, the ability to undertake these chromate-based activities is critical to the corrosion protection of the substrates. By way of example, one of the MROs indicated that one of their responses related to a site that undertook repairs on landing gear. Although anodise sealing (as well as chromate-based deoxidising/etching/pickling and anodising) were reported as only accounting for <5% of production costs, the response made it clear that "the use of chromates in anodising and anodise sealing forms an essential step in the overhaul of landing gear". Thus, loss of anodise sealing could affect all their revenues related to such services even if it only comprised a small percentage of total production costs.

Table 4–5 provides a summary of responses on the revenues generated by the combination of chromate using processes. As can be seen from this table, 21 companies indicated that over 50% of their revenues were linked to chromate using processes.

Table 4–5: Number of companies reporting proportion of revenues generated by or linked to the set of chromate using processes

	<10%	10% - 25%	25% - 50%	50% - 75%	>75%	No response
Build-to-Print	4	1	3	3	9	1
Design-to-Build	0	0	0	1	2	0
MROs only	3	1	0	1	3	0
OEMs and Tier 1*	1	0	0	0	2	4

*These responses cover multiple sites and only reflect those companies carrying out the activities

The figures given in **Table 4–5** also reflect the fact that some of these companies will carry out other surface treatment activities, including for sectors other than A&D. This includes producing components for machinery, food manufacturing, medical equipment, automotive uses, oil drilling and electrical equipment, which may or may not also involve the use of chromates.

As would be expected, although anodise sealing in and of itself does not account for a significant percentage of production costs or turnover, all the OEMs highlighted the critical importance of anodise sealing 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 Cr(VI)-based anodise sealing as mandated in the drawings and performance requirements for those components unless there are certified alternatives. DtBs as design owners also noted that anodise sealing is critical to some of their components/final products and hence to their customers.

It is also of note that four military MROs have highlighted the importance of Cr(VI)-based anodise sealing 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 R&D, risk management measures and monitoring

OEMs

The OEMs have carried out R&D into the substitution of chromates for over 30 years. Further information on the R&D carried out by these companies in particular is provided in Section 3.4. This includes collaborations such as the Highly Innovative Technology Enablers for Aerospace (HITEA) project.

With respect to capital investments relating to anodise sealing, the following investments have taken place:

- Investment of €1.8 million to modernise the anodising and anodise sealing lines so as to reduce emissions with 12 years of life expectancy;
- R&D expenditure into new test lines, equating to around €190,000 in expenditure; and
- R&D expenditure of around €1.8 million into new technologies to replace the existing surface anticorrosive protection of aerospace materials with those less harmful to the environment and human health. This includes verified technologies for surface protection of aluminium.

OEMs have spent €13.5 million on R&D into Cr(VI) replacement efforts, including replacement in anodising and anodise sealing as a process flow.

Design-to-Build suppliers

Two of the DtB companies have had capital investment, in 2019 and 2018, that is relevant to the continued use of chromates. These include:

- Investment of €100,000 for the purchase of equipment for use with a Cr(VI)-free technology with a 10 years' service life; and
- Investment of €80,000 in the purchase of new baths for anodise sealing.

Build-to-Print suppliers

Eleven of the BtP companies have had capital investments in the period from 2010 to 2021 that is relevant to the use of Cr(VI) and Cr(VI)-free alternatives in anodise sealing. These include:

- €600,000 investment in a new anodising and anodise sealing process in 2015, expected to have a 20-year service life. Further investment to upgrade effluent treatment was carried out in 2020 at a cost of €50,000;

- €100,000 investment in various new equipment related to processes including anodising and anodise sealing. This investment was carried out in 2013 (with equipment having a 15-20 year expected life), with a further €80,000 investment in new plant to enable Cr(VI)-free operations to be carried out at the same time;

- Construction of a new hall in 2017 to accommodate new anodising and anodise sealing lines, as well as a treatment plant, laboratory and other chemical processes;
- Investment of €750,000 in a process development area, tanks and other equipment, as well as to provide Cr(VI)-free anodising and anodise sealing facilities (while use of the Cr(VI)-based processes are phased out);
- Investment in a Cr(VI)-free anodising line at a cost of €552,500 in 2018 which should also reduce the need for Cr(VI)-based anodise sealing (depending on certifications); and
- £800,000 investment in 2015 (25-year expected life) in new anodising and anodise sealing lines complete with a new extraction system.

In addition to these, companies identified a range of investments to improve air extraction, exhaust ventilation and waste treatment plant, as well as to replace tanks, rectifiers and other equipment. Others have also spent significant time and resources into improving their health and safety systems and in developing improved monitoring systems.

In terms of R&D into alternatives, six of the companies have either been involved in some of the larger sectoral R&D projects (e.g., Asia/Pacific Airport Coordinators Association (APACA)), have worked with their OEM, or have carried out their own research into alternatives. One company cites own R&D at a cost of €1 million and use of a dedicated engineering team.

MROs

The MROs have also undertaken significant investments into new equipment related to their use of the chromates, including for waste management and emissions reduction. Investments specific to anodise sealing or the adoption of alternatives have not been identified.

More generally, investments have included expenditure to both reduce worker exposures and/or environmental emissions, and on R&D aimed at reducing or eliminating the use of the chromates. One of the MROs of relevance to anodise sealing has spent roughly €1 million on such R&D to date, in addition to R&D on the substitution of the chromates in other "uses".

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 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

4.2.4.1 Importance to end-user markets

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

Because Cr(VI)-based anodise sealing cannot be fully substituted at present, it plays a critical role in ensuring the reliability and safety of final products. Thus, although the economic importance of the chromates in anodise sealing 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 (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
- Impacts on defence operations, including the potential unavailability of critical equipment and impaired operations during military missions, 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 above for the number of air passengers transported in the European Union in 2019 (over 1 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 this combined AoA/SEA through the provision of information demonstrates the critical nature of Cr(VI)-based anodise sealing to the on-going preparedness of their military forces in particular.

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

4.2.4.3 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 **Figure 4–2**[42], with this suggesting CAGR from 2020 to 2031 of around 2.5%.

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

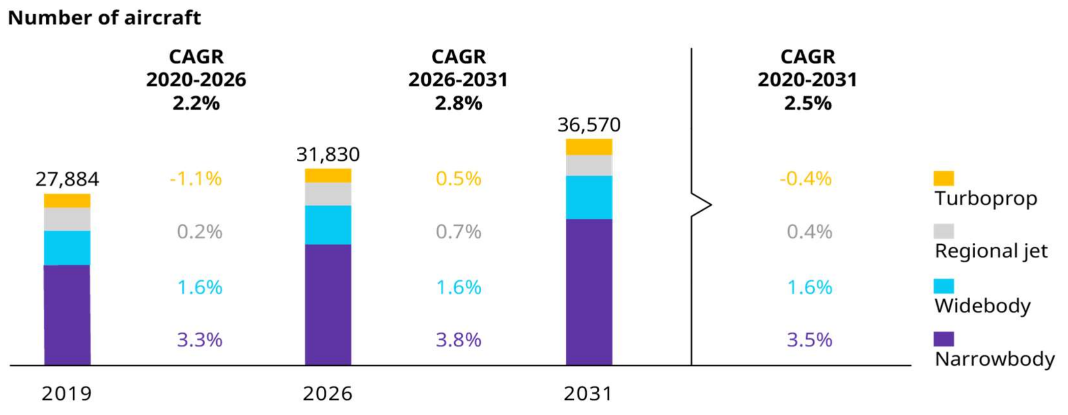


Figure 4–2: Global fleet forecast by aircraft class, 2020-2031
Source: Oliver Wyman analysis

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 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.[43]

Boeing's 2022 Commercial Market Outlook[44] 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 aeroplane 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 majority of commercial aircraft in operation will be of the latest generation. Projections based on generic neutral seating categories (100 plus seater passenger aircraft and 10 tonnes plus freighters) are given in **Table 4-6** below.

43 https://www.airbus.com/sites/g/files/jlcbta136/files/2022-07/GMF-Presentation-2022-2041.pdf

44 https://www.boeing.com/commercial/market/commercial-market-outlook/index.page

Table 4-6: Airbus Global Market Forecast: projected new deliveries 2021-2040								
Pax Units								
Category	**Africa**	**Asia-Pacific**	**CIS**	**Europe**	**Latin America**	**Middle East**	**North America**	**Total**
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 (€50.4 billion, £44.3 billion) in 2020, while the UK export market was around US$13.2 billion (€11.7 billion, £10.3 billion) in 2020.[45]

However, unless operations in the EEA and UK can remain 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 these newer generations of aircraft and military products may shift to locations outside the EEA/UK with a consequent loss in Gross Value Added (GVA) to the EEA and UK economies, with enormous impacts on employment.

4.2.4.4 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 products market encompasses the market for both new and used rotable[46] 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

[45] https://www.statista.com/statistics/263290/aerospace-industry-revenue-breakdown/

[46] 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.

10 years. Globally, the market is expected to have a CAGR of over 3% over the period from 2022-2027, as illustrated in **Figure 4–3**.[47, 48]

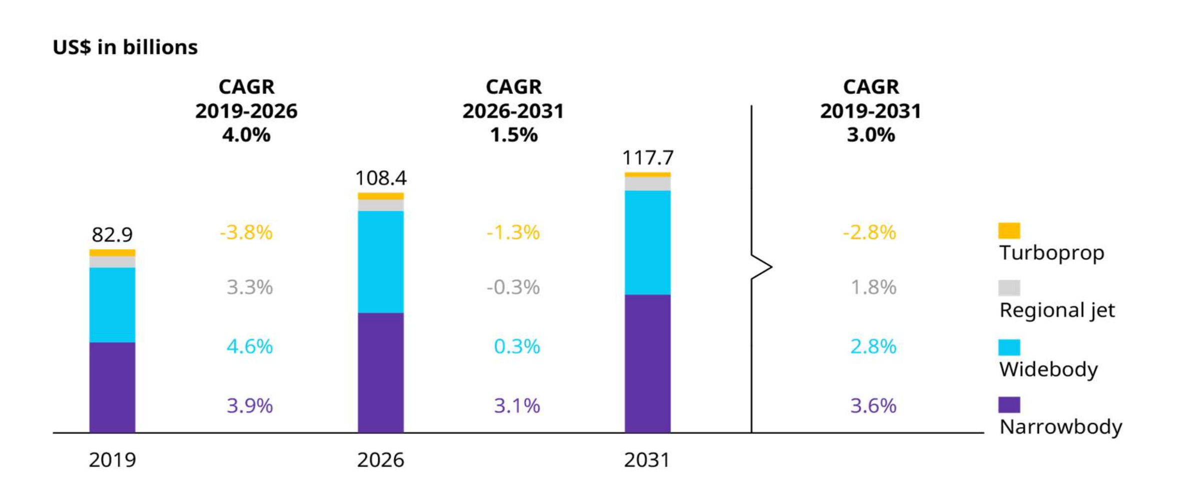


Figure 4–3: MRO market forecast by aircraft class, 2019-2031
Source: Oliver Wyman analysis

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; 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.

4.2.4.5 The defence market

The war in Ukraine has led several EEA countries and the UK to revisit their defence expenditure. 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 2020 of around 1.3% of GDP for the EU[49]. 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[50]. This equates to an increase in spending of around £157 billion between 2022 and 2030.

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[47] Mordor Intelligence, Commercial Aircraft Maintenance, Repair, and Overhaul (MRO) Market – Growth, Trends, Covid-19 Impact and Forecasts (2022 - 2027)

[48] Oliver Wyman analysis: at: A forecast update on the global commercial airline fleet and aftermarket for 2020

[49] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Government_expenditure_on_defence

[50] 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

Such investment, which will include new spending on existing technologies, may also result in a continued reliance on the use of Cr(VI) for anodise sealing 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%.[51]

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 200 kg Cr(VI) per year per site using multiple chromates, with tonnages for each chromate per site as follows:

- 0 to 20 kg chromium trioxide used per year, translating to a maximum of 10.4 kg Cr(VI);
- 0 to 300 kg SD used per year, thereof up to 120 kg Cr(VI);
- 0 to 300 kg PD used per year, thereof up to 105 kg Cr(VI);
- 0 to 20 kg SC used per year, thereof up to 6.4 kg Cr(VI);

The upper Cr(VI) tonnage/year of 200 kg (Cr(VI)) was estimated as a worst case based on sites using several chromates for anodise sealing. This may be an overestimation for sites using only one chromate.

4.3.2 Consultation for the SEA

Most SEA respondents (not included in the CSR work) identifying anodise sealing as important to their turnover indicated total chromate use levels in the region of tens of kg per annum to around 1000kg. These higher levels of chromate consumption were for sites that undertake a number of different surface treatments, with the volumes assumed in the CSRs consistent with their combined set of activities.

Based on the maximums found in the CSR work and the upper bound figures quoted in the SEA responses, estimates of the tonnages of the individual chromates used by the anticipated 125 EEA and 35 UK sites for anodise sealing have been derived. These are figures for 2024 (assuming no decline from 2022 levels):

51 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

- EEA tonnage for 125 sites in ADCR supply chain: up to 2.5 tonnes per annum CT, 10 tonnes per annum SD, 12 tonnes per annum PD, and up to 2 tonne per annum SC;
- UK tonnage for 35 sites in ADCR supply chain: up to 0.5 tonnes per annum CT, 6 tonnes per annum SD, 6 tonnes per annum PD, and up to 0.5 tonnes per annum SC.

These figures should be treated as upper bound values, which may overestimate the actual quantities consumed by the ADCR supply chain.

4.3.3 Article 66 notifications data

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 462 notifications relating to the REACH Authorisations listed above, covering 608 sites across the EU-27 (and Norway).

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. In addition, the notification data covers multiple treatments and hence its use for anodise sealing alone would be misleading.

The distribution of notifications by substance and authorisation is summarised in **Table 4–7**[52]. Note that Authorisations 20/18/21-25 relate to aeroderivative uses of chromium trioxide for surface treatment, but these uses will occur at the same sites as notifying for A&D uses and would therefore result in double-counting. 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.

Table 4–7: Article 66 Notifications to ECHA

Substance	Authorisation	Authorised Use	Notifications	EU Sites
Chromium trioxide	20/18/14-20	Surface treatment of metals	263	357
Potassium dichromate	20/3/1	Surface treatment of metals	15	18
	19/31/0	Sealing after anodising	4	7
	20/2/1	Surface treatment of metals	53	61
Sodium dichromate	20/56/3-5	Surface treatment of metals	61	84
	20/14/0	Sealing after anodising	1	7
	20/4/1	Surface treatment of metals	58	67
Sodium chromate	20/18/14-20	Surface Treatment for aerospace	7	7
Total			462	608

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

[52] Similar data is not publicly available for the UK.

Since there are more sites than notifications, it is assumed that some notifications cover more than one site[53]. Some sites may, of course, use more than one of the four chromates.

It is important to stress that these notifications relate to 'surface treatment' which cover many more processes than anodise sealing. Indeed, only three of the notifications received by ECHA include specific reference to anodise sealing. The associated quantities are low – generally less than 0.1 tonne per year. This confirms that the figures given above reflect upper bound estimates.

4.3.4 Projected future use of the chromates

4.3.4.1 Introduction

The A&D industry is actively working to phase out the use of Cr(VI). It will take further time however to qualify alternatives across all components and products for the A&D industry. Individual companies are at different points along this path, although there are also variations based on specific aircraft/defence application and across different types of components/final products.

Where possible, requirements for Cr(VI)-based anodise sealing in new designs are being phased out, however aircraft that require its use remain in production and operation. Cr(VI)-based anodise sealing therefore remains important to the protection of aluminium substrates.

4.3.4.2 OEMs

The volume of the Cr(VI) used in anodise sealing has varied over time across different OEMs. Three of the OEMs noted that Cr(VI) use has increased over the past seven years due to an increase in aircraft deliveries. In contrast another company indicates that Cr(VI) use over the last seven years has decreased by 5-40 % due to substitution, while another indicated that use has remained steady over this period.

Cr(VI) use in anodise sealing will remain at 2021/22 levels in 2024 but there is an expected decrease by 2028 and ongoing decreases thereafter. Importantly however, some of the OEMs (in particular those producing final products for military use) expect to continue to require the use of the chromates for an extended period to facilitate the maintenance of existing equipment, although demand should decrease post 2032.

4.3.4.3 Design-to-Build

The utilisation rates of anodise sealing lines across the DtB companies have remained high with levels of 80% and 95% for two of the DtBs. As a result, the quantities of the chromates used have remained steady given that these are identified as being required by customers' specifications. Looking to the longer term, one company indicated that they expected consumption of the chromates to increase due to increases in manufacturing levels. The other respondents could not predict changes in use.

All these companies indicated that the use of the chromates is necessary in order to meet customers' performance requirements and/or as part of certification. In some cases, use may also be required by

[53] Article 66 reporting is by legal entity, which can have multiple sites using a chromate for anodise sealing. 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.

DtBs own designs and certified processes, or that continued use is required as part of maintenance, repair and overhaul activities (i.e., is specified in Maintenance Manuals and must therefore be followed for work to be legally compliant).

4.3.4.4 Build-to-Print

The aerospace industry has had many challenges which have had a lasting impact. Over the last several years, 15 respondents indicated a decrease in Cr(VI) use by 5% to 42%. In some cases, companies were operating at low utilisation rates with one company only achieving 30% utilisation. Most of the companies indicated that they were impacted by the COVID-19 pandemic, and this may also have impacted their demand for the chromates.

Looking to the longer term, 14 of the 21 companies expect the level of activity to return to normal levels in the next two years. Nine companies indicated that they did not know how the consumption of the chromates was likely to change between 2024 and 2028, while seven expected a decrease in consumption; only one company indicated an increase in consumption. All BtP companies noted that they used Cr(VI) to meet their customers' certification requirements.

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 their consumption of Cr(VI) in anodise sealing to decrease at the same rate as for the OEMs.

4.3.4.5 MROs

Three MROs (covering multiple sites) stated that they had been impacted by COVID-19, with decreases in consumption of Cr(VI) of 15 - 50%, although they all expect consumption to return to normal. The other two MROs indicated that consumption had remained steady since 2014. One of the MROs carries out anodise sealing using either Cr(VI) or a Cr(VI)-free alternative, depending upon the requirements set down in the relevant Maintenance Manuals.

With regard to future trends, one MRO indicated that they expected Cr(VI) consumption to decrease steadily until its use is phased out after 2032. Two stated that they expected consumption to remain steady, as it was end customer driven and there was a lag between certification of alternatives and the updating of Maintenance Manuals. A fourth company expected consumption to increase (as well as turnover) with the need to service increasing fleet sizes (in part due to the increase in contracts won by this MRO).

All the MROs note that the use of the chromates is required in the Maintenance Manuals which set out repair, maintenance and overhaul requirements as specified by the various OEM and DtB design owners. As a result, they anticipate that a long review period will be needed to ensure that there is time for Manuals to be updated and for them to be able to adopt and implement the alternatives at their sites.

4.3.4.6 Summary

Overall, responses to the SEA questionnaire indicate a downward future trend in the use of Cr(VI) in anodise sealing over the requested review period. However, as indicated by the substitution plan, it is also clear that some of the respondents will require at least a further 12 years to finalise R&D, testing, qualification, validation and certification of alternatives and to implement them at an industrial level where the latter also includes making changes to process specifications, drawings and

Maintenance Manuals. Part of the reason cited for the 12-year period relates to complexity of what needs to be achieved. As noted by respondents:

- *"Such a long review period [is required] to allow sufficient time to develop alternatives and test them in combination with other surface treatments before implementation".*
- *"Full replacement on all components (>1000) will take time for both sealing of chromic acid anodised parts and sulphuric acid anodised parts due to the need for testing, qualification and certification. Will require new-make drawings and repair manuals to be updated."*
- *"We operate as a build and finish to print company for the aerospace sector. The identified processes are out of our control. A sufficient time will be necessary to allow us to modify our process once the OEM's have identified their alternatives and got them passed airworthiness procedures".*
- *"A 12-year review period is desired to ensure that alternatives can be implemented; however, the alternative's implementation depends on the approval of aircraft producer*".

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 Cr(VI)-based anodise sealing 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, and/or 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. Similarly, Potassium dichromate and sodium chromate have been included in Annex XIV of REACH due to their CMR properties as they are all classified as a Carcinogen 1B and Mutagen 1B and Reproductive Toxicants 1B.

The hazard evaluation follows recommendations given by RAC [54]:

- For assessing carcinogenic risk, exposure-risk relationships are used to calculate excess cancer risks; and
- As mutagenicity is a mode of action expected to contribute to carcinogenicity, the mutagenic risk is included in the assessment of carcinogenic risk, and low risks for mutagenicity are expected for exposures associated with low carcinogenic risks.

4.4.1.2 Overview of exposure scenarios

All A&D sites that perform anodise sealing within the ADCR supply chains are specialised industrial sites being 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 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 practicably feasible and use automated processes to the maximum extent possible. The feasibility and the degree of automation can vary between different sites and depend, among other factors, on the size of the site and the frequency of anodise sealing activities. See the CSR for further details of measures in place.

As reported in Section 5, due to the conditions placed on the continued use of the chromates in surface treatments (including anodise sealing), additional risk management measures were implemented by A&D companies, requiring significant investment. A full summary of these conditions is provided in the CSR that accompanies this combined AoA/SEA.

The CSR has identified the following similar exposure groups (SEGs) for tasks with potential Cr(VI) exposure related to anodise sealing:

- Line operators
- Storage area workers
- Laboratory technicians
- Maintenance and/or cleaning workers
- Machinists
- Incidentally exposed workers (without direct Cr(VI)-related activities)

With respect to worker exposures, **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/WCS number	ES/WCS title	Environmental release category (ERC)/Process category (PROC)
ES1	Anodise sealing - use at industrial site	
Environmental contributing scenario(s)		
ECS 1	Anodise sealing - use at industrial site leading to inclusion (of Cr(VI) or the reaction products) into/onto article	ERC 5

[54] ECHA Website: https://echa.europa.eu/documents/10162/21961120/rac_35_09_1_c_dnel_cr-vi-_en.pdf/8964d39c-d94e-4abc-8c8e-4e2866041fc6; assessed in March 2021

Table 4-8: Overview of exposure scenarios and their contributing scenarios		
ES/WCS number	ES/WCS title	Environmental release category (ERC)/Process category (PROC)
Worker contributing scenario(s)		
WCS 1	Line operators	PROC 9, PROC 13, PROC 28
WCS 2	Storage area workers	PROC 5, PROC 8b, PROC 28
WCS 3	Laboratory technicians	PROC 15
WCS 4	Maintenance and/or cleaning	PROC 28
WCS 5	Machinists	PROC 21, PROC 24
WCS 6	Incidentally exposed workers	PROC 0
Exposure scenario for industrial end use at site: ES1-IW1		

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 anodise sealing. 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 anodise sealing. 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 anodise sealing process. Most of their working time they spend in a hall where the anodise sealing tanks are located and where the immersion process takes place, either on activities with direct or indirect Cr(VI) exposure;
- WCS2: Storage area workers who decant liquids and measure solids, clean containers, handle solid wastes, undertake bath make-up and cleaning of baths as part of bath renewal;
- WCS3: Laboratory technicians who may be involved in activities related to anodise sealing with potential for Cr(VI)-exposure, such as undertaking sampling and laboratory analysis of treatment bath solutions;
- WCS4: Maintenance and/or cleaning workers who maintain pipes, pumps, sensors, scrubbers, electrical systems installed in treatment baths, and LEV systems;
- WCS5: Machinists, who are involved in machining operations on sealed parts, including cleaning; and
- WCS6: 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	Number of workers and number of shifts	Excess lifetime lung cancer risk (1/υg/m³)
WCS1	Line operators	1-3 per shift, 5 per day on average	1.08E-03
WCS2	Storage area workers	1-2 per shift, 4 per day on average	1.36E-04
WCS3	Laboratory technicians	1-5 per site	N/A
WCS4	Maintenance and/or cleaning workers	1-5 per shift, 3 per day on average	3.84E-04
WCS5	Machinists	1-15 per site, 5 per day @ 40% of time	1.60E-03
WCS6	Incidentally exposed workers	0-15 per shift, 6 FTE per day	1.00E-0
Source: Information from CSR Note: Excess lung cancer risk refers to 40 years of occupational exposure			

Note that WCS3 (relating to laboratory technicians) is not considered further as the handling of substances in laboratories for quality control purposes under controlled conditions and in amounts below 1 tonne per annum (t/a) falls under the REACH Art. 56(3) exemption. Furthermore, the sampling activities that may be carried out by laboratory technicians are covered under other WCS.

4.4.2.2 Humans via the environment

Excess lifetime cancer risks

The assessment of risks to 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 conducted 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). 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.

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 **Table 4-10**.

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
1.12E-04	1.02E-05	2.76E-04	1.62E-05	3.26E-06
a) RAC dose-response relationship based on excess lifetime lung cancer risk (ECHA, 2013): 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 (ECHA, 2013): 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 for those Authorisations relevant to continued use in anodise sealing is summarised in **Table 4-11** below. 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. As there is the potential for the applicants of this combined AoA/SEA to begin supply to downstream users who are not supporting the ADCR, the numbers of exposed staff relevant to all the original CTAC and CCST parent authorisations is presented here. Note that Authorisations 20/18/21-25 relate to aeroderivative uses of chromium trioxide for surface treatment, but these uses will occur at the same sites as notifying for A&D uses and would therefore result in double-counting.

Taking a simple total of the figures for the number of staff exposed would 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 across all uses
Chromium trioxide	REACH/20/18/14 to REACH/20/18/20	Passivation of non-Al metallic coatings, of stainless steel, chemical conversion coating and anodising and anodise sealing	1107
Sodium dichromate	REACH/20/4/1	Passivation of non-Al metallic coatings, Passivation of stainless steel, chemical conversion coating, anodise sealing, pre-treatment and inorganic finish stripping	408

Table 4-11: Number of workers exposed - Article 66 Notifications data			
Substance	**Authorisation number**	**Use(s)**	**Staff Exposed across all uses**
	REACH/20/5/3-to REACH/20/5/5	Passivation of non-Al metallic coatings, Passivation of stainless steel, chemical conversion coating, anodise sealing, pre-treatment and inorganic finish stripping and anodising and anodise sealing	450
	REACH/14/0	Anodise sealing	N/A
Potassium dichromate	REACH/20/3/1	Passivation of non-Al metallic coatings, chemical conversion coating and anodise sealing	26
	REACH/19/31/0	Anodise sealing	5
	REACH/20/2/1	Passivation of non-Al metallic coatings, chemical conversion coating and anodise sealing	473
Sodium chromate	REACH/19/32/2 to REACH 19/32/3	Chemical conversion coating and anodise sealing	490

Number of workers based on SEA questionnaire data

Responses to the SEA questionnaire indicated that 430 workers (full time equivalent) are directly involved in anodise sealing across the 59 sites for which data were provided. This is broken down in **Table 4-12** below by role in the supply chain, and as extrapolated out to the 125 EEA and 35 UK sites.

Table 4-12: Employees linked to chromate-based anodise sealing activities across all EEA and UK sites					
Number of workers at sites	**Number of sites EEA**	**Number of sites UK**	**No of employees EEA**	**No of employees UK**	**Total**
Number of workers 59 sites involved in anodise sealing					
Build-to-Print	12	14	39	34	73
Design-to-Build	5	1	28	5	33
MRO only	9	2	166	37	202
ADCR members	12	4	110	8	118
Total 59 sites	**38**	**21**	343	84	427
Number of workers at 125 EEA sites and 35 UK sites involved in anodise sealing					
Build-to-Print	60	20	195	49	244
Design-to-Build	10	3	56	15	71
MRO only	23	7	423	129	552
ADCR members	32	5	294	10	304
Total 160 sites	125	35	968	202	1170

In total, this translates to a potential 970 exposed workers across the 125 EEA sites and 200 across the 35 UK sites. These figures are significantly lower than the number implied by the CSR assumptions on the average number of workers exposed but may be more consistent with the Article 66 notifications.

To ensure that the assessment is conservative, the average figures assumed in the CSR are extrapolated out to the total numbers of sites to act as the basis for the assessment. This gives the figures set out in **Table 4-13** as the number of workers exposed under each WCS.

Table 4-13: Number of employees undertaking anodise sealing across the EEA and UK

Worker Contributing Scenarios		Average No. Exposed from CSR	125 EEA sites	35 UK sites
WCS1	Line operators	5	625	175
WCS2	Storage area workers	4	500	140
WCS4	Maintenance and/or cleaning workers	3	375	105
WCS5	Machinists	5	625	175
WCS6	Incidentally exposed workers	6	750	210
Total		**23**	2,875	805

Note that WCS3 (relating to laboratory technicians) is not considered further as the handling of substances in laboratories for quality control purposes under controlled conditions and in amounts below 1 tonne per annum (t/a) falls under the REACH Art. 56(3) exemption. Furthermore, the sampling activities that may be carried out by lab technicians are covered under other WCS.

4.4.3.2 Humans via the Environment

The relevant local population exposure to 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 EEA country and the UK;
- The relevant distance from sites for the local assessment, taken as the default assumption of a 1,000m radius (or 3.14 km^2).

A 1,000m radius is adopted here to estimate the exposed population as, for most sites, the HvE results are driven by emissions to air. Oral exposure risks are typically much lower. As a result, adopting the EUSES default assumption related to the capacity of local sewage treatment plants would over-estimate the number of inhabitants that may be exposed due to emissions from each site.

The resulting estimates of the number of people exposed within the general population are given in **Table 4–14** for the EEA and UK. The allocation of sites is based on information collected from the SEA questionnaires and from ADCR members on the location of their supply chains. The estimated total number of humans exposed via the environment in the EEA is around 40,100, with the UK figure being under 46,200 (with the UK figure appearing disproportionately high due to its high 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.

Table 4–14: General public, local assessment exposed population from anodise sealing across the EEA and UK			
Countries with DUs	**No. Sites per country**	**Population density per km^2**	**Exposed local population within 1000m radius**
Italy	30	200	6,283
Poland	24	123	2,705
France	20	118	10,009
Germany	11	232	8,017
Spain	6	92	1,734
Czech Republic	6	135	1,272
Netherlands	6	421	2,645
Belgium	6	376	1,181
Romania	6	82	258
Hungary	4	105	330
Bulgaria	2	64	201
Portugal	2	112	352
Malta	2	1.63	5,130
Total EEA	**125**		40,118
UK	**35**	**424**	**46,221**

4.4.4 Residual health risks

4.4.4.1 Introduction

Under the Applied-for-Use Scenario, use of Cr(VI) in anodise sealing will continue after the end of the current review period for a total of 12 years.

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[55]. 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.

[55] 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[56] 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: 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 in **Table 4-15** above are applied to the estimates to calculate the total number of additional fatal and non-fatal intestinal cancer cases[57].

(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 authorisation decisions. The number of excess cancer 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 WCS to calculate the total excess cancer cases arising from the continued use of chromates in anodise sealing. **Table 4-16** and **Table 4-17** provide a summary of the results across all WCS for EEA and UK workers.

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[56] Colorectum is taken as a proxy for intestinal cancer cases.

[57] It is assumed that here the dose response relationship pertains to both additional fatal and non-fatal intestinal cases.

Note that WCS3 (relating 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 1 tonne per annum falls under the REACH Art. 56(3) exemption[58]. Furthermore, the sampling activities that may be carried out by laboratory technicians are covered under other WCS.

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	625	1.08E-03	0.68	0.53	0.14
WCS2	500	1.36E-04	0.07	0.05	0.01
WCS4	375	3.84E-04	0.14	0.11	0.03
WCS5	625	1.60E-03	1.00	0.79	0.21
WCS6	750	1.00E-03	0.75	0.59	0.16
		Years - Lifetime	40.00	2.08	0.55
		Years - Review period	12.00	0.62	0.17
		Years - Annual	1.00	0.05	0.01

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	175	1.08E-03	0.19	0.15	0.04
WCS2	140	1.36E-04	0.02	0.02	0.00
WCS4	105	3.84E-04	0.04	0.03	0.01
WCS5	175	1.60E-03	0.28	0.22	0.06
WCS6	210	1.00E-03	0.21	0.17	0.04
		Years - Lifetime	40.00	0.58	0.16
		Years - Review period	12.00	0.17	0.05
		Years - Annual	1.00	0.01	0.00

4.4.4.4 Predicted excess cancer cases with continued use: Humans via the environment

The total number of people exposed 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

[58] https://echa.europa.eu/de/support/qas-support/browse/-/qa/70Qx/view/ids/585-1442-1443-1498-1565

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 excess cases in people exposed via the environment (local assessment) across the EU 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
Italy	30	200	6283	3.16E-05	1.99E-01	**0.16**	**0.04**
Poland	24	123	2705	3.16E-05	8.55E-02	**0.07**	**0.02**
France	20	118	10009	3.16E-05	3.16E-01	**0.25**	**0.07**
Germany	11	232	8017	3.16E-05	2.53E-01	**0.20**	**0.05**
Spain	6	92	1734	3.16E-05	5.48E-02	**0.04**	**0.01**
Czech Republic	6	135	1272	3.16E-05	4.02E-02	**0.03**	**0.01**
Netherlands	6	421	2645	3.16E-05	8.36E-02	**0.07**	**0.02**
Belgium	6	376	1181	3.16E-05	3.73E-02	**0.03**	**0.01**
Romania	6	82	258	3.16E-05	8.14E-03	**0.01**	**0.00**
Hungary	4	105	330	3.16E-05	1.04E-02	**0.01**	**0.00**
Bulgaria	2	64	201	3.16E-05	6.35E-03	**0.01**	**0.00**
Portugal	2	112	352	3.16E-05	1.11E-02	**0.01**	**0.00**
Malta	2	1.633	5130	3.16E-05	1.62E-01	**0.13**	**0.03**
Total	**125**		**40118**		1.27E+00	**1.00**	**0.27**
			Years – Lifetime cases		**70.00**	**1.00E+00**	**1.58E-01**
			Years - Review period		**12.00**	**1.72E-01**	**4.56E-02**
			Years - Annual		**1.00**	**1.43E-02**	**3.80E-03**
UK	**35**	424	46621	3.16E-05	1.47E+00	**1.16**	**0.31**
			Years – Lifetime cases		**70.00**	**1.16E+00**	**3.09E-01**
			Years - Review period		**12.00**	**2.00E-01**	**5.30E-02**
			Years - Annual		**1.00**	**1.66E-02**	**4.42E-03**

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 2024 (inclusive of the end of 2024) to the end of 2036 (i.e., a 12 year review period) has been adopted and a 4% discount rate has been employed for calculating net present values[59]. It has been assumed that the levels of exposure to Cr(VI) for workers and members of the general population remain 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 the 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[60] 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[61]. 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[62]. 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**.

[59] EC Better Regulation Toolbox – Tool #61: https://ec.europa.eu/info/sites/default/files/file_import/better-regulation-toolbox-61_en_0.pdf

[60] 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.

[61] ECHA (2016b) Valuing selected health impacts of chemicals. Available at: http://echa.europa.eu/contact

[62] 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[63]			
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)[64]			
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 lung cancer studies is €16,807 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 figures are high compared to the UK data; as a result, the average across the two UK studies is taken here, with this being around €14,295 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 5 years, 5% after 10 years[65]. With respect to intestinal cancer morbidity cases, we have taken a percentage survival of 76% after one year since diagnosis, 59% after five years, and 57% after 10 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 Net Present Value (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.

[63] 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.

[64] 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.

[65] 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.

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:

(3) (π × (€ 3,920,000)) + (σ × (€ 460,000 + € 30,840) = Total lung cancer costs

(4) (δ × (€ 3,920,000)) + (η × (€ 460,000 + €84,790)) = 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 **€912,000 for the EEA and €255,000 for the UK**, based on the assumption that Cr(VI)-based anodise sealing 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	0.62	0.17	0.17	0.05
Annual number of lung cancer cases	0.05	0.01	0.01	0.00
Present Value (PV, 2024)	€ 884,334	€ 27,585	€ 247,613	€ 7,724
Total PV costs	**€ 911,919**		**€ 255,337**	
Total annualised cost	**€ 210,525**		**€ 58,947**	

***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: humans via the environment

Table 4-21 applies the economic value of the associated health impacts to the additional statistical cases of cancer for the general population (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 approximately **€243,000 for the EEA and €292,000 for the UK**, based on the assumption that anodise sealing continues over the entire review period at 2024 tonnages; 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	0.17	0.05	0.20	0.05
Annual number of cancer cases	0.01	0.00	0.02	0.00
Present Value (PV, 2024)	€ 242,937	€ 8,276	€ 282,318	€ 9,618
Total PV costs	**€ 251,213**		**€ 291,936**	
Total annualised cost	**€ 57,995**		**€ 67,396**	
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 anodise sealing by workers in the A&D sector has been accounted for in the worker estimates presented in **Table 4-16** above.

4.4.7 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 continued use of the chromates in anodise sealing across the sector at an estimated 125 EEA sites and 35 UK sites covered by this combined AoA/SEA.

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	0.80	0.22	0.37	0.10
Annual number of cancer cases	0.07	0.02	0.03	0.01
Present Value (PV, 2024)	1,127,270	35,862	529,932	17,342
Total PV costs	**€ 1,163,132**		**€ 547,274**	
Total annualised cost	**€ 268,520**		**€ 126,343**	
Source: *Derived estimates from responses to the SEA questionnaire, Article 66 data, Eurostat data and CSR*				

5 Socio-Economic Analysis of Non-Use

5.1 The Non Use Scenario

5.1.1 Summary of consequences of non-use

The inability of companies to undertake anodise sealing across the EEA and in the UK using one or more of the chromates would be severe. This use is critical to corrosion protection and active corrosion inhibition across a broad range of components and assemblies. This includes application to newly produced components and for ensuring on-going corrosion protection, and other beneficial properties, following maintenance and repair activities.

Additionally, essential attributes are provided by Cr(VI)-based anodise sealing, which must be considered when assessing alternatives. This includes chemical resistance, layer thickness and impact on fatigue strength, which, alongside the key functionalities, provide safety and reliability of components.

If anodise sealing were no longer authorised and where qualified and certified alternatives are not available, Design Owners (i.e., OEMs and DtB companies) would be forced to re-locate some or all of their component production and aircraft manufacturing activities out of the EEA or UK. This would have subsequent effects for other parts of the A&D supply chains, as summarised below.

A refused Authorisation would have impacts on the EEA/UK chromate suppliers and the critical set of key functions provided by anodise sealing would be lost to A&D downstream users in the EEA and UK

↓

Due to certification and airworthiness requirements, downstream users would be forced to undertake Cr(VI)-based anodise sealing activities, as well as anodising processes dependent upon these, outside the EEA/UK, or shift to suppliers outside of the EEA/UK

↓

OEMs would shift manufacturing outside the EEA/UK due to the need for anodise sealing 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 anodise sealing only (and especially so for repairs)

↓

Design-to-Build suppliers may have more flexibility and shift their production activities outside the EEA/UK, resulting in the loss of profits and jobs

↓

Build-to-Print suppliers in the EEA would be forced to cease anodise sealing, and linked treatments, leading to relocation of this and related activities with consequent impacts on profits and jobs

↓

MROs would have to shift at least some (if not most) of their activities outside the EEA, as anodise sealing is an essential part of maintenance, repair and overhaul activities

↓

Relocation of MRO activities would cause significant disruption to Aerospace and Defence

↓

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

Civilian 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 sealing must be carried out promptly and in sequence to protect against corrosion, 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 a large portion of the value chain (production, repair and maintenance) outside of the EEA/UK, as summarised below.

5.1.2 Identification of plausible non-use scenarios

Discussions were held with the applicants, OEMs, DtBs, BtP suppliers and MROs to establish what the most likely non-use scenarios would be in the event of the non-Authorisation of anodise sealing. These included discussions surrounding the effects from the loss of anodise sealing, how activities could otherwise be organised and what options could be available to the companies, while they worked on meeting the strict qualification and certification requirements placed on the A&D sector, but also how activities could otherwise be organised.

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, how these impact on why they use Cr(VI) in anodise sealing, past investments and R&D, and the most likely impacts of a refused re-authorisation. Information on the first three of these was summarised in Section 4 as part of the description of 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 and airworthiness requirements, as detailed further below. Follow-up questions were asked to establish why producing components overseas and shipping them back to the EEA/UK was not feasible, with this then ruled out based on the answers received regarding the logistical difficulties and economic infeasibility. These were considered to be non-plausible scenarios and are discussed in Section 5.1.3 below.

Table 5-1 below details the choices presented in the SEA questionnaire and a count of the number of companies selecting each (39 companies in total provided responses, covering the 59 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 are presented below and 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: Company responses to SEA survey on most likely non-use scenarios				
	OEM	Build-to-Print only	Design-to-Build only	MROs – only
The decision is up to our customer		5		1
We may have to cease all operations as the company will no longer be viable		5	1	4
We will focus on other aerospace uses or on non-A&D uses		2		
We will shift our work outside the EEA/UK	5	1		1
We will stop undertaking use of the chromate(s) until we have certified alternative(s)		6	1	1
It is unclear at this time	1	1		
Number of responses (companies)	6*	20*	3	8
*One response left blank and one responded for EEA and UK sites				

5.1.2.1 OEMs

In discussions, the OEMs all stressed that the aim is the replacement of the use of Cr(VI) in anodise sealing with an alternative that enables the components to be qualified and certified. In some cases, a qualified alternative has been identified, but more time is required to implement the alternative across the entire supply chain (particularly where a significant number of suppliers may be involved in anodise sealing).

With respect to the plausibility of the different non-use scenarios identified above, the following are clear from consultation with the OEMs across the 15 sites for which data was provided in the SEA questionnaire responses:

- **We will shift our work involving chromates to another country outside the EEA.** This is the most plausible scenario for four of the OEMs directly involved in anodise sealing. Given the reliance on the use of Cr(VI)-based anodise sealing in supply chains, it is also the most likely response for those OEMs who rely on suppliers carrying out anodise sealing. This would be accompanied by losses in turnover of between 30 – 100% at the sites operated by these OEMs. The ability of one of these OEMs to shift its manufacturing relevant to anodise sealing outside the EEA/UK may be restricted, however, as it manufactures final products for the defence sector. If shifting work to countries outside the EEA is unacceptable due to the costs or timeframe involved in setting up the required manufacturing sites and supporting infrastructure, then a cessation of all operations may be the ultimate outcome for at least one of the OEMs with multiple sites in both the EEA and UK.

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 (i.e. September 2024) for chromium trioxide, potassium dichromate, sodium chromate and sodium dichromate, 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 also 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 the OEMs would move all or only some of their manufacturing outside the EEA/UK depends on the integrated "system" of activities undertaken at individual sites. Anodise sealing is only carried out across a subset of sites, but it may be critical to certain divisions and to the operations of suppliers to those sites. As noted in Section 2, the larger ADCR members may be supported by up to 17 suppliers undertaking anodise sealing regionally (with this figure used in generating the number of sites in total assumed to be carrying out anodise sealing in the EEA in particular). In terms of impacts on individual companies, the estimated loss of production and turnover ranges from around 30% to 100% of current levels at individual sites, with production expected to stop completely at sites where anodise sealing is part of the overall process flow for key components. As noted above, these impacts would be experienced by sites involved in civil aviation and/or defence manufacturing.

The impact of the decisions made by the OEMs (and to a lesser degree larger DtB companies) will determine the most likely responses across their supply chains. Due to the vertical integration of manufacturing activities, it is not feasible to only cease anodise sealing; all activities related to the manufacture of the relevant components, aircraft and other products may need to be moved outside the EEA/UK. Note that this shifting of activity outside the EEA/UK may involve either relocation or sub-contracting (for smaller components). Not only would manufacturing be impacted, but as noted above, MRO activities would also be affected with some of these operations also moving outside the EEA/UK. This includes relocation of machining activities, due to the increased likelihood of corrosion of machined components prior to coating.

Particular difficulties would be faced by companies in the defence sector. 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 have to be maintained in their current location could continue within the EEA/UK.

5.1.2.2 Design-to-Build

The SEA consultation concluded that DtB companies would cease use of the chromates until they had a certified alternative for production of components, as the development, testing, qualification and certification of alternatives will be very costly, and the components they manufacture have long lifetimes and require high costs to be re-qualified. One company identified that they could relocate chromate operations outside the EU.

More generally, follow-up discussions highlighted that if OEMs were to stop production or move their production activities outside the EEA/UK, then these companies would face closure or would be forced to also move their operations. Sub-contracting to companies outside the EEA/UK was not viewed as feasible given the logistics involved in shipping and warehousing parts (see further discussion below).

5.1.2.3 Build-to-Print

BtP companies rely on their customers to define the production methods that they must use. As a result, the potential responses of Build-to-Print companies to the non-use scenario are constrained. Most confirmed that the choice of whether to use chromates in anodise sealing is not theirs but their customers'. Several noted that they could not shift to alternatives for anodise sealing until these were qualified and certified for use in the production of components by their customers and the authorities, and the alternatives were deemed 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 undertake Cr(VI) -based anodise sealing in the EEA/UK, then they would have to either cease operations, sub-contract out the whole process 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.

It is of note that a supplier may be requested to sign a manual or code of conduct by the OEM, to ensure expectations for work are met, 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).

5.1.2.4 MROs

For companies that operate as MROs only, there is less choice. They will not undertake manufacturing per se, only the overhaul, repair and maintenance of different aircraft components, which can differ in size and complexity (ranging from the overhaul of a complete aircraft to maintenance of a single component).

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 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 anodise sealing using the chromates is only required to a very limited extent, it may remain essential as part of maintenance and repairs carried out to ensure that airworthiness regulations are met.

The inability to undertake anodise sealing to the requirements set out in Maintenance Manuals may make repair and overhaul services unviable for MROs. Without the ability to provide the full range of processes that may be required, it would be difficult to win business. 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 substances for anodise sealing. Where these requirements mandate the use of Cr(VI) then the MRO must use the chromate as instructed unless the manuals also list a qualified alternative.

As a result, those MRO sites which offer the full range of services including anodise sealing would no longer be viable and would have to cease operations in the EEA/UK. This is the case for two of the MROs, which would cease their EEA/UK operations, as a partial service would not be practical or feasible at their sites for the civil aviation customers. Of these companies, one indicated that they would potentially move these operations to Turkey, the Middle East or elsewhere.

The MRO that indicated they would cease using the chromates at their sites until certified alternatives were available also noted that this may have significant impacts on their customers, as well as on their own operations and turnover.

With respect to turnover losses, these ranged from 20 - 100% losses. However, the company indicating that direct losses would be around only 20% also noted that this could have a knock-on effect leading to a further 50% loss due to impacts on other activities that would be linked from a repair and maintenance perspective; indeed, the losses would be significant enough for this company to indicate that they may have to cease activities at the affected site.

Finally, two military MROs indicated that the use of the chromates in anodise sealing is important to maintenance, repair and overhaul of their military equipment. They did not provide full SEA responses but noted that the inability to carry out any of their identified uses of the chromates would impact on the operational and mission readiness of their air and other forces.

5.1.3 Non-plausible scenarios ruled out of consideration

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[66], 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, the scenario of moving to a poorer performing alternative would mean that, where no alternative provides an equivalent level of performance to the chromates, OEMs would have to accept an alternative that is less efficacious in delivering corrosion protection. The use of a less effective alternative would downgrade the performance of the final product, and the reduction in the functional performance of the alternative would give rise to several unacceptable risks/impacts:

- The highly likely risk of EASA (airworthiness authorities) and MoDs 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.

In an inadequately performing surface treatment, corrosion pits can form. These can turn into fatigue cracks which potentially endanger the whole final product. This is a particularly critical risk for the aerospace industry as corrosion pits can be extremely difficult to detect. Such issues likely would not appear suddenly but after several years, when hundreds of aerospace components are in-service. The potential for decreased performance from Cr(VI)-free anodise sealing would necessitate shorter inspection, maintenance and repair intervals to prevent failures, and flight safety obligations preclude the aerospace industry from introducing inferior alternatives on components.

[66] 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.

Additionally, as discussed in Section 3, corrosion resistance (or any of the other key functionalities), cannot be considered in isolation. 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. A poorer performing alternative may provide the key functionalities, but not meet the performance requirements associated with other technical feasibility criteria, leading to increased maintenance.

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 fewer 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 components.
- 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 increased number of aircraft required by each airline would be needed to compensate for inspection/overhaul downtime and early retirement.
- 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 the limitations of a change to the surface treatment system, 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.

Because the lack of experience with Cr(VI)-free solutions can have a critical safety impact, 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 and proven success, and therefore possible unknown or hidden properties, the performance of a Cr(VI)-free system cannot be highly rated. Consequentially, a significant reduction to the maintenance interval would be required. 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 would be required. This would result in investment in additional spare A&D products, to be used while products being repaired are out of service.

As a result, OEMs rule out moving to poorer performing alternative as a plausible scenario, as the risks are unacceptable. 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 benefits provided by anodise sealing are crucial to the manufacture of the relevant aircraft components in the EEA/UK; if there are no qualified alternatives certified for the use on components then such manufacturing work would cease.

Overseas production followed by maintaining EEA/UK inventories

To be competitive, companies have to 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 with 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). It is 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 components 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.[67] If such facilities are required at around 100 sites across the EEA and UK (to cover civilian and military requirements for storage of sealed and other components affected by a refused

[67] See for example the cost model available at: https://costmodelling.com/building-costs

authorisation), 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 components, such as airframes, because these components are not removed from the aircraft; these components 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.

- 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 anodise sealing 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 the circular economy.

It is not possible to estimate these impacts quantitatively due to their multi-fold nature (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.

The result would be that the cost of operating in the EEA/UK would increase considerably and become economically infeasible. 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 non-EEA/UK 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 be sealed quickly after machining. 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 components for military aircraft and equipment. However, as an overall strategy, it would not be feasible.

5.1.4 Conclusion on the most likely non-use scenario

The most likely non-use scenario is driven by the responses of the OEMs to the questions on the non-use scenario. They are the actors that carry out the R&D and testing (sometimes in collaboration with their chemical suppliers) 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 treatment plant 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 and UK suppliers (importers and distributers) of the chromates used in anodise sealing would be impacted by the loss of sales, with the market for Cr(VI)-based anodise sealing for A&D relocating outside the EEA/UK.

2. EEA/UK based producers of anodise sealing formulations would either cease manufacturing their current formulations or move manufacture outside the EEA/UK for sale to companies relocating their activities. Relocation of formulation manufacturing would require formulators to undertake necessary testing programmes to satisfy that a change in manufacturing location does not impact the performance and properties (of the formulations) that must continue to be met across all specifications that those formulations are qualified against. There is a risk that if the formulations manufactured in a new facility do not demonstrate continued ability to satisfy the specifications against which they are qualified, this could lead to the obsolescence of affected parts and products, including aircraft and military equipment. Even where relocation is possible and shown not to be of detriment, this would not be feasible before the end the current authorisation period.

3. OEMs that carry out anodise sealing as part of their own manufacturing would move a significant proportion of their manufacturing operations outside the EEA/UK, with the consequent loss of significant levels of turnover and employment. They will move those manufacturing activities reliant on the use of anodise sealing 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. The losses to the EEA/UK would range from around 30% - 50% of manufacturing turnover for some sites, rising to 65% - 100% of manufacturing turnover at others. On average it is assumed losses at affected sites would be around 60% of manufacturing turnover, with associated losses in jobs.

4. OEMs who do not carry out anodise sealing themselves may still 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. An alternative option would be increasing the capacities of existing non-EEA/UK suppliers that are already qualified by OEMs.

5. 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 of 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.

6. In some cases, these newly located supply chains would be developed using DtB (and BtP – see below) suppliers who have moved operations from the EEA/UK to other countries in order to continue supplying the OEMs. Those DtBs that undertake surface treatments for sectors other than A&D, and also using non-chromate-based alternatives where these are certified, are less likely to cease activities in the EEA/UK and hence as a group would be associated with a reduced level of profit losses. Overall, for the DtB companies, it has been assumed that turnover losses of around 40% would be realised based on the SEA data and discussions with key design owners. It must be recognised that this level of turnover loss implies that some companies losing a high percentage of turnover would still be able to cover their fixed costs and to remain financially viable.

7. A significant proportion of the existing BtP companies involved in anodise sealing – 80% based on SEA responses – do not supply other sectors and are reliant on the A&D sector; furthermore, the types of products that they manufacture are specific to the aerospace sector. This applies to those who indicated they "don't know" what the most plausible scenario would be for them and those that would cease trading or move outside the EEA/UK. There will also be significant loss of turnover for those that indicated they would cease anodise sealing until a certified alternative was available or that they would shift to other activities. Given the spread of losses reported in responses to the SEA questionnaire and interdependency of these companies with decisions made by the OEMs, it has been assumed that turnover losses across the BtP suppliers of around 60% would occur.

8. MRO sites that carry out anodise sealing as part of their services will also be severely hit 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 on average a loss of 55% of turnover at affected sites would occur.

9. 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.

10. Airlines and their passengers would be impacted by increased costs and planes on the ground, while military forces' mission readiness would be impacted by the risk of equipment becoming obsolete due to the inability to carry out repairs and/or maintenance activities according to manufacturers' requirements.

11. Taken together there would be significant economic impacts 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 that OEMs and DtBs will not have certified alternatives, which have been fully implemented across their supply chains for all components, 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"[68].

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 retain proximity. Such relocation would involve not just anodise sealing, but the associated pre-treatments, main treatments 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 production of just the specific components that require anodise sealing. **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 anodise sealing 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.

[68] 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)

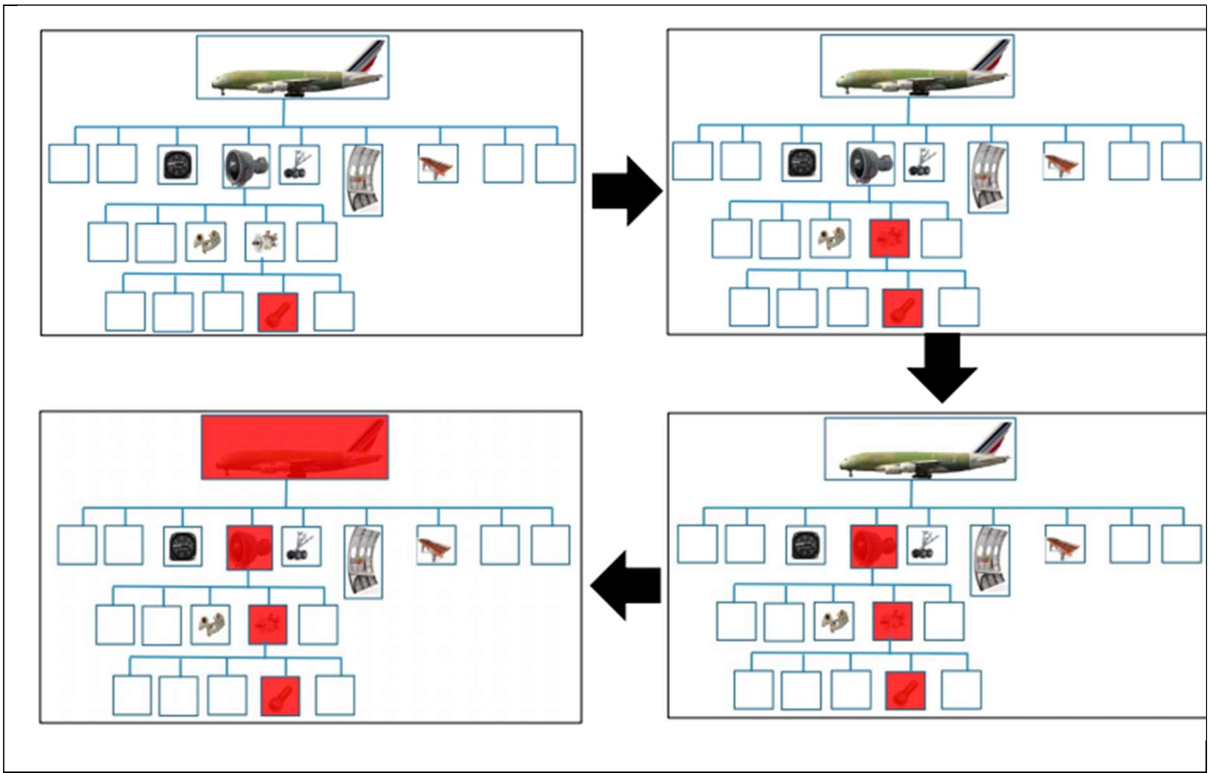

Figure 5–1: Interdependency of component availability in the manufacture of a final product
Source: GCCA (AfA 0116-01)

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 them 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 may make it overly optimistic. The infrastructure of the sector is based in part around manufacturing clusters or hubs (see also **Figure 5-3**), with smaller suppliers located around the sites operated by the larger OEMs. Not all of 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 in the EEA/UK 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 formulator of the products, would be impacted by the loss of sales of the four chromates for use in anodise sealing. At the specific supplier level, these impacts may vary in their significance, as the importance of the different chromates used in anodise sealing 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 2 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 formulators. Over time, as consumption of the chromates reduces in line with companies' substitution plans, sales and hence revenues will continue to decrease.

No quantitative estimates for the formulation 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 theoretically be possible to move anodise sealing activities outside the EEA/UK due to already existing supply chain sites in other countries, for example, the USA, Canada, China, Mexico, Morocco, 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 obligations 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 is 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 for the OEMs, MROs and the associated BtP and DtB suppliers.

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. The approaches do not account for foregone future turnover that would be achieved under the continued use scenario due to growth in the global demand for air traffic. They also do not account for profit losses due 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 are presented in **Table 5-2** below.

The job losses reported by respondents, which range from a few per site where only anodise sealing would cease to all employees in the event of closure are significant:

- For the 59 sites providing responses to the SEA questionnaire: 28,400 jobs (around 23,200 in the EEA and 5,200 in the UK) involving workers directly involved in anodise sealing and linked manufacturing activities across product lines or due to the cessation of MRO activities;

- Extrapolated out to the total 160 sites expected to be carrying out anodise sealing across the EEA/UK: 72,800 jobs (around 62,300 in the EEA and 10,400 in the UK) would be expected to be lost due to the cessation of anodise sealing and linked manufacturing activities across product lines or to the cessation of MRO services, including as a result of companies moving operations outside the EEA/UK.

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 anodise sealing and linked processes		Additional direct job losses – due to a cessation of manufacturing/MRO activities	
From SEA Survey	**EEA**	**UK**	**EEA**	**UK**	**EEA**	**UK**
Build-to-Print (26 sites)	12	14	275	301	484	96
Design-to-Build (6 sites)	5	1	345	15	315	63
MROs (11 sites)	9	2	1,629	362	5,847	1,299
OEMs (16 sites)	12	4	2,235	725	12,062	2,337
Total 59 sites	38	21	4,483	1,403	18,709	3,795
Job losses - Extrapolation of job losses under the Non-Use Scenario to the estimated 160 sites undertaking anodise sealing treatments						
Build to Print (80 sites)	60	10	1,374	431	2,421	137
Design-to-Build (13 sites)	10	3	690	45	630	189
MROs (30 sites)	23	7	4,162	1,267	14,943	4,548
OEMs (37 sites)	32	5	5,959	906	32,166	2,921
Total sites (160)	125	25	12,185	2,649	50,160	7,795
Total EEA across 125 sites			62,346			
Total UK across 35 sites			10,443			

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. This can be clearly seen by the UK figures which assume no additional direct job losses. Although these figures may appear high, they should be seen within the context of the roughly 890,000 employees (2019[69]) within the European aerospace sector, taking into account the critical importance of the chromates in anodise sealing.

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**.

The estimated losses in GVA across the 160 sites equate to:

- €5,700 million per annum for the 125 EEA sites due to the cessation of anodise sealing, related treatments and associated manufacturing and assembly activities; and
- €900 million per annum for the 35 UK sites due to the cessation of anodise sealing, related treatments and associated manufacturing and assembly activities.

For comparison, turnover for the EU A&D industry is around €259 billion[70] per annum, while that for the UK A&D sector is around €57 billion (£50 billion) based on 2020 figures[71]. Thus, although these figures may 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 Cr(VI)-based anodise sealing no longer be permitted.

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**. 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 (implied) values of lost operating surpluses generated by this GVA-based approach equate to:

- Loss of jobs at the 125 EEA sites: €1,700 million per annum; and
- Loss of jobs at the 35 UK sites: €300 million per annum.

69 Statista 2022: https://www.statista.com/statistics/638671/european-aerospace-defense-employment-figures/

70 https://www.statista.com/topics/4130/european-aerospace-industry/#topicHeader__wrapper

71 https://www.statista.com/statistics/625786/uk-aerospace-defense-security-space-sectors-turnover/

Table 5-3: GVA losses per annum under the Non-use scenario (2022 job figures, GVA data for 2018)						
	GVA per worker assumed by role		GVA lost per annum due to loss of Anodise sealing and linked jobs € million		GVA lost per annum due to a cessation of manufacturing/MRO activities - € million	
	EU	UK	EU	UK	EU	UK
Build-to-Print (26 sites)	59,964	59,964	16.57	18.17	29.19	5.77
Design-to-Build (6 sites)	59,964	59,964	20.79	0.90	18.99	3.80
MROs (11 sites)	85,000	85,000	138.43	30.76	497.01	110.45
OEMs (16 sites)	98,500	98,500	220.11	71.41	1,188.14	230.19
Total 59 sites			395.91	121.25	1,733.33	350.21
GVA losses - Extrapolation to the estimated 125 EU and 35 UK sites undertaking anodise sealing treatments						
Build-to-Print (80 sites)	59,964	59,964	82.84	25.96	145.95	8.25
Design-to-Build (13 sites)	59,964	59,964	41.59	2.71	37.97	11.39
MROs (30 sites)	85,000	85,000	353.77	107.67	1,270.14	386.56
OEMs (37 sites)	98,500	98,500	586.97	89.27	3,168.39	287.74
Total sites (160)			1,065.17	225.61	4,622.44	693.94
Total EEA across 125 sites - € million			**5,688**			
Total UK across 35 sites - € million			**920**			
*Weighted average GVA 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.						

Table 5-4: Operating surplus losses due to a cessation of manufacturing/MRO activities under the Non-Use Scenario						
	Total GVA losses due to lost jobs - Direct all € millions		Total personnel costs all lost jobs due to a cessation of manufacturing/MRO activities - € millions per annum		Implied operating surplus losses due to a cessation of manufacturing/MRO activities - € millions per annum	
	EU	UK	EU	UK	EU	UK
Build-to-Print (26 sites)	46	24	29.82	15.60	15.94	8.34
Design-to-Build (6 sites)	40	5	25.92	3.06	13.86	1.64
MROs (11 sites)	635	141	421.63	93.70	213.81	47.51
OEMs (16 sites)	1,408	302	1,009.37	216.18	398.89	85.43
Total sites (59)	**2,129**	**471**	1,486.75	328.54	642.49	142.92
Operating surplus losses - Extrapolation to the estimated 125 EU and 35 UK sites undertaking anodise sealing treatments						
Build-to-Print (80 sites)	229	34	149.09	22.29	79.70	11.92
Design-to-Build (13 sites)	80	14	51.85	9.19	27.72	4.91
MROs (30 sites)	1,624	494	1,077.51	327.94	546.40	166.29
OEMs (37 sites)	3,755	377	2,691.66	270.22	1,063.70	106.79
Total sites (160)	**5,688**	**920**	3,970.10	629.64	1,717.51	289.91
*Weighted average GVA 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.						

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 Cr(VI)-based anodise sealing for the A&D sector, as well as surface treatment and other processes for other sectors. They also account for potential loss in turnover from 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 (27 sites)	567	661	74	86
Design-to-Build (6 sites)	157	31	20	4
MROs (11 sites)	353	78	30	7
OEMs (15 sites)	8,794	2,931	923	308
Total 59 sites	**9,870**	**3,702**	**1,047**	**404**
Extrapolation of turnover and GOS losses to the estimated 90 sites undertaking anodise sealing treatments				
Build-to-Print (80 sites)	2,834	945	368	123
Design-to-Build (13 sites)	313	94	41	12
MROs (30 sites)	902	275	76	23
OEMs (37 sites)	23,451	3,664	2,462	385
Total sites (160)	**27,500**	**4,977**	**2,947**	**543**
*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 considered to be due to the turnover-based estimates taking better account of the loss in associated manufacturing, maintenance or repair activities, given the importance of Cr(VI)-based anodise sealing to both of these sets of companies.

- GVA based approach estimates of lost operating surplus:
  - Losses of €1,700 million per annum for the EEA
  - Losses of €300 million per annum for the UK
- Turnover based approach of lost operating surplus:

- Losses of €2,900 million per annum for the EEA
- Losses of €500 million per annum for the UK

These 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 was provided by any of the military organisations, reliant upon the continued use of Cr(VI)-based anodise sealing, 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 military forces.

Table 5-6: Comparison of profit loss estimates from the two methods

	Total job losses		% Turnover lost		Ratio of lost profits based on turnover approach to lost operating surplus based on jobs (Based on €billions lost)	
	EEA	UK	EEA	UK	EEA	UK
Build-to-Print (80 sites)	3,796	567	60%	60%	4.62	10.30
Design-to-Build (13 sites)	1,320	234	40%	40%	1.47	2.48
MROs (30 sites)	19,105	5,815	55%	55%	0.14	0.14
OEMs (37 sites)	38,125	3,828	60%	60%	2.31	3.60
Total sites (160)	62,346	10,443	€27,5 billion	€4.98 billion	1.72	1.87

5.2.2.6 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 four to 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 seven to 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 EEA and UK assets. However, given the potential scale of the impacts of a refused authorisation for the sector as a whole, 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 Cr(VI)-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 anodise sealing using alternatives is not relevant.

The OEMs determine whether there are alternatives that 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 one, two, four, seven 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 € millions	
	EU	UK	EU	UK
1 year profit losses (2025)	2,947	543	1,718	290
2 year profit losses (2026)	5,558	1,023.70	3,239	547
4 year profit losses (2028)	10,698	1,970.32	6,235	1,052
7 year profit losses (2031)	17,689	3,257.81	10,309	1,740
12 year profit losses (2036)	27,659	5,094	16,119	2,721

5.2.2.7 Other impacts on Aerospace and Defence Companies

Under the Non-use Scenario there would be an enormous impact on the A&D sector in the EEA/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 chromates in anodise sealing across the entirety of the EEA and UK A&D sectors. It is non-exclusive in this respect. It has been funded by the major (global) OEMs and DtB manufacturers in the EEA and the UK, with additional support provided by their suppliers and by Ministries of Defence, 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 major 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 components, these alternatives will be implemented throughout their value chain.

5.2.3.2 Competitors outside the EEA/UK

Under the non-use scenario, it is likely that some of the major OEMs and DtB suppliers would move outside the EEA/UK, creating new supply chains involving BtP manufacturers 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 Cr(VI)-based anodise sealing 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 anodise sealing, they would have to be performed outside the EEA/UK until the OEMs have gained approvals and certifications for the use of alternatives on components, 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 disassembled 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 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 a "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 per annum. Scaling this up to the EEA 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)[72], 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[73] 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 increase by an average of 4.3% per annum over the next 20 years, as illustrated in **Figure 5–2**. 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.

72 https://www.statista.com/statistics/1258900/aircraft-lease-rates-aircraft-model/#statisticContainer

73 https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf

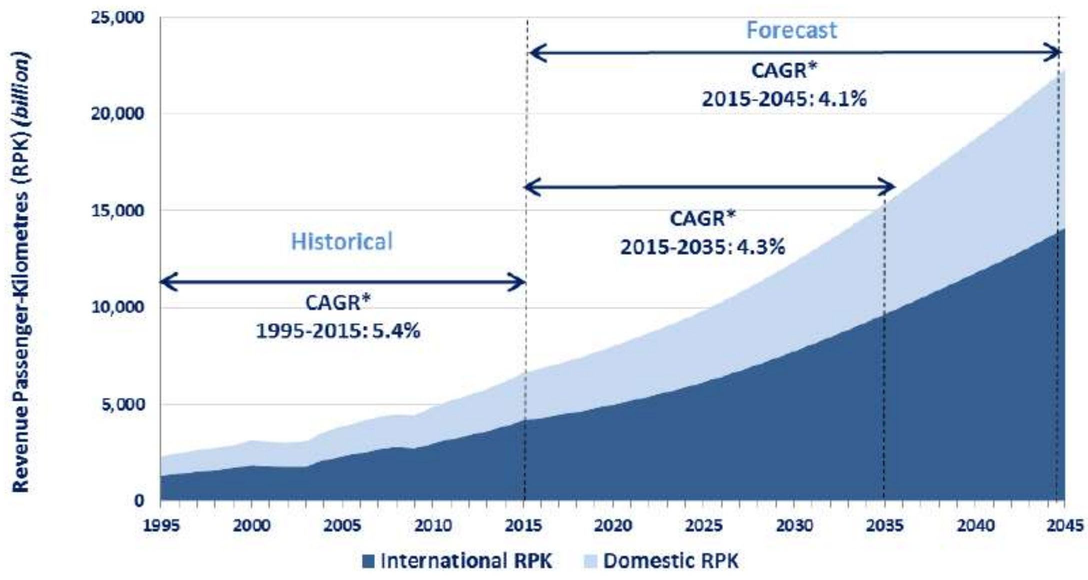

Figure 5–2: Forecast compound annual growth rates – Revenue Passenger-kilometres

Post COVID-19, projections are for a lower rate of increase in air traffic, with Airbus suggesting a growth rate between 2019 and 2040 of around 3.9% CAGR.[74] The impact of COVID-19 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[75] (covering inter-regional and intra-regional/domestic) for the period between 2018 and 2038.

This level of growth in EEA air traffic, together with the jobs and contributions to GDP that it would bring, could be impacted under the NUS. Impacts on the ability of MROs to undertake repairs and carry out maintenance where this would require the use of Cr(VI)-based anodise sealing 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 review period (unless airlines responded by buying more planes or stockpiling of components, which would inevitably give rise to increases due to the costs of holding spares and/or bringing spare planes on-line).

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.

Two national Ministries of Defence have provided information regarding their use of anodise sealing, with SEA responses also provided by defence suppliers. In addition, MROs providing services to MODs have also provided information to ensure that they are able to continue to maintain and repair military final products into the future. The implications of having to cease these activities are significant.

[74] Airbus (undated): Airbus Global Market Forecast 2021 – 2040. Available at: Global Market Forecast | Airbus

[75] https://www.statista.com/statistics/1094689/annual-growth-rate-air-passenger-traffic-europe/

Military final products which could not be maintained to appropriate safety standards would have to be removed from service. Not only would this impact on the availability of key equipment in the case of a military emergency, but it would also affect the mission readiness of operational forces in particular.

It is also worth noting that Governments are likely to be reluctant to send military final products to MRO facilities located in non-EU countries, although the US, Canada and Turkey are NATO members, and as such may be suitable candidates to service European military aircraft. There would be impacts on mission readiness if repairs cannot be done locally. 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 under Article 2(3) of REACH; 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. 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 of estimated direct and indirect economic effects through innovations, new technologies and products.[76]

Indeed, the European Commission announced in July 2022 that it plans to grant a total EU funding of almost **€1.2 billion** supporting **61 collaborative defence research and development projects** selected following the first ever calls for proposals under the European Defence Fund (EDF).[77] The aim will be to support high-end defence capability projects such as the next generation of fighter aircrafts, tanks and ships, as well as critical defence technologies such as military cloud, Artificial Intelligence, semiconductors, space, cyber or medical counter-measures. It will also spearhead disruptive technologies, notably in quantum technologies and new materials, and tap into promising SMEs and start-ups. Some of these gains may not be realised if the main EEA defence OEMs have to divert resources into shifting part of their manufacturing base outside of the EEA.

However, under the NUS, companies manufacturing components for defence, and servicing military aircraft and other derivative defence products would most likely 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. If some production moved out of the

76 https://www.evropskyvyzkum.cz/cs/storage/bf5134fec407f6e005288c0e2631ad232c38c013?uid=bf5134fec407f6e005288c0e2631ad232c38c013

77 https://ec.europa.eu/commission/presscorner/detail/en/IP_22_4595

EEA/UK under the NUS, as indicated by some OEMs as their most likely response, then the above multiplier effects would be lost.

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 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 for substances - see formulation SEA for SD mixtures	Not assessed
A&D companies	• Annualised lost profits: ○ EEA: €1,700 – 2,900 million ○ UK: €290 – 540 million • 12 year lost profits: ○ EEA: €16,100 – 27,700 million ○ UK: €2,700 – 5,100 million	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 employment 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 CO_2 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 anodise sealing 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 Cr(VI) and not using Cr(VI) 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 repair requiring the use of Cr(VI)-based anodise sealing, 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 paucity of the components needed for their maintenance and repair. This would create excess waste and 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 components and assemblies. The industry has been active in trying to decrease buy-to fly ratios (the ratio of material inputs to final component output), and the non-use scenario would significantly undermine these efforts as the more frequent production of new components would increase the waste and scrappage generated. Scrap is material which is wasted during the production process.

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).

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 Cr(VI) 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

The main social costs expected under the NUS are the redundancies that would be expected to result from the cessation of production activities (all or some) and the closure and relocation of sites. As indicated in the assessment of economic costs, the estimated reduction in job losses is based on responses to the SEA questionnaires covering 59 sites in total. Direct job losses will impact on workers at the site involved in anodise sealing and linked pre-treatment, main treatments (i.e., anodising) and post-treatment processes, as well as workers involved in subsequent manufacturing and assembly steps and related activities (e.g., lab workers, etc.). 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 the impacts across the A&D sector may make it 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 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 anodise sealing to the manufacture of components, as well as to maintenance and repairs of such components at a subset of MRO facilities. No consideration is given to job losses at those companies providing services that are contracted to provide cleaning and other services to the BtPs, DtBs, MROs and ORMs.

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[78]. The figures in **Table 5-9** indicate that approximately 73,000 A&D jobs would be in jeopardy under the NUS.

Table 5-9: Predicted job losses in aerospace companies under the NUS

Role	Total job losses due to cessation of manufacturing activities or relocation under the NUS	
	EEA	UK
Build-to-Print (80 sites)	3,796	567
Design-to-Build (13 sites)	1,320	234
MROs (30 sites)	19,105	5,815
OEMs (37 sites)	38,125	3,828
Total sites (160)	62,346	10,443

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[79]).

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[80] 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 A&D sector production sites varying from seven 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

78 https://www.eudsp.eu/event_images/Downloads/Defence%20Careers%20brochure_1.pdf

79 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

80 At the time of publication the UK was still an EU Member State

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 the companies and locations. For the purposes of these calculations, a figure of €40k 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 underestimate the average salary, given that A&D jobs are higher paid than those in other industries.

The resulting estimates of the social costs of unemployment are given in **Table 5-10** based on consideration of the geographic distribution of Article 66 notifications, the location of SEA respondents, and the location of suppliers in the ADCR members' supply chains, as well as MROs. The estimated social costs under the NUS are around €6,900 million for the EEA and €900 million for the UK due to the cessation of the anodise sealing and linked manufacturing activities.

Table 5-10: Social Cost of Unemployment – Job losses at A&D companies under the NUS

Country	Employment losses due to cessation or relocation of manufacturing	Social costs of unemployment (€)
Italy	14,963	1,813,519,093
Poland	11,846	1,113,498,728
France	9,975	1,264,874,703
Germany	5,611	583,558,124
Spain	3,117	349,137,339
Czech Republic	3,117	341,655,825
Netherlands	3,117	293,025,981
Belgium	3,117	377,816,478
Romania	3,117	298,013,657
Hungary	1,247	137,161,098
Bulgaria	1,247	111,723,949
Portugal	1,247	141,151,239
Malta	623	91,355,236
Total EEA	**62,346**	**6,916,491,450**
United Kingdom	10,443	873,074,749
Total rounded	**72,800**	**7,789,566,000**

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 A&D 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 5-9** given that it includes the loss of jobs at suppliers to the aerospace OEMs. The figures exclude 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[81] quotes an employment multiplier of between 2.2 and 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[82](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, and 16,000 employees with over €2.5 billion turnover (See Annex 2). Both clusters are an essential part of the local economy.

[81] 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

[82] https://www.eacp-aero.eu/about-eacp/member-chart.html

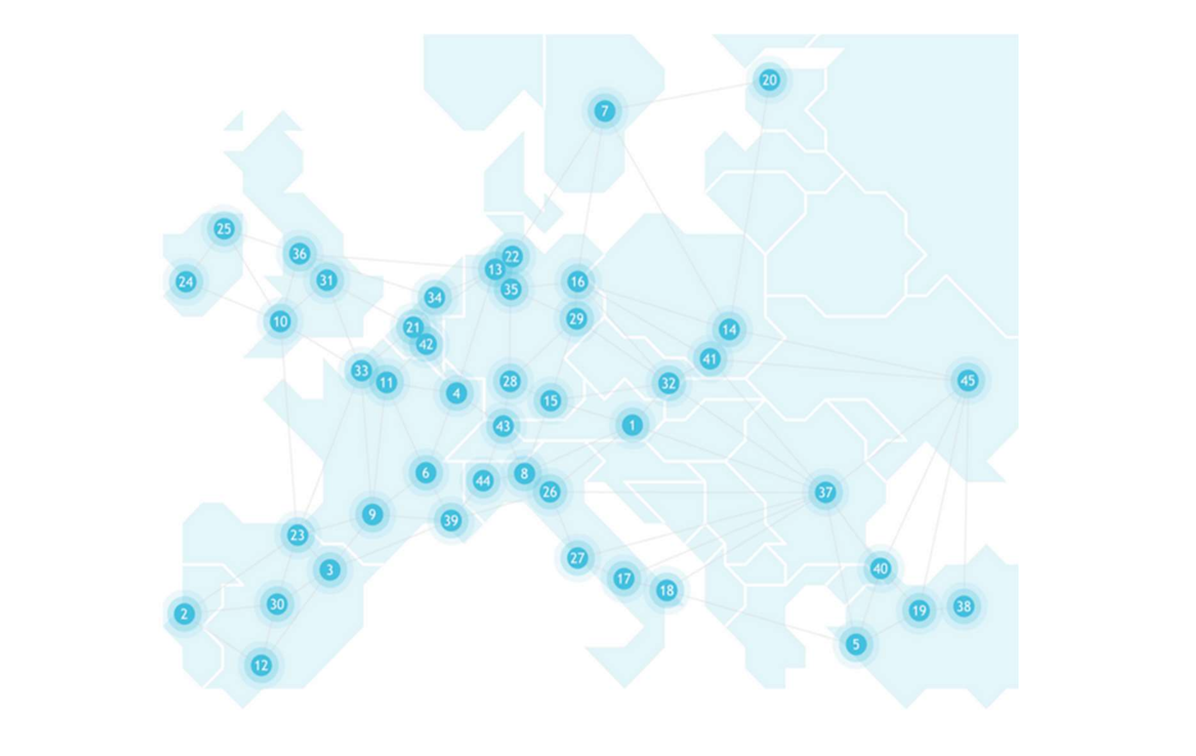

Figure 5-3: Aerospace clusters across Europe

5.4.2.2 Air transport multiplier effects

A 2019 "Aviation Benefits Report"[83] 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 directly within the aviation sector, with the remaining 9.6 million arising 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.

[83] Published by the ACI, CANSO, IATA, ICAO and the ICCAIA, available at: https://www.icao.int/sustainability/Documents/AVIATION-BENEFITS-2019-web.pdf

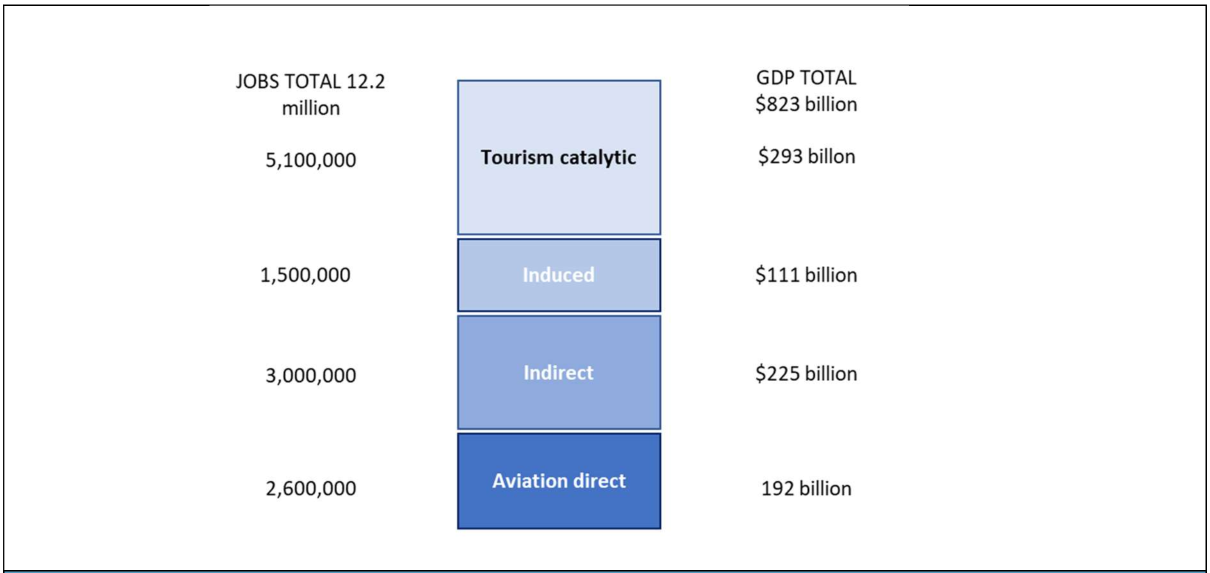

Figure 5-4: Aviation related multiplier effects
Source: Based on: ***https://www.icao.int/sustainability/Documents/AVIATION-BENEFITS-2019-web.pdf***

The potential employment losses associated with a decline in European aviation can be seen by reference to the impacts of COVID-19[84]. A “COVID-19 Analysis Fact Sheet” produced by Aviation Benefits Beyond Borders reports the following:

- A reduction from 2.7 million 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 due to the loss of anodise sealing alone, 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:

- Job losses at A&D companies:
    - Around 62,300 jobs in the EEA due to the loss of anodise sealing, linked surface treatments, assembly and/or manufacturing activities, and
    - Over 10,400 jobs in the UK due to the loss of;
- Social costs of unemployment:
    - €6,900 million for the EEA associated with direct job losses and
    - €900 million for the UK associated with direct job losses;

[84] https://aviationbenefits.org/media/167482/abbb21_factsheet_covid19-1.pdf

- Indirect and induced unemployment at the regional and national level due to direct job losses; and
- 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 societal costs associated with the non-use scenario. Figures are provided as annualised values, with costs also presented as a PV over a two-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 four-year period, with over 60% incurring losses for seven years and 55% for the full 12-year period as design owners work continues towards development, testing, qualification, validation, certification, and industrialisation of alternatives.

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%, 2 years**	**€ annualised values**
Lost producer surplus[1]: Impacts on applicants - Lost profits EEA - Lost profits UK Impacts on A&D companies[1]: - Lost profits EEA - Lost profits UK	Applicants: not quantified See also formulation SEA A&D companies EEA: €3,200 – 5,600 million UK: €500 – 1,000 million	Applicants: not quantified See also formulation SEA A&D companies EEA: €1,700 – 2,900 million UK: €290 – 540 million
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: €6,900 million UK: €900 million	EEA: €3,500 million UK: €400 million
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 (PV)	EEA: €10,200 – 12,500 million UK: €1,900 – 1,400 million	EEA: €5,200 – 6,400 million UK: €700 – 1,000 million
2. 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.	
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 anodise sealing on turbine blades and engine components 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		

6 Conclusion

6.1 Steps taken to identify potential alternatives

When creating a Substitution plan for substances subject to Authorisation, suitable alternatives to Cr(VI) for anodise sealing should be "generally available"[85]. At present, this condition has not been met, as there are not alternatives which have met the strict regulatory requirements within the A&D industry for all components onto which anodise seals containing Cr(VI) are currently applied.

Alongside the various R&D activities, as described in Section 3.4.1, and information reported in academic literature and patent reports as described in Sections 3.4.3, 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 anodise sealing are shown in **Figure 6-1**:

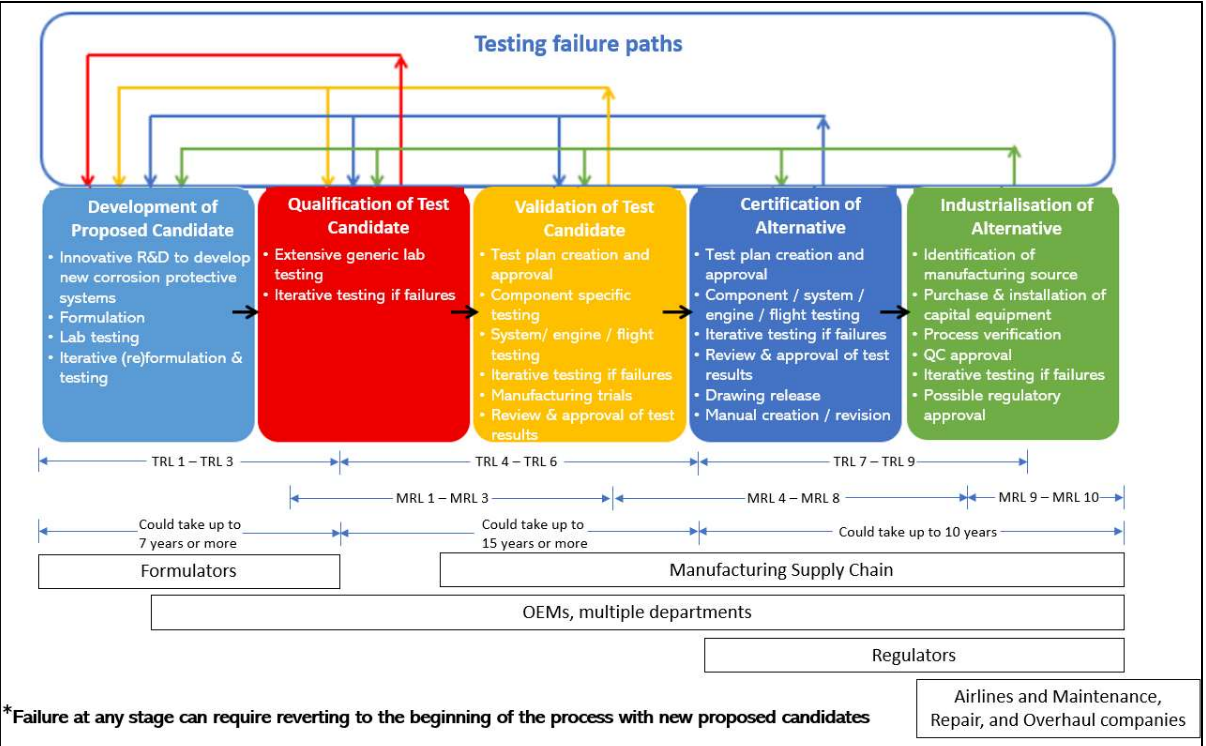

Figure 6-1: Schematic showing the key phases of the substitution process.
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note 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)

85 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)

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;
  - Negotiation of supplier(s) contracts.
- Demonstration of compliance followed by industrialisation; 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 anodise sealing. Individual members often have multiple substitution plans within anodise sealing, 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, for certain substrates, and following certain anodic processes, thereby reducing their Cr(VI) usage, many technical challenges remain.

As discussed in Section 3.7.2 and shown in **Figure 6-2** below, of the 34 distinct substitution plans for anodise sealing assessed in this combined AoA/SEA, 29% 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 it is anticipated Cr(VI) will no longer be used for the process and components covered in that substitution plan.

The proportion of substitution plans that are expected to achieve MRL 10 is then expected to progressively increase to 59% in 2028, 85% in 2031, and 91% in 2036. The potential need for more than 12 years has been identified by some OEMs due to their inability to identify any 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.

In 2031 (equivalent to seven years beyond the expiry date for the existing authorisations), 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, a proportion are not expected to have achieved MRL 10 and are expected to be at the validation, certification, or industrialisation stage. For these substitution plans (which are from several member companies), there is still expected to be a need for the use of Cr(VI).

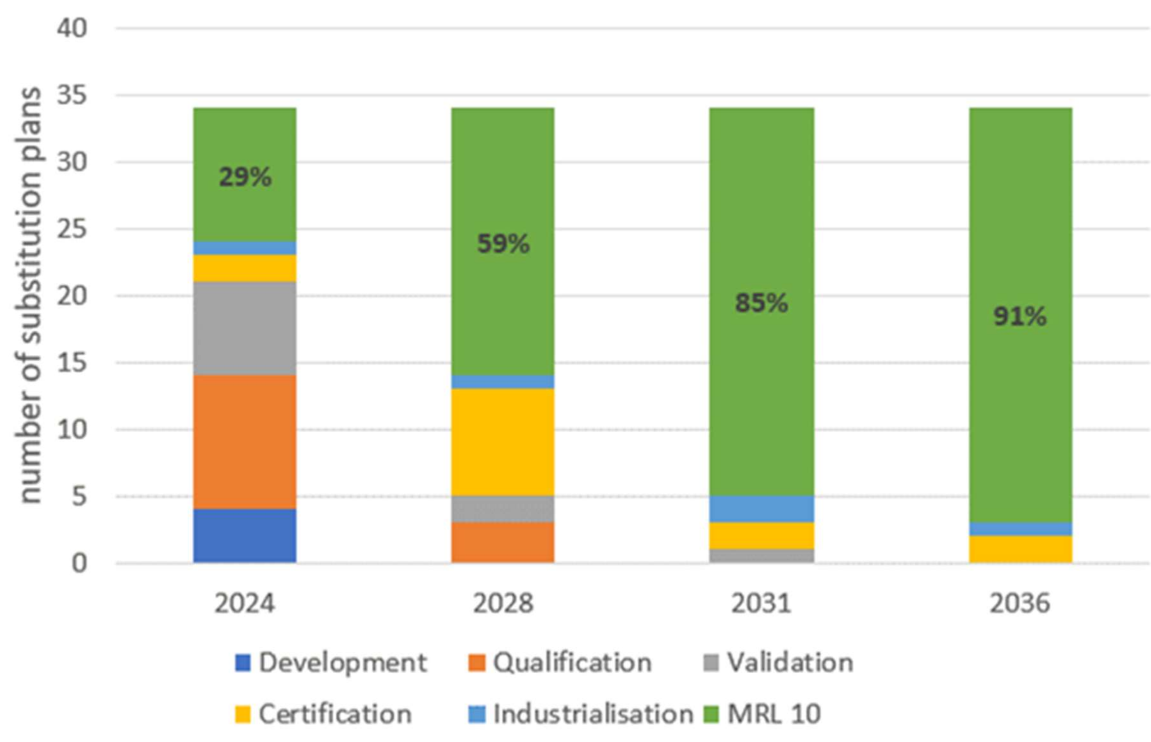

Figure 6-2: Expected progression of substitution plans for the use of Cr(VI) in anodise sealing, by year
The vertical axis refers to number of substitution plans (some members have multiple substitution plans for anodise sealing). The percentage value shown on each of the green bars indicates the proportion of substitution plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which manufacturing is in full rate production/deployment and it is therefore where it is expected that Cr(VI) will be fully substituted under the relevant plan.
Source: RPA analysis, ADCR members

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

6.3 Comparison of the benefits and risk

Table 6-1 summarises the socio-economic benefits of continued use of the chromates in anodise sealing by companies in the A&D sector. Overall, net benefits of over €10 billion for the EEA and €1.4 billion for the UK (Net Present Value social costs over two years/risks over 12 years, @4%) can be estimated for the continued use scenario. These figures capture continued profits to the applicants and 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 €1.16 million and €0.55 million for the EEA and UK respectively over 12 years).

As can be seen from **Table 6-1**, the ratio of the benefits of continued use to the monetised value of the residual health risks is around 8,731 on the lower bound assumptions for the EEA and 2,594 on the lower bound assumptions for the UK.

Table 6-1: Summary of societal costs and residual risks (NPV costs over 2 years/risks 12 years, 4%)

Societal costs of non-use		Risks of continued use	
Monetised 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: €3,200 – 5,600 million (£2,800 – 4,800 million) UK: €500 – 1,000 million (£470 – 880 million)	Monetised excess risks to directly and indirectly exposed workers (€ per year over 12 years)	EEA: €0.21 million (£0.19 million) UK: €0.058 million (£0.050 million)
Social costs of unemployment	EEA: €6,900 million (£5,900 million) UK: €900 million (£750 million)	Monetised excess risks to the general population (€ per year over 12 years)	EEA: €0.058 million (£0.050 million UK: €0.067 million (£0.058 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 excess health risks): - EEA: €10,200 – 12,500 million (£8,700 – 10, 700 million) - UK: €1,400 – 1,900 million (£1,200 – 1,600 million) • Ratio of annualised societal costs to risks: - EEA: 8,731: 1 to 10,725: 1 - UK: 2,594: 1 to 3,466 : 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:

If the Applicants are not granted an Authorisation that would allow continued sales of the chromates, critical substances and formulations would be lost to A&D downstream users in the EEA and UK

Due to certification and airworthiness requirements, downstream users would be forced to undertake anodising where this also required chromate-based anodise sealing outside the EEA/UK or shift to suppliers outside of the EEA/UK

OEMs would shift most of their manufacturing activities outside the EEA/UK as it would not be technically feasible in some cases, as well as inefficient and costly, to transport parts in and out of the EEA/UK

Design-to-Build suppliers may have more flexibility and shift some or all of their production activities outside the EEA/UK, resulting in the loss of GVA and jobs to the EEA/UK

Build-to-Print suppliers in the EEA would be forced to cease anodising treatments reliant upon anodise sealing as a follow-on process treatment; as a result, BtP suppliers in the EEA/UK would be replaced by suppliers outside the EEA/UK

MROs will have to shift at least some (if not most) of their activities outside the EEA/UK, as anodise sealing is an essential part of maintenance, repairs and overhaul activities

The relocation of MRO activities outside the EEA will cause significant disruption to civil aviation. This will impact on both passenger flights and cargo transport. It will also impact other aviation such as helicopters used for medical emergencies

Ministries of Defence will face logistic difficulties with respect to the maintenance of aircraft and other equipment, with this impacting on mission readiness or the need to retire equipment prematurely. This will include the need to reach servicing agreements with non-EEA countries

Passengers and freight shippers will face reduced flight availability and routes, as well as increased costs

Overall, it is clear that the benefits of continued use of the chromates in anodise sealing significantly outweigh the residual risks from continued use.

Three further points are relevant. Firstly, the use of the four chromates in anodise sealing 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 EEA 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.[86] 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.[87]

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) (ECHA, 2013):

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.*

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*

86 https://ec.europa.eu/info/sites/default/files/swd-strategic-dependencies-capacities_en.pdf

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

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, which are always required to meet the highest possible safety standards. As noted in Section 4.4, 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 EU aerospace industry[88]. They are a key driver underlying the difficulties facing the sector in substituting the use of the chromates in anodise sealing across all affected 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,

[88] 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.

due to the level of investment and costs that would be involved in such an activity for out of production A&D products; as 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. For example, 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. 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, manufactured and maintained 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 have to 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 and aircraft/equipment they are used in.

As such, a review period of at least 12 years is warranted and requested for the highly complex systems 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 anodise sealing, 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.

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. Cr(VI)-based anodise sealing, due to its extensive performance history, represents the baseline that alternatives must match to demonstrate equivalence.

For example, modern commercial aircraft (including helicopters) 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 Cr(VI)-based anodise sealing. Conversely, there is still limited experience with Cr(VI)-free alternatives 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 because of service life (and hence maintenance requirement) limitations due to a change in the surface treatment system, 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 utilise newly developed alloys that do not require a Cr(VI)-based coating (as typically used to provide corrosion protection on metallic legacy components). However, even in newer designs there may still be a need for the use of Cr(VI)-based anodise sealing, 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 and 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 or technologies. This is illustrated by the achievements of one OEM in reducing their use of the chromates by 75% (by weight) (see **Figure 6-3**).

This 75% reduction (by weight) in the use of the chromates 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 Cr(VI)-based anodise sealing (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 components and products which must meet military requirements (including those pertaining to UK, EEA and US equipment).

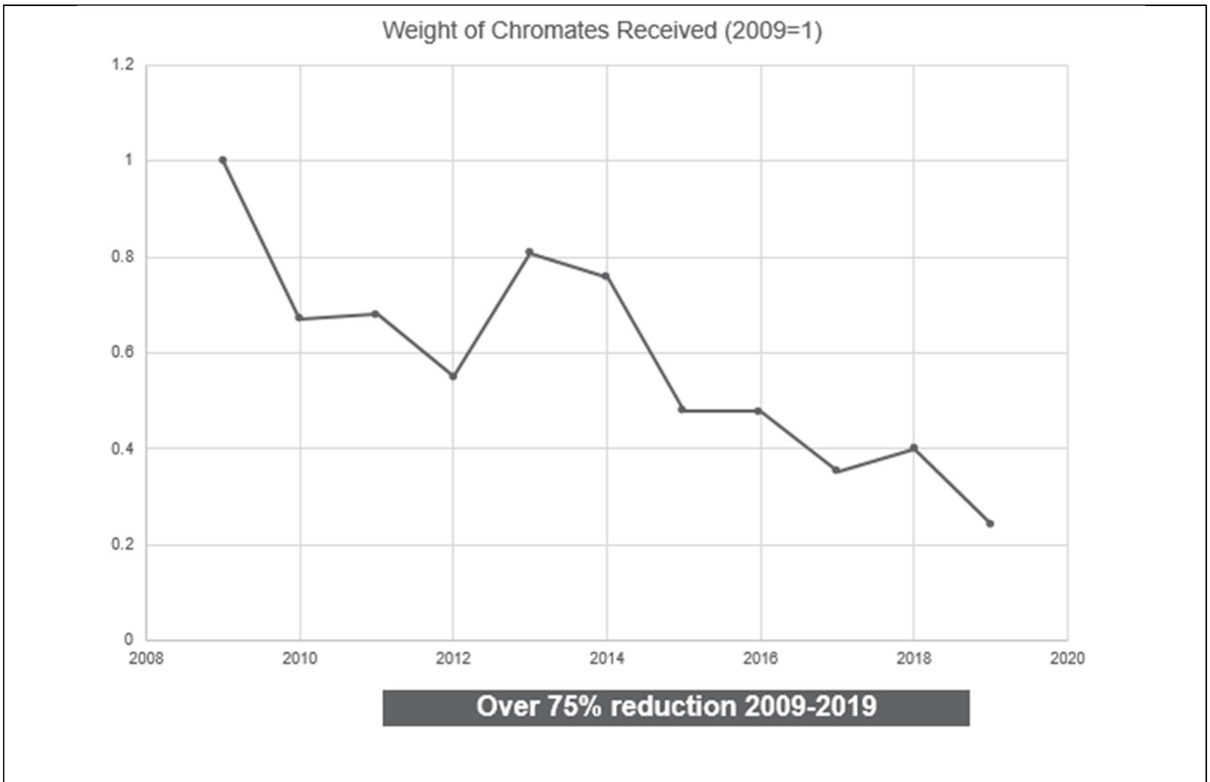

Figure 6-3: Reductions in chromate dependency over the period 2009 -2019

The European aerospace and defence security industry is heavily regulated to ensure passenger/operator safety. The consequence is that there are very long lead times and testing cycles 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 plus 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)[89].

A PricewaterhouseCoopers (PwC) study[90] 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 program schedule have worsened the economics*."

Corrosion prevention systems are critical to aircraft safety. Testing 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 aerospace and defence industry is the almost unique challenge of obtaining relevant long-term corrosion performance information. In the case of anodise sealing, it

[89] https://www.asd-europe.org/sites/default/files/atoms/files/ASD_Facts%26Figures_2021_.pdf

[90] http://www.strategyand.pwc.com/trends/2015-aerospace-defense-trends

requires testing of changes in a process of corrosion protection, which may include changes in pre-treatments, anodising treatments and post-treatment surface coatings.

Aerospace companies cannot apply a less effective corrosion protection process as aviation 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. In particular, 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)-free alternative.

As noted previously, there is a complex relationship between each 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 technically feasible 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 Cr(VI)-free anodise sealing 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 and reliability.

In addition, several of the ADCR members 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-EEA territory and import of finished surface treated components or products into the EEA is more complex, as it could create a dependence on a non-EEA supplier in a conflict situation.

They also note that 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 anodise sealing 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 anodise sealing 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 EEA defence sector requires only small quantities of the chromates in anodise sealing. Based on 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, anodise sealing as a surface treatment on 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 and 6: Comparison of socio-economic benefits and risks to the environment and effective control of the remaining risks

As demonstrated by the information collected in 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 both reduced exposures for 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[91].

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[92]) 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 (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 in particular.[93]

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91 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

92 https://asd-europe.org/sites/default/files/atoms/files/ASD_Facts%26Figures_2021_.pdf

93 https://www.airbus.com/sites/g/files/jlcbta136/files/2022-07/GMF-Presentation-2022-2041.pdf

Boeing's 2022 Commercial Market Outlook[94] 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 aeroplane 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 some cases where components do not have technically feasible alternatives available. **Figure 3-4** 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 Cr(VI)-based anodise sealing. As illustrated in Section 4, on-going substitution is expected to result in significant decreases in the volumes of the four chromates used in anodise sealing 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 chromates in surface treatments carried out by the A&D industry. This series of Review Reports has adopted a narrower definition of uses original Authorised under the CTAC, CCST and GCCA parent applications for authorisation. Please see the Explanatory Note for further details.

In total, the ADCR will be submitting 11 Review reports covering the following uses and the continued use of chromium trioxide, sodium dichromate, potassium dichromate, sodium chromate and dichromium tris(chromate):

1) Formulation
2) Pre-treatments
3) Electroplating (hard chrome plating)
4) Passivation of stainless steel
5) Anodising
6) Chemical conversion coating
7) Anodise sealing
8) Passivation of non-aluminium metallic coatings

94 https://www.boeing.com/commercial/market/commercial-market-outlook/index.page

9) Inorganic finish stripping
10) Chromate rinsing after phosphating
11) Slurry coatings

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8 Annex 1: Standards applicable to anodise sealing

Table 8-1 lists examples of standards and specifications reported by ADCR members applicable to the use anodise sealing. The specifications/standards listed here are test methods and do not define success criteria for alternatives validation.

Table 8-1: Examples of standards applicable to anodise sealing

Standard Reference	Standard Description	Key function/Standard type
AMS 2470	Anodic Treatment of Aluminium Alloys Chromic Acid Process	Industry QC spec
AMS 2471	Anodic Treatment for Aluminium Base Alloys Sulfuric Acid Process	Industry QC spec
ASTM B117	Standard Practice for Operating Salt Spray (Fog) Apparatus	Corrosion resistance
ASTM B137	Standard Test Method for Measurement of Coating Mass per Unit Area on Anodically Coated Aluminum	Coating weight measurement
ASTM B764	Standard Test Method for Simultaneous Thickness and Electrode Potential Determination of Individual Layers in Multilayer Nickel Deposit (STEP Test)	Layer thickness
EN 2101	Chromic acid anodizing of aluminium and wrought aluminium alloys	Industry QC spec
EN 3665	Filiform corrosion resistance test on aluminium alloys	Corrosion resistance
EN 4704	Tartaric-Sulphuric-Acid anodizing of aluminium and aluminium wrought alloys for corrosion protection and paint pre-treatment (TSA)	Industry QC spec
EN 6072	Metallic materials – Test methods – Constant amplitude fatigue testing	Fatigue assessment
ISO 1463	Metallic and oxide coatings – Measurement of coating thickness – Microscopical method	Layer thickness
ISO 2106	Anodizing of aluminium and its alloys – Determination of mass per unit area (surface density) of anodic oxidation coatings – Gravimetric method	Layer density
ISO 2177	Metallic Coatings – Measurement of Coating Thickness – Coulometric Method by Anodic Dissolution	Layer thickness
ISO 2360	Non-conductive coatings on nonmagnetic electrically conductive base metals – Measurement of coating thickness – Amplitude-sensitive eddy-current method	Industry QC spec
ISO 2409	Cross-cut test	Adhesion to subsequent coating or paint
ISO 2812-1	Determination of resistance to liquids – Part 1: Immersion in liquids other than water	Chemical resistance

ISO 9227	Corrosion tests in artificial atmospheres - Salt spray tests	Corrosion resistance
MIL-DTL-53030	Primer coating, epoxy, water based, lead and chromate free	Industry QC spec
MIL-PRF-8625	Anodic coatings for aluminium and aluminium alloys	Industry QC spec
Source: ADCR members "Standard description" obtained from https://standards.globalspec.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

Table 9-1: European Aerospace Clusters

Cluster Name	Country	City	Number of Companies	Employees	Sales/turnover
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
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 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 10-1**. 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 10-1: Contribution of UK aerospace, defence, security and space sectors to the economy in 2020[95]

The UK aerospace sector is considered by the government to be "hugely important to the UK economy"[96], 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 10-1** .

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)[97]. 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.

[95] https://www.adsgroup.org.uk/wp-content/uploads/sites/21/2022/06/ADS-FF2022-Twit-header-72.jpg

[96] BEIS, Aerospace Sector Report, undated.

[97] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/763781/aerospace-sector-deal-web.pdf

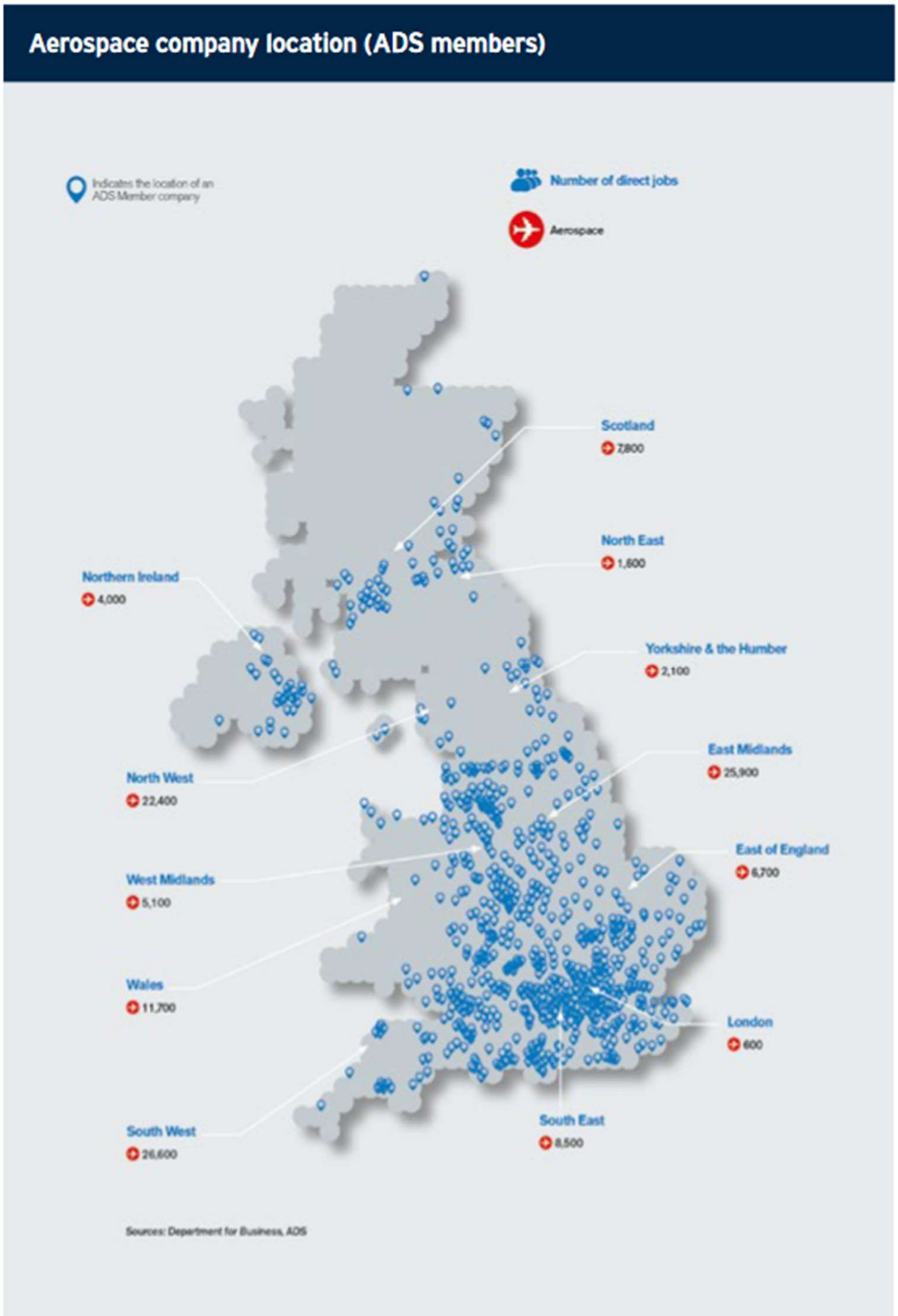

Figure 10-2: Location of aerospace manufacturing sites and associated jobs in the UK[98]

[98] Sources: ONS, BEIS, ADS Industrial Trends Survey 2020

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 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 and 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 spill overs. 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.

10.2 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 10-3**[99]. Again, the importance of the sector to UK exports and value added, as well as employment is clear from the figure below.

[99] Sources: https://www.adsgroup.org.uk/industry-issues/facts-figures/facts-figures-2022/

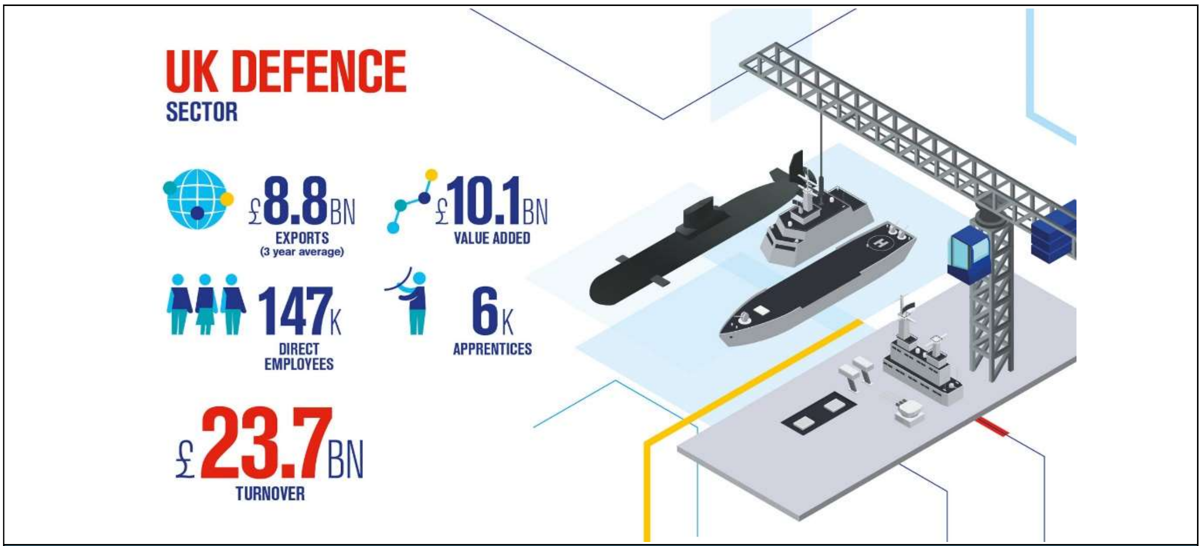

Figure 10-3: UK defence sector contribution to the economy in 2021