ANALYSIS OF ALTERNATIVES

and

SOCIO-ECONOMIC ANALYSIS

Complete version

Legal name of applicant(s):	Boeing Distribution (UK) Inc. Henkel Ltd MacDermid Performance Solutions UK Ltd Wesco Aircraft EMEA Ltd
Submitted by:	Boeing Distribution (UK) Inc. on behalf of the Aerospace and Defence Chromates Reauthorisation Consortium
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Substance:	Chromium trioxide (includes "Acids generated from chromium trioxide and their oligomers", when used in aqueous solutions)
Use title:	Anodising using chromium trioxide in aerospace and defence industry and its supply chains.
Use number:	1

Note

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

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Abbreviations

ADCR – Aerospace and Defence Chromates Reauthorisation

A&D – Aerospace and Defence

AfA – Application for Authorisation

AoA – Analysis of Alternatives

AoG – Aircraft on the Ground

BCR – Benefit Cost Ratio

BtP – Build-to-Print

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

GOS – Gross operating surplus

ICAO – International Civil Aviation Organisation

MoD – Ministry of Defence

MRO – Maintenance, Repair and Overhaul

NADCAP - National Aerospace and Defence Contractors Accreditation Program

NATO – North Atlantic Treaty Organisation

NUS – Non-use scenario

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

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 that is 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 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 specifications 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
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, service, or processes have 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

Term	Description
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 ratios, in a specific form.
Formulator	Company that manufactures formulations (may also design and develop formulations).
Gross Domestic Product	Gross domestic product (GDP) is 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	Gross value added is 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 localised 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. Also known as cyclic heat-corrosion resistance.
Hot corrosion resistance	The ability of a coating or substrate to withstand attack by molten salts at temperatures in excess of 400°C
Industrialisation	The final step of the substitution process, following Certification. After having passed qualification, validation and certification, the next step is to industrialise the qualified material or process in all relevant activities and operations of production, maintenance, and the supply chain. Industrialisation may also be referred to as implementation.
Layer thickness	The thickness of a layer or coating on a substrate

Term	Description
Legacy parts	Any part that is already designed, validated, and certified by Airworthiness Authorities or for defence and space, 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 Build-to-Print suppliers and undertakes ISO audits of their processes
Net Present Value	Valuation method to value stocks of natural resources. It is obtained discounting future flows of economic benefits to the present period.
Original Equipment Manufacturer (OEM)	Generally large companies which design, 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	An article or complex object
Pickling	The removal of surface oxides and small amounts of substrate surface by chemical or electrochemical action.
Present Value	The discounted sum of all future debt service at a given rate of interest. If the rate of interest is the contractual rate of the debt, by construction, the present value equals the nominal value, whereas if the rate of interest is the market interest rate, then the present value equals the market value of the debt.
Pre-treatment	Pre-treatment processes are used prior to a subsequent finishing treatment (e.g. chemical conversion coating, anodising) to remove contaminants (e.g. oil, grease, dust), oxides, scale, and previously applied coatings. The pre-treatment process must also provide chemically active surfaces for the subsequent treatment. Pre-treatment of metallic substrates typically consists of cleaning and/or surface preparation processes.
Producer surplus	Represents the gain to trade a producer receives from the supply of goods or services less the cost of producing the output (i.e. the margin on additional sales)
Proposed candidate	A formulation in development or developed by a formulator as a part of the substitution process for which testing by the design owner is yet to be determined. In the parent applications for authorisation, this was referred to as a 'potential alternative'.
Qualification	1. Part of the substitution process following Development and preceding Validation to perform screening tests of test candidate(s) before determining if further validation testing is warranted. 2. The term qualification is also used during the industrialisation phase to describe the approval of suppliers to carry out suitable processes.
Requirement	A property that materials, components, equipment, or processes must fulfil, or actions that suppliers must undertake.
Resistivity	Property that quantifies how a given material opposes the flow of electric current. A low resistivity indicates a material that readily allows 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).

Term	Description
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 public 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, engines, 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 of a coating or substrate 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 Aviation Authority certifying that an Aerospace product type 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 specifications.
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 14 December 2022 the information is not publicly available and, in accordance with the due measures of protection that we have implemented, a member of the public should not be able to obtain access to this information without our consent or that of the third party whose commercial interests are at stake.

Signature: Date: 14 December 2022

Sr. Chemical Policy Analyst
The Boeing Company

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 combined AoA/SEA dossiers. These combined AoA-SEAs cover all uses of soluble chromates considered to be relevant by the ADCR consortium members. Although formally they are upstream applications submitted by manufacturers, importers or formulators of chromate-containing chemical products, the applications are based on sector-specific data and detailed information obtained from actors throughout the supply chain.

For the purposes of this document, the term ‘aerospace and defence’ comprises the civil aviation, defence/security and space industries, as well as aeroderivative products. The aerospace and defence (A&D) industry has been working towards the substitution of Cr(VI) across various uses for the past 25-30 years. Although there have been numerous successes and levels of use have decreased significantly, the specific use of chromium trioxide in anodising is still required for many components and final 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[1] as being important to innovation, competition and a strong and well-functioning single market.

This combined AoA/SEA is one of a set that have been prepared by the ADCR Consortium to cover the range of different uses of the chromates that continue to be required in the EEA (and UK) by the A&D sector. It is linked to the initial parent authorisations but covers only the single use of chromium trioxide in chromic acid anodising (CAA)[2] as carried out by the A&D sector, rather than a broader set of surface treatment activities. All applicants submitting this combined AoA/SEA hold parent authorisations for this substance-use combination.

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) Anodising using Chromium trioxide in aerospace and defence industry and its supply chains.

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

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

This “applied for use” involves the continued use of chromium trioxide (CT) across the EEA and the UK in anodising for a further 12-year period at approximately 180 sites in the EEA and 30 sites in the UK. This includes sites involved in the production of components and final products, as well as those undertaking maintenance, repair and overhaul services (MRO) for both civil aviation and military bodies, as well as aeroderivative uses.

It is estimated that these sites in the EEA use between 75 - 125 tonnes per annum of chromium trioxide in anodising, while sites in the UK use between 10 - 35 tonnes per annum.

1.2 Availability and suitability of alternatives

For the past several decades, ADCR members who are “design owners” (including Original Equipment Manufacturers (OEMs) and Design-to-build manufacturers (DtB) selling products used in civil aviation and military aircraft and ground and sea-based defence systems and aeroderivatives have been searching for alternatives to the use of Chromium trioxide in anodising. At the current time, chromium trioxide is the only chromate still used in anodising as part of an overall system of surface treatments providing the following key functions fundamental to A&D:

- Wear resistance
- Corrosion resistance);
- Chemical resistance;
- Adhesion promotion (adhesion to subsequent coating or paint); and
- Layer thickness.

Anodising is an electrolytic oxidation process where the surface of a metal is converted to an oxide which has desirable functional properties. The anodising process creates an oxide layer that partly grows into the substrate and partly grows onto the surface (CTAC consortium, 2015). During the process, a porous surface is created, which must then be sealed (or painted) to provide a high level of corrosion resistance and hence adequate protection to the substrate. Post-treatment steps include sealing after anodising, chromate rinsing, and coating with a primer (where anodising essentially acts as a pre-treatment). Anodising also may be followed by stripping to remove the coating without attacking the substrate itself. This process is used for rework, maintenance, and repair operations. In other cases, anodising may be followed directly by a coating. It may also be used to mask or protect areas where other types of anodising (e.g. sulphuric acid anodising) may result in fatigue strength issues.

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 and certification and industrialisation activities.

These companies are at different stages in the implementation of alternatives. Within the sector and for some types of final products, substitution has already underway. In other cases, companies expect to be able to substitute CT in anodising across some or all of their current components, final products and MRO (maintenance, repair and overhaul) processes within the next 4 - 7 years; while others face greater challenges due to the more demanding requirements of their products and have not yet been able to identify technically feasible alternatives for all components and products that will meet performance requirements. They will require up to a further 12 years to develop, gain certifications for and then implement current test candidates; a further set are constrained by military and/or MRO requirements which may mean that it will take 12 years to implement technically feasible substitutes.

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

Companies engaged in maintenance, repair, and overhaul (MRO) activities face particular substitution difficulties, as they are mandated to continue use of chromium trioxide in anodising 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.

The companies supporting this combined AoA/SEA are engaged in the manufacture and supply to both civilian and military customers (where the latter includes not just air forces but also non-aircraft defence systems, such as ground-based installations or naval systems), as well as emergency services. The consortium includes as formal members Ministries of Defence (MoD) located in the EEA and UK, with additional information provided by other EEA MoDs (or their MROs) concerned over the on-going mission readiness of their current military forces and 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** . By the end of year 4, usage is likely to have reduced by up to half, with additional reductions achieved by year 7; however, it will take the full 12 years for all substitution plans to be achieved (and assuming no setbacks). The potential need for more than 12 years has been identified by MROs and MoDs for continued use in the maintenance, repair, and overhaul of in-service aircraft, and defence systems and equipment. In particular, there may be issues for equipment with very long service lives (e.g., defence equipment).

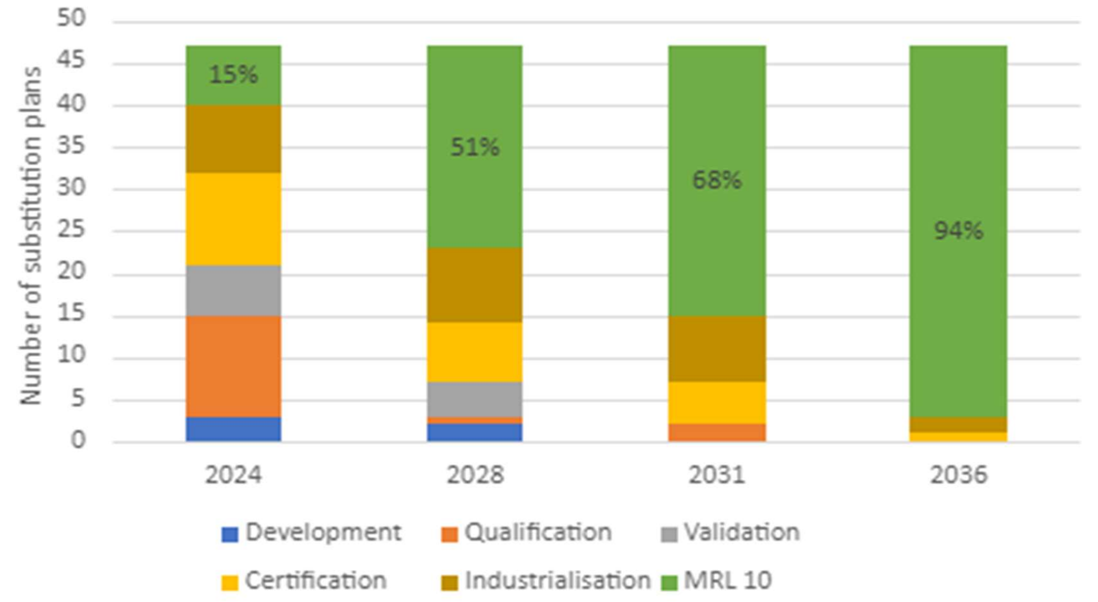

Figure 1-1: Expected progression of substitution plans for the use of Cr(VI) in anodising, by year. The vertical axis refers to number of substitution plans (some members have multiple substitution plans for anodising). The percentage value shown on each of the green bars indicates the proportion of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

1.3 Socio-economic benefits from continued use

The continued use of Chromium trioxide in anodising specifically (ADCR Use #1) over the review period will confer significant socio-economic benefits to ADCR members, their suppliers and to their end customers which include civil aviation, the military, and emergency services. It will also ensure the continued functioning of A&D supply chains in the EEA and UK within, contributing to wider economic growth and the employment benefits that come with this.

The continued use of CAA delivers net social benefits to the A&D industry (and its employees through avoided unemployment) exceeding €2,768 million per annum in the EEA and €719 million per annum in the UK (lower bound annualised values[3]).

The benefits can be summarised as follows (with the lower and upper bounds for profit losses reflecting different calculation approaches – see Section 5 for the detailed calculations):

- Importers of the chromium trioxide used in anodising will continue to earn profits from sales to the A&D sector;
- OEMs will be able to rely on the continued use of chromium trioxide in anodising by their EEA and UK suppliers and in their own production activities. The avoided profit losses to these

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[3] Profit losses are taken over two years prior to annualization, with residual risks taken over 12 years, both at a 4% discount rate.

companies under the non-use scenario would equate to between €180 to €813 million for the EEA and €142 to €240 million for the UK in present value terms over a 2-year period (starting in 2025, discounted at 4%), as well as being able to maintain their subsequent manufacturing activities in both jurisdictions. These figures exclude the potential profits that could be gained under the continued use scenario from the global increase in demand for air transport and defence products;

- DtB and Build-to-print (BtP) manufacturers would be able to continue their production activities and meet the performance requirements of the OEMs (or their own where DtBs are design owners). The associated profit losses that would be avoided under the continued use scenario are calculated at €504 - €1,401 million for the EEA and €173 - €350 for the UK in present value terms over a 2-year period (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, with the consequent profit losses equating to between €59 – €260 million for the EEA and between €45 – €130 million for the UK in present value terms over a 2-year period (discounted at 4%);

- Continued high levels of employment in the sector, with these ensuring the retention of highly skilled workers paid at above average wage levels. From a social perspective, the benefits from avoiding the unemployment of workers involved in anodising alone and linked surface treatment and manufacturing activities are estimated at €3,863 million for the EEA and €1,176 million in the UK. The losses vary significantly across the different EEA countries, with France incurring the highest social costs of unemployment, followed by Germany and Italy.

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

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

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

The proportion of socio-economic benefits from continued use of the chromates under the continued use scenario that can be monetised sums to roughly €5,440 million in the EEA and €1,423 million in the UK for the lower bound estimates over a 2-year period. The level of disruption that would be caused through the inability to continue chromic acid anodising within the EEA and UK to A&D customers and society would outweigh the losses to A&D companies across the value chain (including OEMs, DtBs, BtP suppliers, MROs and MoDs).

1.4 Residual risk to human health from continued use

It is projected that in 2024, based on the continuing implementation of Risk Management Measures and substitution as feasible, between 75 and 125 tonnes of chromium trioxide will be used by the A&D sector for anodising in the EEA and between 10 and 35 tonnes per annum for anodising in the UK. Over the following 12-year period, use is expected to decline by around 90% assuming that current substitution plans are successful. Achieving a full 100% reduction is the goal of members but may not be possible for all defence applications, MROs and producers of legacy spare parts. Nevertheless, worker and humans via the environment exposure to chromium trioxide will continuously reduce over the 12-year period, as substitution plans are progressed.

Risks to workers have been estimated based on the use of exposure monitoring data for 2021 and 2022, supplemented by modelling data as appropriate. Across the 180 EEA sites where chromic acid anodising is anticipated as taking place, an estimated total of 3,960 workers may be exposed to Cr(VI); for the 30 UK sites where anodising takes place, approximately 660 workers may be exposed. These estimates represent conservative assumptions given the anticipated reduction in chromium trioxide use, as substitution takes place.

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 chromic acid anodising is considered to take place, an estimated 83,300 people in the EEA and around 40,000 people in the UK[4] are calculated as potentially being exposed to Cr(VI) due to anodising activities. Again, these figures are conservative due to the on-going substitution of CAA with alternatives.

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

- EEA: 0.10 fatal cancers and 0.03 non-fatal cancers per annum at a total social cost of €422,240 per annum;

- UK: 0.03 fatal cancers and 0.01 non-fatal cancers per annum at a total social cost of €108,000 per annum.

1.5 Comparison of socio-economic benefits and residual risks

The ratios of 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: 2,975 : 1 for the lower bound of economic losses or 3,009 : 1 for the upper bound economic losses;

- UK: 3,042 : 1 for the lower bound of economic losses or 3,844 : 1 for the upper bound economic losses.

The above estimates represent a significant underestimate of the actual benefits conferred by the continued use of chromium trioxide in anodising carried out by the A&D industry, 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;

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[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 time lag.

- 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 costs of flights for passengers and 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; 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 anodising activities, with chromium trioxide now the only relevant chromate and the estimated maximum volumes of chromium trioxide used in anodising in the EEA being 125 tonnes per annum (based on maximum consumption per any site times the number of sites), and in the UK at a maximum of 35 tonnes per annum.

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

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

- A Binding Occupational Exposure Limit Value (OELV) has been introduced under EU Directive 2004/37/EC that will become more stringent after 17 January 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 chromic acid anodising.

- As indicated in the Substitution Plan, companies are progressing towards the certification and implementation of substitutes for additional components using alternatives. Those uses that currently take place are those where the components or the final products face more demanding performance requirements.

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

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

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

- **The costs of moving to alternatives are high**, not necessarily due to the cost of the alternative substances but **due to the strict regulatory requirements that must be met to ensure airworthiness and safety for military use**. These requirements mandate the need for testing, validation, 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, a lack of testing facilities, age of available text vehicles (engines, aircraft, defence equipment, etc.). On a cumulative basis, the major OEMs and DtB companies that act as the design authorities could not afford to undertake action across the range and numbers of components that still require the qualification, certification and industrialisation of alternatives. These activities themselves are costing the companies hundreds of millions of Euros, and tens of millions in relation to anodising.

- **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 chromium trioxide in anodising, and 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 plus years**. This includes participation in research initiatives partially funded by the European Commission and national governments. Considerable technical and actual progress has been made in developing, testing, validating qualifying and certifying components for the use of alternatives, however, it is not technically nor economically feasible for the sector to have

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[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)

achieved full substitution within a 4- or 7-year period. Although some companies have been able to qualify and certify the use of alternatives for some of their components, others are still in the early phases of testing and development work. They will not be able to qualify and certify proposed or test candidate within a 7-year time frame.

- Even then, **it may not be feasible for military MROs/MoDs to move completely away from the use of chromium trioxide in anodising due to mandatory maintenance, repair and overhaul requirements.** They must wait for OEMs to update Maintenance Manuals with an appropriate approval for each treatment step related to the corresponding aircraft parts. The corresponding timescale for OEMs carrying out such updates varies and there can be significant delays while OEMs ensure that substitution has been successful in practice.

- In this respect, **it is important to note that the use of the substance is required (and may be required beyond 12 years) to ensure the operational capabilities of the military and the ability to comply with international obligations as partner nations at the EU level and in a wider field, e.g. with NATO.**

- Given the above, an Authorisation of appropriate length is critical the continued operation of aerospace and defence manufacturing activities in the EEA and UK. The sector is subject to stringent regulatory requirements for the qualification and certification of parts, components due to the critical nature of their end products. It is also fundamental to ensuring an uninterrupted continuation of MRO 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 in anodising** 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 chromium trioxide in anodising is not authorised while work continues on developing, qualifying and certifying alternatives.

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

2 AIMS AND SCOPE OF THE ANALYSIS

2.1 Introduction

2.1.1 The Aerospace and Defence Chromates Reauthorisation Consortium

This combined AoA and SEA was developed by the Aerospace and Defence Chromates Reauthorisation (ADCR) Consortium on behalf of the applicants. It provides an updated assessment from that presented in the parent Applications for Authorisation (AfA) for the purposes of this combined AoA/SEA. For the purposes of this document, the term ‘aerospace and defence’ (A&D) comprises the civil aviation, defence/security and space industries.

This is an upstream application submitted by manufacturers, importers and/or formulators of chromium trioxide. It is an upstream application due to the complexity of the A&D supply-chain, which contains a large number of 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 across the A&D sector. 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 final products; 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 have 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 OEMs and DtBs companies that are the design owners for A&D final products, together with their 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. In total, the data used in developing this combined AoA and SEA represents information provided by companies/organisations covering over 260 sites in Europe involved in use of the hexavalent chromates in surface treatment activities, although only a subset of these undertake chromic acid anodising.

The initial parent application for authorisation covered multiple surface treatments and substrates. This combined AoA/SEA covers only the authorised use of chromic acid anodising and, therefore, adopts a narrower definition of “use” compared to the original CTAC application. The other surface treatments that are still being supported by the ADCR are covered by separate, complementary submissions for each “use”.

CAA as a use is defined as:

> *Anodising using chromium trioxide in aerospace or defence industry and its supply chains.*

Chromium trioxide-based anodising, or chromic acid anodising (CAA), is a surface treatment of metallic surfaces, mainly carried out to create a hard protective (and insulating) layer on the surface of components made from aluminium and its alloys (particularly those containing copper, iron and silicon), but is also relevant to magnesium and its alloys. Importantly, it does this by forming an oxide layer on the surface that is fully integrated into the material.

Where anodising is used as a surface treatment, it is mainly carried out on aluminium and its alloys (estimated at around 95% of anodised substrates). Aluminium is used in part due to its ability to naturally form oxides on its surface thereby protecting it from corrosion. This natural property is utilised via applying a voltage to generate the anodic coating. This is far thicker than the naturally occurring oxide layer. Aluminium is also highly versatile and lightweight, with twice the strength-to-weight ratio of stainless steel. Its strength also increases under sub-zero temperatures which is a valuable characteristic in aircraft.

The use of CAA 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 its use in defence, space and in aerospace derivative products, which include non-aircraft turbines, defence systems, such as ground-based installations or naval systems. Such products and systems also must comply with numerous comparable requirements including those of the European Space Agency (ESA) and of national Ministries of Defence.

These “aeroderivative" products use components and designs adapted from the manufacturing processes and supply chains and make up a small percentage (1 – 2%) of the total A&D hardware volume in the European Union (EU) and are used to generate electricity or propulsion in civil and defence marine, oil and gas, and industrial applications. As the components used in aeroderivatives are designed to the same thresholds as aerospace and produced in the same manufacturing lines, the same arguments for the use of the chromates treated components in the aerospace industry apply to aeroderivatives. High performance requirements are mandatory for aeroderivatives, as well as for aerospace components due to operation in harsh and corrosive environments (e.g., at sea). Aeroderivatives are distinct from other industrial products which are not covered by this combined AoA/SEA.

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

2.1.2 Aims of the combined AoA and SEA document

The downstream users supporting the ADCR consortium have no qualified (from a technical perspective) and economically feasible alternatives for use on all of their components, 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 chromium trioxide in anodising activities carried out within the EEA and UK, as it is fundamental and integral to providing the technical performance required of aerospace components. It is a core surface treatment integral to preventing corrosion, and imparting chemical resistance, wear resistance, improved adhesion and layer thickness properties to critical aerospace components. It forms part of an overall process, which may include both pre- and post-treatments, aimed at ensuring the compulsory airworthiness and safety requirements of aircraft and military equipment.

Although the A&D sector has been successful in implementing alternatives to CAA for some components with less demanding requirements, or easier geometries the aim of this application is to enable the continued use of chromium trioxide in anodising beyond the end of the existing review period which expires in September 2024. It demonstrates the following:

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

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

- The R&D that has been carried out by the OEMs, DtBs and their suppliers towards the identification of feasible and suitable alternatives for chromium trioxide in anodising. 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 those products and out-of-production civilian and military aircraft and defence equipment.

- 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 Chromium trioxide in anodising over an appropriately long review period; and

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

- It should be noted that this combined AoA/SEA is one of a set that has 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 one soluble Cr(VI) compound for anodising:

- Chromium trioxide (includes "Acids generated from chromium trioxide and their oligomers", when used in aqueous solutions)	EC 215-607-8	CAS 1333-82-0

Chromium trioxide (CT) was included in Annex XIV of REACH (Entry No. 16) due to its carcinogenic (Cat. 1A) and mutagenic properties (Cat. 1B). As CT is mainly used as an aqueous solution in anodising, this RR also covers the acids generated from CT and their oligomers (Entry No. 17). In the remainder of this document, references to CT always include the acids generated from CT and their oligomers.

Table 2-1 summarises the initial applications which are the parent authorisations to this combined AoA-SEA.

Table 2-1: Overview of Initial Parent Applications and Authorisations (note that there are no UK grandfathered authorisations)					
Application ID/ authorisation number	**Substance**	**CAS #**	**EC #**	**Applicants**	**Parent Authorisation – Authorised Use**
[0032-04](0032-04) REACH/20/18/14, REACH/20/18/16 REACH/20/18/18	Chromium trioxide	1333-82-0	215-607-8	ChemServices as OR for Brother; Boeing Distribution Ltd; Cromital as OR for Sisecam chemicals (CTAC consortium)	Surface treatment for applications in the aeronautics and aerospace industries, unrelated to functional chrome plating or functional chrome plating with decorative character, where any of the following key functionalities is necessary for the intended use: corrosion resistance/active corrosion inhibition, chemical resistance, hardness, adhesion promotion (adhesion to subsequent coating or paint), temperature resistance, resistance to embrittlement, wear resistance, surface properties impeding deposition of organisms, layer thickness, flexibility, and resistivity
[0032-05](0032-05) REACH/20/18/21 REACH/20/18/23 REACH/20/18/25	Chromium trioxide	1333-82-0	215-607-8	ChemServices as OR for Brother; Boeing Distribution Ltd; Cromital as OR for Sisecam chemicals (CTAC consortium)	Surface treatment (except passivation of tin-plated steel (electrolytic tin plating - ETP)) for applications in architectural, automotive, metal manufacturing and finishing, and general engineering industry sectors, unrelated to functional chrome plating or functional chrome plating with decorative character, where any of the following key functionalities is necessary for the intended use: corrosion resistance/active corrosion inhibition, layer thickness, humidity resistance, adhesion promotion (adhesion to subsequent coating or paint), resistivity, chemical resistance, wear resistance, electrical conductivity, compatibility with substrate, (thermo) optical properties (visual appearance), heat resistance, food safety, coating tension, electric insulation or deposition speed

2.3 Scope of the analysis

2.3.1 Brief overview of uses

2.3.1.1 Process description

CAA by the A&D industry and its supply chain in the EEA and the UK currently involves the use of CT only (other hexavalent chromates are no longer used).

Anodising in A&D supply chains is carried out exclusively in industrial installations. It may be used to protect or repair a metallic component. It is often preceded by some form of pre-treatment and is frequently followed by anodise sealing coating (with this occurring within a matter of hours to ensure corrosion protection), and it may be followed by inorganic finish stripping.

As noted above, aluminium and its alloys and magnesium its alloys can be processed by anodising; aluminium represents the very large majority of the substrates treated by anodising (> 95%).

Anodising is a chemical electrolytical process. The metallic components to be treated act as the anode and the respective cathode is inert. The current passes through the metallic components in an electrolyte which consists of an acidic solution containing CT. An anodic oxide layer is formed on the surface of the components creating uniformly distributed pores. The anodic film formation is mainly driven by the applied voltage but also by the temperature and the immersion duration. The thickness of the anodic coating layer formed on the surface is typically a maximum of 10 µm. CAA has the characteristic of a self-limiting oxide layer growth rate allowing easier control of layer thickness where required. The resulting oxide layer is normally porous, so a sealing process is often needed to achieve sufficient corrosion resistance. Where adhesion properties are also required (for instance for a subsequent painting step), sealing may not be performed before the additional coating operations are carried out.

Anodising is mostly carried out by immersion of components in treatment baths. Typically, the treatment baths for anodising 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 a chromate for pre- or post-treatment processes or 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 off the anodising solution from the components.

Figure 2-1: Anodising bath

Selective anodising can also be performed when limited, targeted areas of large, complex metallic components need anodising to either restore a previously anodised surface or to fulfil an original performance requirement. This local treatment is done using a swab/electrode. When anodising, the tool used acts as the cathode and the component to be treated becomes the anode. The anodised coating is formed on a localised area of the metallic surface in the presence of the electrolyte.

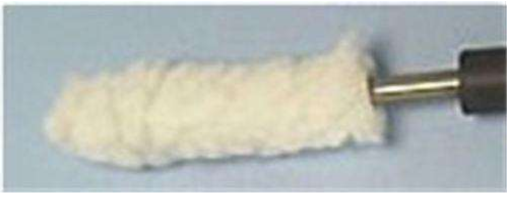

Figure 2-2: Anodising electrode

2.3.1.2 Relationship to other uses

Anodising with CT is usually combined with pre-treatment(s) (e.g., deoxidising, etching, pickling or desmutting) and a post-treatment (anodise sealing or inorganic finish stripping), as illustrated below.

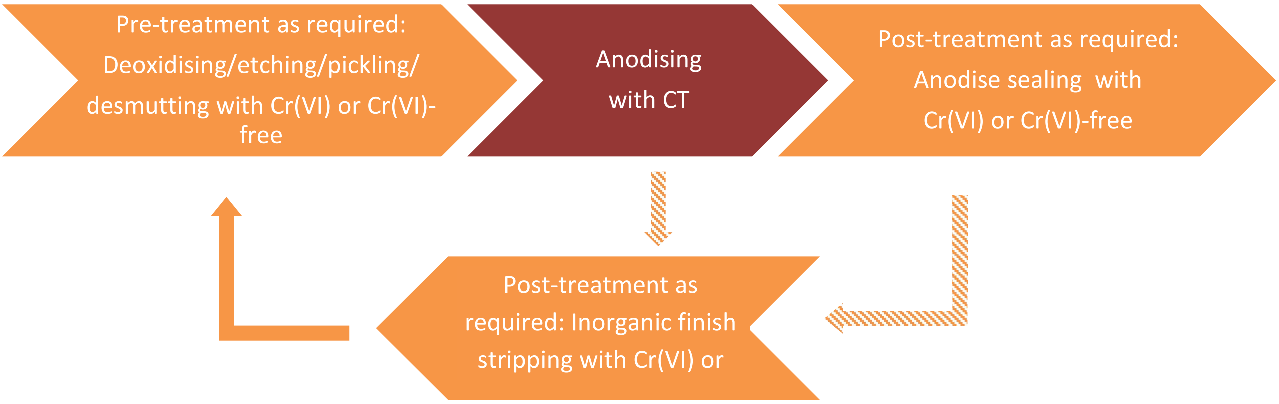

Figure 2-3: Schematic presentation of corrosion protection system

The pre-treatments can involve the use of chromates or 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 CSR for pre-treatments. Further details on the inorganic finish stripping process and the anodising sealing process are described in their respective CSRs.

Although not indicated in the diagram, it is also important to note that chemical conversion coatings may be used to touch-up or to repair damage to anodised surfaces. In addition, chemical conversion coatings are routinely used to protect the electrical contact point on the processed component after the anodising process is complete.

Please see the other ADCR submissions (as applicable) for further details on the availability of alternatives and the socio-economic impacts of a refused re-authorisation.

All these “uses” form part of a process flow, and that the benefits from the continued use of chromium trioxide in anodising may also rely on the ability to continuing using a hexavalent chromate in the other processes.

2.3.2 Temporal scope

Because of the lack of qualified and feasible alternatives for the use of CT in anodising for A&D components, it is anticipated that it will take ADCR members and their supply chains up to a further 12 years to develop, qualify, certify, and industrialise alternatives across all components and the entire value chain; the longest timeframes are required by MROs/MoDs 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 chromium trioxide 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 **Error! Reference source not found.**.

<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>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>“Non-use”</td><td>Loss of profit along the supply chain</td><td>12 years</td><td>Based on the length of requested review period</td></tr>
<tr><td></td><td>Impacts on growth and GDP</td><td>12 years</td><td>Based on the length of requested review period</td></tr>
<tr><td></td><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></td><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 due to concerns over the loss of the availability of the chromates for on-going maintenance and repair of military equipment.

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

With respect to CAA:

- Over two thirds of the larger ADCR members (OEMs, DtBs, BtPs and MROs) – 17 of 24 – are supporting the reauthorisation of this use in the EEA; this includes for their own use as well as for use by their suppliers. Two of the smaller members also identified the need for CAA into the future. In addition to the ADCR members supporting this use, military uses exist across the EEA by national military bodies that were unable to formally join the ADCR;

- Ten of the 24 larger members are supporting the reauthorisation of this use in the UK, with five of the smaller members also supporting this use. As for EU REACH, the larger members are supporting both their use and use by their UK suppliers.

2.3.3.2 Suppliers of chromate substances and mixtures

The types of chromium trioxide products used in anodising are listed in the table below. In broad terms, CT may be used in a solid form (flakes or powder), in an aqueous solution and either as a pure substance or in a mixture.

Table 2–3: Products used in anodising

Product Type A	Solid CT (flakes or powder), pure substance (100%) or mixture (50-100%); **52% Cr(VI)**
Product Type B	Aqueous solution of CT as purchased (1-10% CT (w/w)); **max. 5.2% (w/w) Cr(VI)**
Product Type C	Mixture containing CT, used to perform local anodising (< 5% CT (w/w)); **max. 2.6% (w/w) Cr(VI)**

Chromium trioxide is not manufactured within the EEA or UK, with all uses reliant on imports of the substance. Following import, formulation may take place with CT products then delivered to downstream users either directly or via distributors. Some distributors operate across many European countries while others operate nationally.

2.3.3.3 Downstream users of CT for anodising

Anodising 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 and sub-systems;

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

- 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.

Commercial aircraft, helicopter, spacecraft, satellite and defence manufacturers are involved in the value chain and in the use of CAA.

Any individual downstream user company may fit into more than one of the above categories, acting as both an OEM and an MRO where they service products already in use or carry out repairs to components as part of assembly. Similarly, a company may fall into different categorisations depending on the customer and the component/final product. The complexity of the supply chain relationships is illustrated in **Figure 2-4** below.

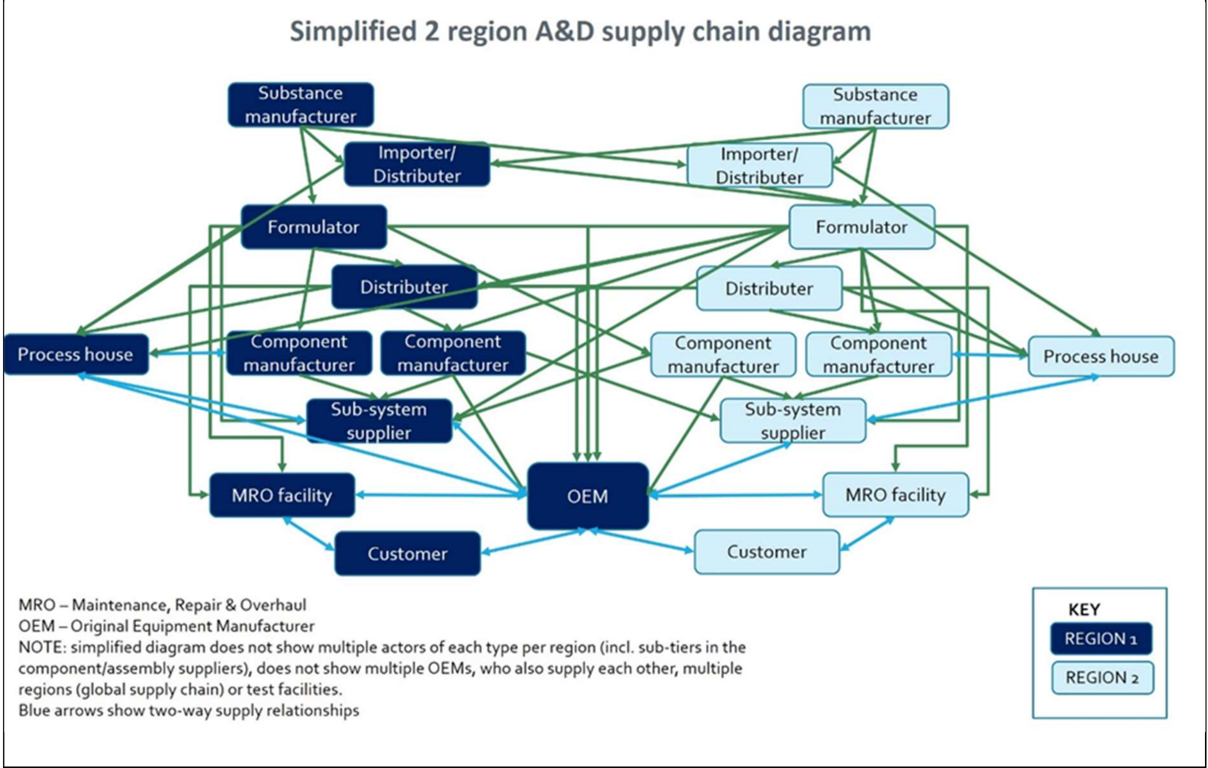


Figure 2-4: Complexity of supply chain roles and relationships within the A&D sector

The assessment presented in this combined AoA/SEA is based on responses to an SEA questionnaire provided by the following numbers of companies by role (see **Table 2–4**). In total, the data covers 64 sites involved in the use of CAA (43 in the EEA and 21 in the UK), out of 126 sites operated by the companies. It is important to note that some of the companies operate in both the EEA and/or UK.

As some of the ADCR members supported CAA in order to cover their value chain (DtBs, BtPs or MROs), they did not provide responses themselves to the SEA questionnaire. Instead, they distributed the questionnaires to relevant suppliers. As a result, the numbers in Table 2-4 below vary from the number of ADCR members supporting CAA.

Table 2–4: Distribution of SEA respondents supporting chromic acid anodising

	EEA		UK	
Member Category	**Number of companies**	**Number of sites undertaking CAA**	**Number of companies**	**Number of sites undertaking CAA**
OEMs	8	15	4	4
Design-to-build build	5	5	4	4
Build-to-print	19	19	12	12
MROs	4	4	1	1

2.3.3.4 OEMs, DtB and BtP Manufacturers

The design owner (often the OEM but potentially also a DtB company) defines the performance requirements of the components required for an aerospace, defence and space product, as well as the materials and processes to be used in manufacturing and maintenance.

The OEMs will often act as the design owner and define the performance requirements of the components required for an A&D product, as well as the materials and processes to be used in manufacturing and maintenance. They may undertake CAA, as will some of their suppliers. As design owners, OEMs are responsible for the integration and validation of the final product and certification approval of the use of an alternative on a component and in the final product. OEMs may themselves treat components in a similar manner to their suppliers. As they operate at the global level, they may have facilities both in the EEA, the UK and located in other regions. They are also global exporters of aircraft and military equipment (highlighting the need for global solutions).

DtB manufacturers develop in-house designs to meet and the performance requirements of their customers. These suppliers may have more control over the substances that they use in manufacturing their components but must still ensure that they are able to achieve the strict performance requirements set by the OEMs or their customers. They will carry out some own R&D into alternatives and may 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 substance to be used in to meet the requirements set by their customers. As a result, BtP manufacturers have no choice in whether they use chromium trioxide for anodising as the substances that must be used are determined by their OEM customers. Such suppliers, therefore, carry out no research into alternatives (although they may act as test facilities for their customers).

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

2.3.3.5 Maintenance, Repair and Overhaul

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

A representative life cycle of a typical aerospace product – commercial aircraft - is illustrated in **Figure 2-5**. 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 2-6 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 the performance of such systems, where performance has been assured for many decades.

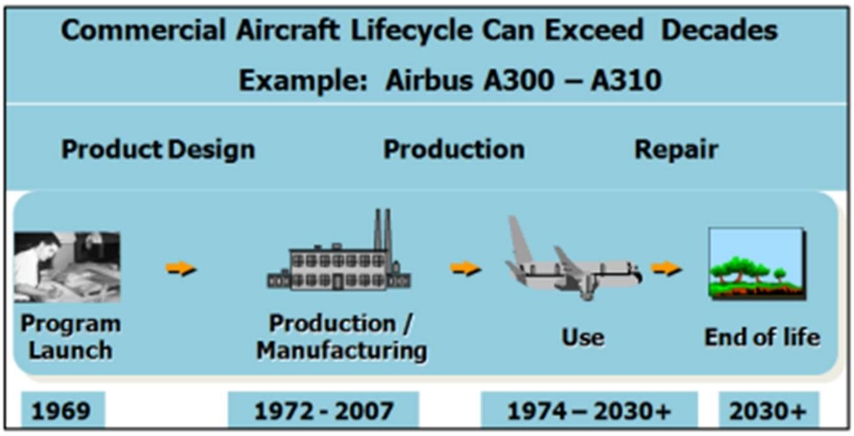
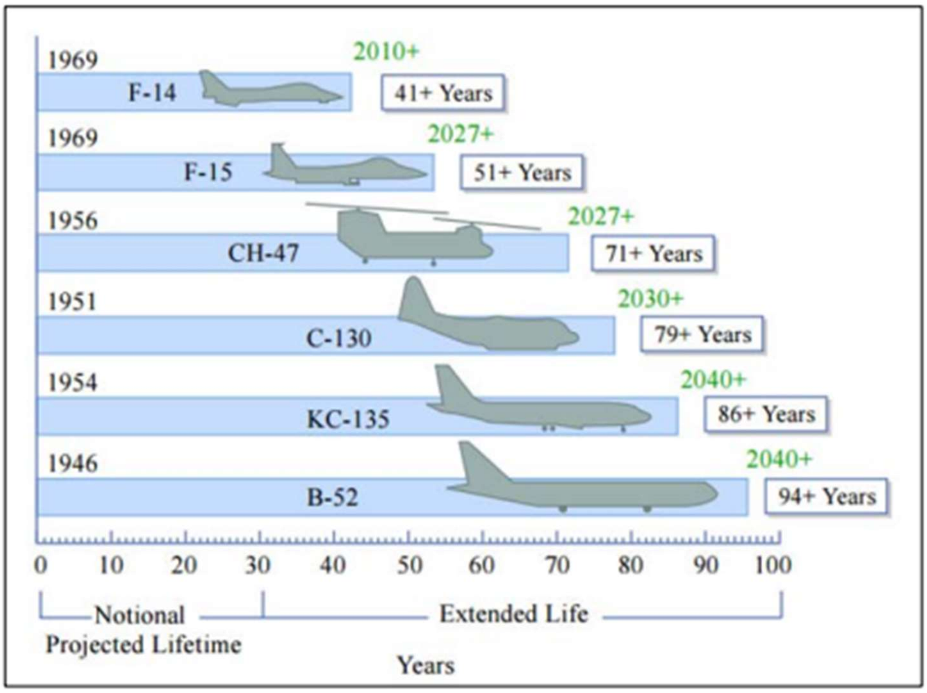


Figure 2-5: Commercial Aircraft Service Life, from ECHA & EASA (2014)[9]



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

Figure 2-6: Life cycles of defence aircraft, from A Haggerty (2004)[10]

Even if new designs/components – coming onto the market in the short to medium term – might succeed in dispensing with the use of chromic acid anodising, final products already placed on the market still need to be maintained and repaired using CAA until suitable alternatives are validated and certified for use in MRO for those existing products. Maintenance manuals for such existing products (which the user is legally obliged to comply with) detail, amongst other information, the processes, and materials initially qualified (sometimes decades ago) and required to be used, which form a substantial portion of the type certification or defence approval. As a result, MROs (and MoDs) face on-going requirements to undertake anodising in strict adherence to the requirements of qualified repair and maintenance schemes to ensure continued safe operation of the A&D final products.

As indicated earlier, there will be an overlap between those companies undertaking work as MROs and those also involved as DtB suppliers or even BtP suppliers, who also carry out MRO activities or manufacture legacy parts. As a result, companies falling into this category are spread geographically across the EU and UK.

2.3.3.6 Estimated number of downstream user sites – ADCR member data

Based on the information provided by the OEMs and DtBs with an EEA focus, it appears each has on average around 10-20 approved suppliers and/or own sites involved in anodising. This relates to 12 of the companies, suggesting that there could be up to as many as 240 (= 12 x 20) sites involved in CAA across the EEA (although not all approved suppliers will be undertaking CAA due to substitution that has recently taken place or changes in contracted components and products).

Furthermore, there are countries – France, Germany, Italy and Poland - where several OEMs and DtBs have major facilities. As such, there is likely to be some overlap since some BtP and DtB companies will provide CAA services to more than one OEM/DtB in their area. Taking this into account, the estimated number of sites in the EEA has been taken as 180. This reflects a maximum number and includes sites carrying out CAA for military purposes.

Based on the information provided by UK OEMs and DtBs, as well as reviewing data on companies undertaking anodising for the A&D sector, there are approximately 30 sites in total across Great Britain that may be involved in the provision of anodising services to ADCR members. Again, this reflects a maximum number and includes sites carrying out CAA for military purposes.

2.3.3.7 Estimated number of downstream user sites – Article 66 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 263 notifications relating to the REACH parent Authorisations focused on A&D uses of chromium trioxide, listed in Table 2-1. These notifications covered 357 sites across the EU-27 (and Norway). Note that Authorisations 20/18/21-25 relate to aeroderivative uses of chromium trioxide for anodising, but these uses will occur at the same sites as notifying for A&D uses and would therefore result in double-counting.

Table 2–5: Number of sites using CT for surface treatment, including anodising as notified to ECHA as of 31 December 2021

Substance	Authorisation	Authorised Use	Notifications	EU Sites

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

Chromium trioxide	20/18/14-20	Surface Treatment for aerospace	263	357
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				

It is important to stress that these notifications relate to 'surface treatment' which covers many more processes than anodising. Around 25 of the notifications appear to include specific reference to anodising (of aluminium components for aerospace applications). These data are considered to support the figure of 180 sites undertaking CAA in the EEA. HSE did not provide data on the number of notifications made under UK REACH in time for incorporation into this assessment.

2.3.3.8 Geographic distribution

It is probable that the geographical distribution of sites will be very similar to that of the 357 sites notified under REACH/20/18/14-20 with activities focused in France, Germany, Italy, Spain and Poland. As such, the distribution of the estimated 180 EEA sites involved with CAA in the EEA is shown in the table below. There is no comparable publicly available data for the UK, so no breakdown is provided by country for Great Britain.

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

Country	**# Sites**
France	45
Germany	30
Italy, Spain, Poland (15 each)	50
Czech Republic, Sweden (10 each)	20
Finland, Netherlands, Belgium (5 each)	15
Denmark, Hungary, Norway, Romania, Bulgaria, Ireland, Malta, Greece, Lithuania, Portugal, Slovakia (1-3 each)	20
Total EU (plus Norway) sites	**ca. 180**
Total UK	**ca. 30**

2.3.3.9 Customers

The end actors within this value chain are the customers of A&D final products treated with CAA.

With respect to civil aviation, the global air transport sector employs over 10 million people to deliver in a normal year some 120,000 flights and 12 million passengers a day. In 2017, airlines worldwide carried around 4.1 billion passengers. They transported 56 million tonnes of freight on 37 million commercial flights. Every day, airplanes transport over 10 million passengers and around US$ 18 billion (€16 billion, £14 billion) worth of goods. Across the wider supply chain, subsequent impacts and jobs in tourism made possible by air transport, assessments show that at least 65.5 million jobs and 3.6% of global economic activity are supported by the industry.[11] 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

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

billion (€5.8 billion, £5.1 billion).[12] 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[13]. 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 CAA, including naval systems, ground based radars, ground vehicles etc.

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

2.4 Consultation

2.4.1 Overview

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

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

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

- 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.

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

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

[13] *Source:* Eurostat (gov_10a_exp)

involved in repackaging) and/or as a distributor for other applicants/formulators of the chromates for use in CAA.

Only a minimal amount of economic data was collected from the applicants, as losses in profits to this group of companies is not what drives the requested re-authorisations 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

2) 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

3) 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).

4) 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.

It is important to note that as work progressed over these different phases of consultation, members identified reduced needs with respect to the on-going use of chromates for CAA.

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 organisation 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, and as indicted earlier, data for over 260 sites within the ADCR members' supply chains was provided in responses to these questionnaires. The information provided by these organisations relevant to CAA – which includes A&D companies as well as Ministries of Defence – is included in the SEA components of this document.

2.4.3.3 MROs

For consistency purposes, MROs were asked to also complete the BtP questionnaire. Again, these were supplied directly to MROs or were distributed by the key suppliers to the larger ADCR members. Military MROs that did not join the consortium also provided data on their activities to ensure that these would also be covered by a renewed Authorisation. These data are taken into account 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

Anodising is an electrolytic oxidation process where the surface of a metal is converted to 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).

As noted previously, the chromate of relevance to the Applied for Use is:

- Chromium trioxide (includes "Acids generated from chromium trioxide and their oligomers", when used in aqueous solutions)	EC 215-607-8	CAS 1333-82-0

Chromium trioxide is the source of the tetrahedral Cr(VI) oxoanion. Not all oxoanions exhibit the same properties as Cr(VI). Cr(VI) has the advantage of being more stable to thermal and photochemical degradation compared to some other tetrahedral oxoanions, for example permanganate (MnO_4^-). Compared to Cr(VI), permanganate has the disadvantage of being both very strongly coloured, deep purple, and unstable. The permanganate oxoanion can degrade forming manganese dioxide which catalyses further degradation; exponentially reducing its shelf life.

The anodising process is typically performed in an immersion bath, as illustrated in **Figure 3-1**.

Figure 3-1: Anodising immersion baths
Source: Lockheed Martin

In addition to immersion, local application is possible using an anodising electrode, sometimes referred to as brush anodising, as illustrated in **Figure 3-2**. This may be used for restorative purposes or to meet the performance requirements of the OEM. A swab or brush electrode acts as the cathode and the component to be anodised becomes the anode. The anodic coating forms on the metallic substrate in the localised region in the presence of the electrolyte.

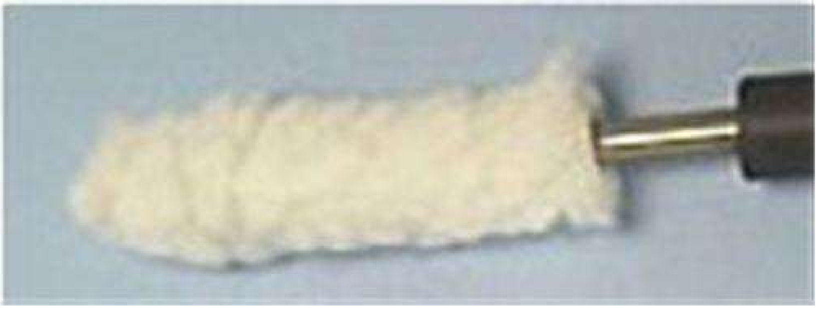

Figure 3-2: Selective anodising electrode

CAA is performed under acidic conditions and produces a thin oxide layer of the substrate typically controlled to 2 – 5µm thick. This is significantly thicker than the natural oxide surface of an untreated aluminium surface (which is typically 0.005µm), and thinner than surfaces created by non-CAA process for example Sulphuric Acid Anodising (SAA) (which is typically 15µm and greater) (CTAC, 2015).

3.1.1.1 Process steps and overview of key functions

CAA comprises several different process steps including pre-treatment and post-treatments. Pre-treatment steps include cleaning/degreasing, pickling/etching, deoxidising, desmutting and stripping. An anodic process can result in a porous surface with insufficient corrosion resistance. Under this scenario the coating must be sealed to provide adequate protection to the substrate; this is called anodise sealing. Anodising may be followed by stripping - to remove the anodic coating without degrading the substrate itself. This process is used for rework, maintenance, and repair operations. Stripping with chromic acid is also used for routine quality control (QC) purposes. These QC processes may be monthly for example, to ensure the anodising process is delivering the required anodic coating weight by weighing the amount of coating stripped from a specified area. In other cases, anodising may be followed by an additional coating, for example a bonding primer for adhesive bonding (CTAC, 2015).

The key functions of chromic acid anodising are:

- Wear resistance
- Corrosion resistance
- Chemical resistance
- Adhesion promotion (adhesion to subsequent coating or paint);
- Layer thickness; and

Anodic coatings often provide superior strength and adhesion compared to most paints and metal plating, however at the expense of being more brittle. This reduces susceptibility to crack or peel from aging and wear although anodic coatings are less tolerant of cracking from exposure to thermal stress (CTAC, 2015)

Corrosion resistance is important to increase the life of the component in service, especially in situations where the component is relatively inaccessible and cannot be easily or frequently inspected.

Corrosion resistance is also important to prevent corrosion of the component during intermediate steps in the manufacturing process. When combined with anodise sealing or other treatments such as primers, (not described in this combined AoA/SEA), further corrosion resistance is imparted, should this be required. This may depend on the operational environment of the component. Interdependency between uses is discussed in Section 3.2.1.

Chemical resistance (which is closely related to corrosion resistance) refers to the ability of the component to withstand contact with fluids encountered in the service life of the part, such as lubricants, hydraulic fluids, greases, fuels, solvents, de-greasers, cleaning fluids, and de-icing fluids.

Adhesion promotion to subsequent coating, paint, or layer can refer to paints, primers, (including bonding primers e.g. for structural bonding), adhesives and sealants but can also apply to other functional coating layers such as lubricants.

Layer thickness is important from the perspective that chromic acid anodising has an insignificant impact on the dimensions of the treated part. The anodic layer thickness from CAA is reported to be in the region of 2 – 7μm (CTAC, 2015). CAA is capable of producing a layer thickness of 0.0 to 10μm with most uses controlled to 2-5μm. ADCR members report typical thickness of up to 10μm. Selection of a test candidate considers the impact on component dimensions and tolerances from the thickness of the anodic layer. A process that leads to uncontrollable coating build-up affecting the performance of the component when integrated into assemblies and sub-systems would be unacceptable. For example, an anodise layer that is too thick can cause increased wear when the component is integrated and moves in relation to other components.

The electrical resistance properties of anodised coatings can help to mitigate galvanic corrosion. Therefore, test candidates must also exhibit sufficient electrical resistivity in line with chromic acid anodising.

Any alternative to Cr(VI) should not adversely affect layer thickness or resistivity, or adversely affect the ability to control them through the normal process operating conditions (such as time, temperature, pH, and degree of agitation).

3.1.1.2 Components and assemblies that may be treated with the Annex XIV substance

As detailed above, anodising, 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.)

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
Environmental control systems	Propellers	Engine External components	Missile and gun blast control equipment
External fuel tanks	Transmission housing	Fuel pump	Missile launchers
Flight control systems		Gearbox	Pyrotechnic Equipment
Fuselage		Hydraulic intensifier	Radomes
Hydraulic damper		Ram air turbine	Rocket motors
Hydraulic intensifier		Starter	Safe and arm devices
Landing equipment		Vane pump	Sonar
Nacelles			
Pylons			
Rudder and elevator shroud areas			
Transall (lightning tape)			
Undercarriage (main, nose)			
Valve braking circuit			
Window frames			
Wing fold areas			
Source:(GCCA, 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 decrease in the level of corrosion protection and wear resistance since some or all of the following consequences may occur (GCCA, 2017)

- Substantial increase in inspections, some of which are very difficult or hazardous to perform;
- Increased overhaul frequency or replacement of life-limited components;
- Possible early retirement of aircraft due to compromised integrity of non-replaceable structural parts
- Whole fleets may be grounded until a repair/replacement plan is in place for the whole aircraft fleet - This could impact many or all aircraft fleets; and
- Reduced flight durations

Defence systems would be similarly impacted, affecting the continuity of national security.

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.

3.1.1.3 Service life and maintenance intervals of components and assemblies

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

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

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

As an example, for commercial aircraft the A-checks occur every 400-600 flight hours, the B-checks are performed every 6-8 months, and the C-checks are completed every 20-24 months. C-checks typically take up to 6,000 man hours to complete. The D-checks are completed every 6-10 years and typically take up to 50,000 man-hours to complete. At Lufthansa, the D-check begins with the stripping of the exterior paintwork. The aircraft is taken apart and each system is checked thoroughly using the most modern methods for non-destructive material testing such as X-rays, eddy current probes. 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 are typically not inspected. Corrosion protection of these regions must be robust for 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 and 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**[14]**,** 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 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 up to fatal failures of vital/critical components

The civil aviation industry must comply with the airworthiness requirements derived from Regulation(EC)No 2018/1139[15] in the European Economic Area (EAA). Similar airworthiness requirements exist in all countries where aeronautical products are sold. These regulations require a systematic and rigorous framework to be in place to qualify all materials and processes to meet stringent safety requirements that are subject to independent certification and approval through the European Aviation Safety Authority (EASA), and other agencies requirements. 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.

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[14] 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

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

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 2-1**).

Military/defense OEMs have additional challenges because individual defense customers usually assume full design/change authority upon accepting the military/defense hardware designs. This means that any intent to change the hardware configuration, including coatings and surface treatments, must be approved by the military/defense agency, 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 program 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 defense customers, it is often required to obtain permission from each customer prior to hardware changes and these customers rarely agree. The combination of (a) not mission essential, (b) fiscal constraints, and (c) multiple conflicting customer opinions, greatly complicates any military/defense 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.

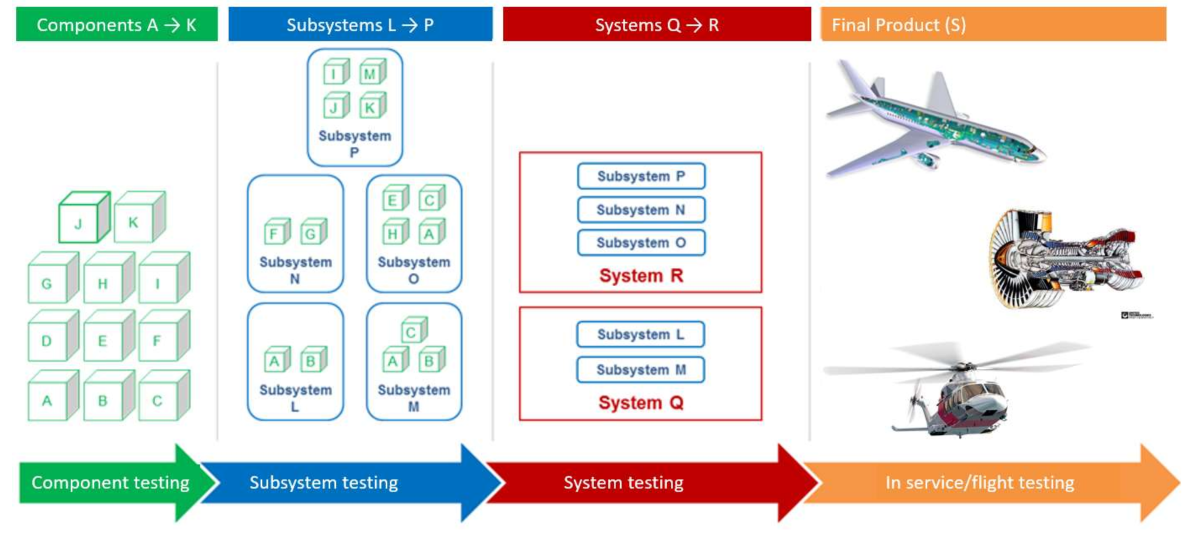

Figure 3-3: Assessment requirements in the implementation of alternatives
Source: Adapted from GCCA white paper

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.
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.

Table 3–2: Technology Readiness Levels as defined by US Department of Defence		
TRL	**Definition**	**Description**
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	Mfg. strategy refined and integrated with Risk Management Plan. Identification of enabling/critical technologies and components is

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

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

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

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

3.1.2.2 Process, requirements, and timeframe

Identification and Assessment of need for substitution

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

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

The above work requires contributions from numerous personnel from various departments including Materials and Processes, Research and Development, Design and 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., fatigue life compatibility of the component's geometric complexity with the coating technique);
- Industrial requirements (e.g., robustness, processability, and repeatability); and
- Environment, Health and Safety (EHS) requirements (e.g., is there an equivalent level of concern).

For some alternative's workstreams 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.

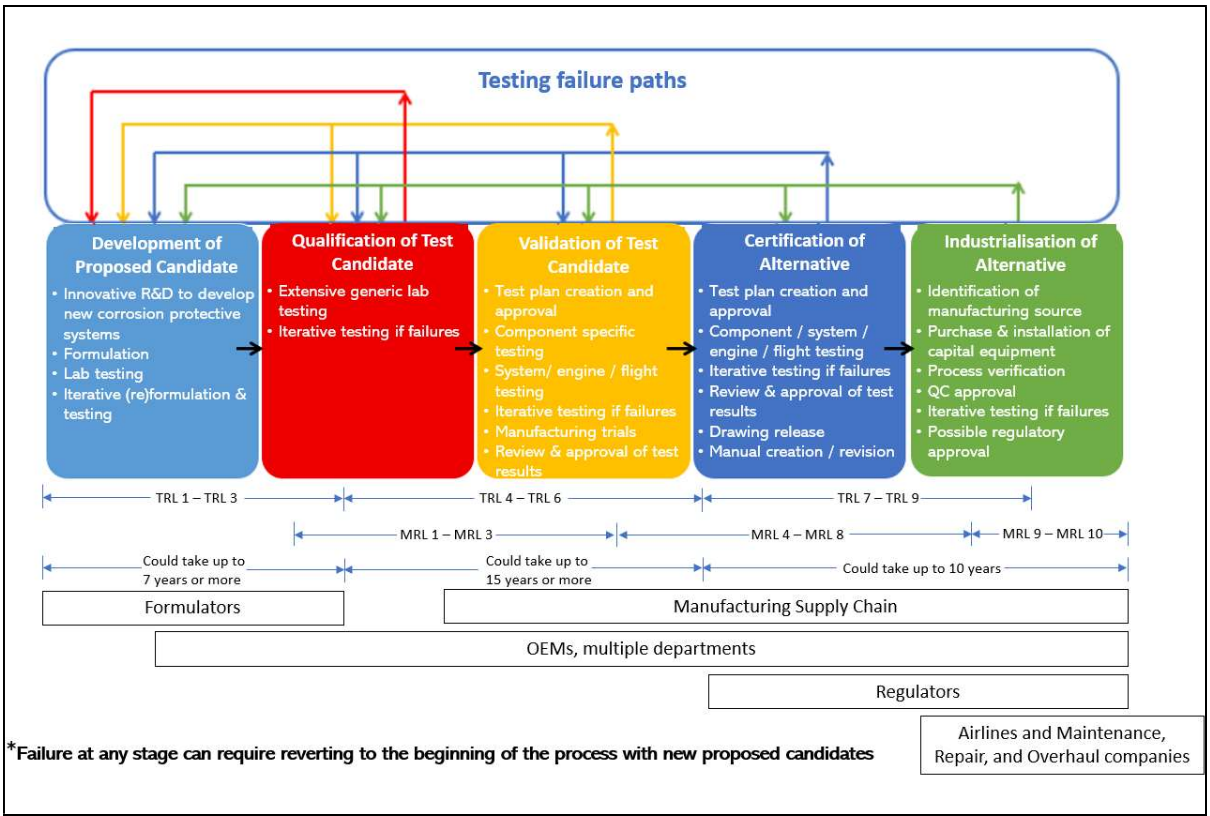

Figure 3-4: Schematic showing the key phases of the substitution process
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note 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 criteria required by the design owner. Failure against any of these criteria may result in rejection of the proposed candidate, further modification of the formulation, or additional testing. Although it may only be the Cr(VI) compound within a mixture which is subject to regulatory action, the other constituents may also require substantial change to continue to meet the stated performance requirements.

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

Development typically involves an iterative process of re-formulation and re-testing to identify one or more proposed candidate. It is important to note that many iterations of these formulas are rejected in the formulator's laboratory and do not proceed to evaluation by the design owner. Formulators estimate that it typically takes two to five years of testing potential formulations before a proposed candidate is identified for submittal to the design owner[16].

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, refer to **Figure 3-4** see 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

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[16] GCCA

performance requirements and only successfully qualified test candidates can progress to the validation stage described below.

Validation of test candidate

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

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

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

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

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

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

Certification of alternative

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

Steps in the Certification stage include:

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

For the civil aviation industry, the output of the original certification process is a Type Certificate, issued by the airworthiness authority (e.g. EASA) and granted to the engine, propeller, and airframe OEM. This is issued for the original design of the final product, rather than for each individual component, however every component of the final product must be designed, developed, and validated as meeting the requirements of the overall product and system design. The overall compliance demonstration for a new Type Certificate therefore may cover several thousand individual test plans, of which some will require several years to complete. This interconnection is illustrated using the example of an aircraft in **Figure 3-5** 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[17], each of these components will need to be approved individually:

> *"Importantly, even if an alternative is in use in one component in aerospace[18] 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."*

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

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

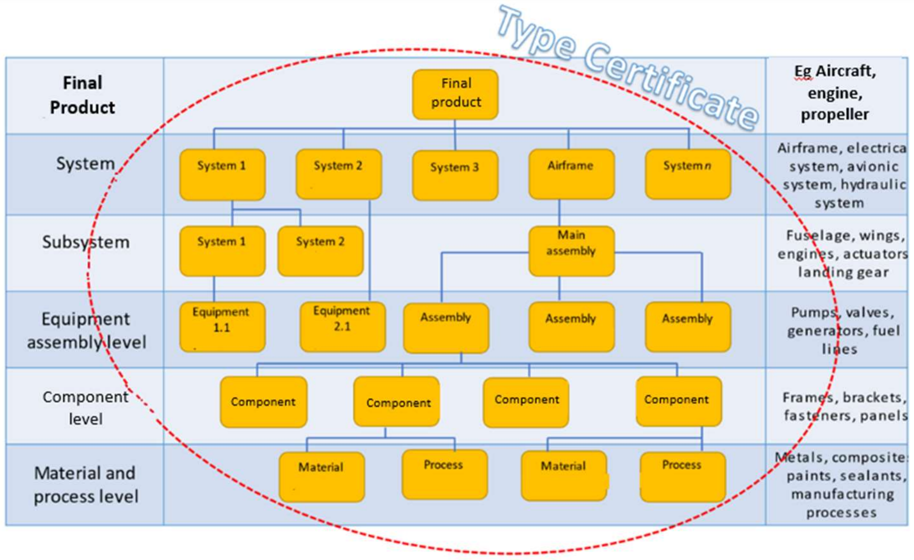

Figure 3-5: System hierarchy of a final product
Figure 3-5 shows the interconnection of each level in the system hierarchy, and how changes at a lower level have impacts on higher levels
Source: ADCR Member

After the alternative is certified, design drawings and 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 program, and method for repair, is stated in the maintenance manual and must be officially approved. For most A&D organisations, repair approval is distinct from design approval, although the processes are analogous and may be undertaken concurrently. Once repair approval is complete the alternative will be included in maintenance manuals.

During initial manufacture, all the components of the system are in a pristine and relatively clean condition, whereas during repair and maintenance, the components are likely to be contaminated and suffering from some degree of (acceptable) degradation. Furthermore, certain cleaning and surface preparation techniques that are readily applicable during initial manufacture may not be available or practical during repair and maintenance. Carrying out MRO activities on in-service products is further complicated due to restricted access to some components, which are much more readily accessible during initial manufacture and assembly. These factors are significant with respect to surface treatments, as their performance is strongly dependent upon the condition of the surfaces to which they are applied. As such, all of these conditions must be addressed in the repair approval process.

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

Industrialisation of alternative

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

Elements of the Industrialisation of alternative process include:

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

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

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

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

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

The industrialisation process includes the creation and approval of process documents or manufacturing/repair documents. These documents allow detailed implementation of the manufacture and/or repair of each component.

Using the example of a commercial aircraft, a simplified example of the process, described above and leading to industrialisation of the alternative, is illustrated in **Figure 3-6** below. This is a simplified example, in some cases, many different types of components will need validation testing and there are cases where different test candidates are used on different parts to replace a single original chromate use.

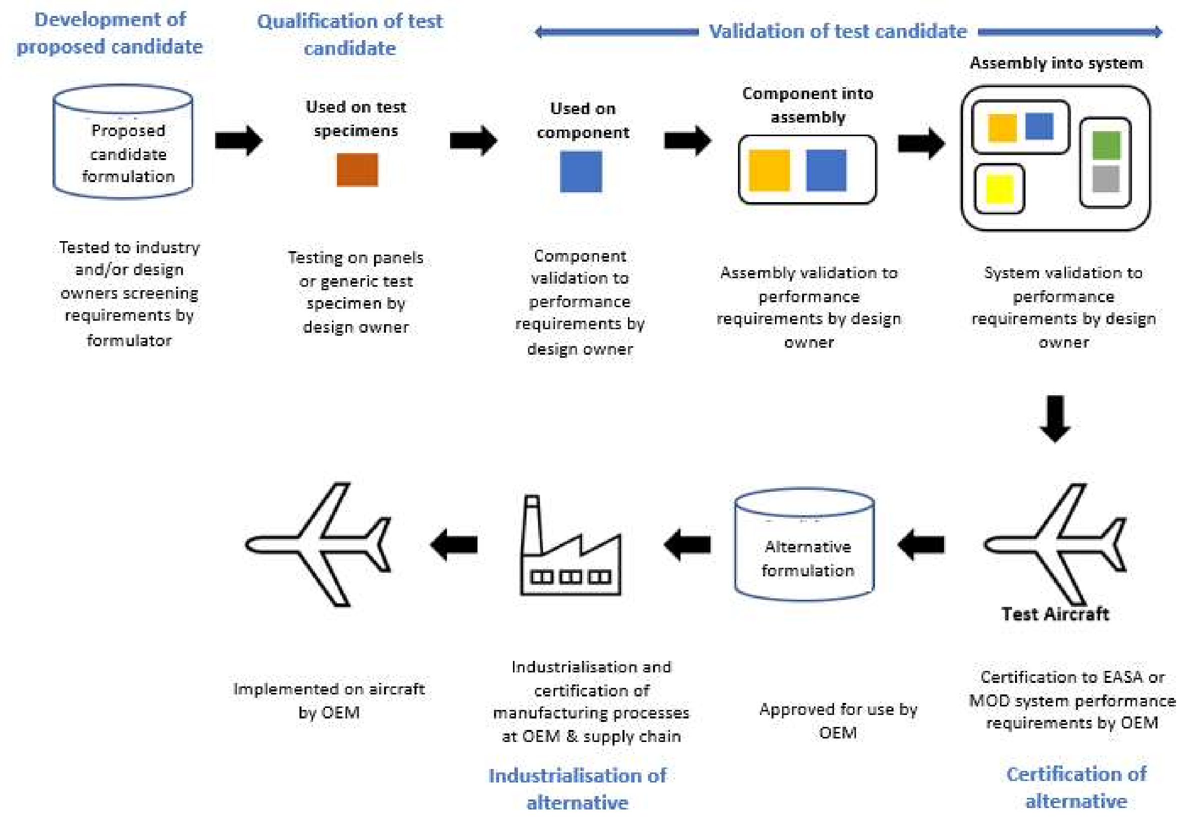

Figure 3-6: Process to Certify a Formulation for use on Aircraft. Formulations used in production have completed this process. New or reformulations must follow same process for use in production.
Source: ADCR Member

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 anodising

3.2.1.1 Introduction

The development of technical feasibility criteria for Cr(VI) in anodising (and potential alternatives) 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 chromates and test candidate (substances and technologies) need to meet in order to deliver the functions tied to anodising.

In parallel, scientific literature describing anodising and the assessment of the technical feasibility of specific alternatives was collated (with the assistance of the ADCR consortium members) and incorporated into the analysis.

The criteria used in the assessment of the technical feasibility of selected test candidates are as follows:

- Wear resistance
- Corrosion resistance ;
- Chemical resistance;
- Adhesion promotion (adhesion to subsequent coating or paint); and
- Layer thickness.

The electrical resistance properties of anodised coatings can help to mitigate galvanic corrosion. Therefore, test candidates must also exhibit sufficient electrical resistivity in line with chromic acid anodising

In addition to the above criteria, the impact of the test candidate on performance requirements including inter-granular attack/end-grain pitting and fatigue strength must be tested in parallel for sensitive designs and must meet or exceed the performance threshold achieved with chromic acid anodising

As noted above, this combined AoA/SEA covers the use of chromium trioxide for anodising. Chromium trioxide includes “acids generated from chromium trioxide and their oligomers", when used in aqueous solutions.

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

The anodic coating formed by the anodising process is mainly driven by the applied voltage during the anodising cycle. The unsealed anodic coating is not strongly resistant to corrosion. However, CAA causes Cr(VI) to be entrapped in the pores of the anodic layer. This entrapped Cr(VI) is reduced, precipitating insoluble Cr(III) compounds providing post anodising corrosion resistance.

Mode of action is important to consider when analysing test candidates; how does the chemistry of Cr(VI) contribute to a particular function, what are the benefits from using Cr(VI) and are these benefits replicated by another substance or process, if not, what are the implications upon the performance requirements of the intended use?

The discussion below explains the relevance and importance of each of the technical feasibility criteria in more detail whilst considering important key performance requirements in the context of the overall use.

Pre-treatments

Pre-treatments are used to facilitate the anodising treatment and compliment the technical functions of the main use.

Deoxidising is used to remove surface oxides and exposed intermetallic particles from the surface of the substrate. This process of removing contamination such as metal oxides serves to activate the surface ready for the anodising process. Other cleaning processes remove contaminants resulting from, for example, machining or shot peening which could interfere with the anodising treatment. Further examples of pre-treatments include degreasing, pickling/etching, desmutting and alkali cleaning. Both Cr(VI) and non-Cr(VI) pre-treatments may be used prior to anodising as dictated by the design owner's specification.

The application of abrasive blast pre-treatment to roughen the substrate surface prior to anodising may be used for later adhesion although this is not common practice and may not always be permitted if consistent cleaning cannot be achieved. Mechanical cleaning may be required for touch-up areas as required.

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, **Error! Reference source not found.**, proposed candidates are at an early stage of evaluation represented by TRL 1 – 3, and not recognised as credible test candidate at this stage. These proposed candidates are screened against the technical feasibility criteria, or key functions imparted by the use 'anodising'. 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 and performance thresholds 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 AoA, the importance of the performance thresholds and standards are multi-fold; to ensure reproducibility of the testing methodology, define acceptable performance parameters and determine if proposed candidates exhibit regression; inferior performance, or are 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 for evaluation as potential alternatives. 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 and identify potential test candidates that meet all key functions and performance requirements such as impact on fatigue strength.

Interrelationship of technical feasibility criteria and performance requirements impacting the surface treatment 'system'

When considering technical feasibility criteria and performance, in many instances these are strongly interrelated in the delivery of the use, and it is not possible to consider one criterion independently of the others when assessing proposed alternatives. Anodising is a constituent part of a 'system' which combined with other processes delivers the overall desired technical feasibility criteria and performance requirements such as adhesion promotion to a subsequent coating/paint layer, including primers, e.g., structural bonding primers. Other ‘uses’ contributing to this system in addition to subsequent coatings include pre-treatments and chemical conversion coating, which is used for touch-up repair of CAA coatings.

To illustrate, unsealed anodising promotes good adhesion of a primer. Corrosion resistance is principally provided by subsequent primers; therefore corrosion resistance is partly dependent upon the adhesion property delivered by the unsealed anodic layer when supplemented with a primer.

Increasing the layer thickness of the anodic coating will preferentially affect its corrosion resistance, and/or chemical resistance. As introduced in section 2.3.1.1, CAA has the characteristic of a self-limiting rate of oxide growth which is advantageous for controlling layer thickness within required parameters. However, if the anodic coating is difficult to control and becomes too thick, it may adversely affect the fatigue strength of the substrate alloy negating the benefit of the increased layer thickness. Therefore, it is particularly important to ensure that corrosion resistance is achieved without adversely affecting fatigue strength or fatigue life of the treated component. It can be seen that many elements of the technical feasibility criteria and performance requirements have a degree of interdependency.

Changing one use in isolation is often not the most efficient means of achieving the required performance from the treatment system as compatibility between uses, and therefore test candidates, cannot be assured. 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 uses at different times. When anodise seal is required, it is often good practice to approve test candidates for both the anodising and anodise seal treatments together to ensure both are compatible with one another.

A further consideration is alignment with development of other Cr(VI) free processes used for repair or touch-up of anodic coatings, for example chemical conversion coating. Parallel development is necessary as a Cr(VI)-free repair or touch-up process is required to support the introduction of the Cr(VI)-free use. Conversion coatings are routinely used after the anodising process to touch-up the electrical contact point. Therefore the substitute conversion process must be compatible with the anodising test candidate process as the touch up coating overlaps the adjacent anodised surface. 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 time-frame.

Practical consideration may also apply, as it may not be possible to accommodate Cr(VI)-free and Cr(VI) processes in parallel within the same production environment due to lack of space on site. Extra space for the Cr(VI)-free process may be required for a variety of reasons for example the need for extended waste treatment processing facilities, and managing segregation of components treated via different processes etc. Pre-treatments may include chemical pickling/etching, deoxidising, desmutting, and other supplementary chemical or mechanical cleaning steps such as degreasing. The selection of pre-treatments and the alternative chosen to deliver the anodising use need to be considered against the design parameters of each treated part. How do components interact with each other, and the treatment system delivering the technical feasibility criteria? Interactions between elements of the surface treatment system may not be anticipated. These may only manifest themselves when more advanced testing of component in simulated service environments is conducted or when used in multi-part assemblies.

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[19]:

- Hardware[20] base alloy(s);
- Contact or mating surfaces with other parts;
- Exposure to fluids;
- Structural stress and strain; and
- External environment.

External environmental variables affecting in-service conditions for different assemblies of 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[21], vibration, erosion.

These can all affect the corrosion behaviour of a component and the performance requirements of the alternative delivering the surface treatment 'system'. Due to the complexity of these assemblies and 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

Aluminium substrates

Corrosion resistance to counteract potential corrosive degradation from exposure to aggressive environmental conditions is important to the service life, reliability, and safety of parts. This is an essential requirement where access to the component or assembly, for maintenance or inspection purposes, is restricted or not possible.

Chromic acid anodising is performed in an acidic solution containing chromium trioxide and, in some cases, other acids.

The component to be treated forms the anode of an electrical circuit, the 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 of the substrate. This oxide formation improves the corrosion resistance of the substrate. Some of the aluminium is dissolved, as ions, into the process bath, which leads to bath losses and the need to replace some of the bath solution (CTAC consortium, 2015).

The oxidation and reduction processes are analogous to chromate conversion coating. Aluminium metal is oxidised to Al^{3+} and Cr(VI) is simultaneously reduced to Cr(III) as follows:

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

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

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

(1) $2\ Al \rightarrow 2\ Al^{3+} + 6e^{-}$

(2) $2\ Al^{3+} + 3\ H_2O \rightarrow Al_2O_3 + 6\ H^{+}$

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

Although the chemistry of anodising is analogous to conversion coating, the anodic film formation is mainly driven by the applied voltage during the anodising cycle (CTAC consortium, 2015).

All anodised coatings are porous. The substrate evolves gaseous oxygen from the metal/solution interface throughout the anodising process, with the oxygen bubbles escaping through the pores. Unsealed anodised coatings of all types are not strongly corrosion resistant unless they are sealed. Chromic acid anodised coatings have some corrosion resistance in the unsealed state due to entrapment of Cr(VI) species in the pores, allowing precipitation of insoluble Cr(III) compounds to prevent corrosion subsequent to the anodising process.

Magnesium substrates

The anodising process may also be used for non-aluminium/aluminium alloy substrates. Magnesium substrates are used in the fabrication of aerospace and defence products and are also subject to the anodising process to increase their corrosion resistance or to ready the surface prior to applying an organic finish for example[22]. Anodising is beneficial as magnesium is a very active metal from a chemical and electrochemical point of view, which can increase drastically the degradation of the material once corrosion starts. As with other materials, the corrosion sensitivity of magnesium alloys is strongly dependent upon the aggressiveness of the environment. Immersed in fresh water, magnesium alloys tend to produce a slightly protective and poorly soluble layer of magnesium oxide, which is enough to ensure a moderate corrosion protection. However, the presence of chloride ions, even at a very low concentration, results in the dissolution of magnesium into highly soluble magnesium hydroxide, which leads to a severe degradation of the material. Unfortunately, the presence of chloride ions is very common, and their concentration can reach high values, especially in marine environments. Furthermore, the corrosion sensitivity of magnesium alloys increases strongly with temperature. As with the anodising process described for aluminium alloys the anodic coating is formed as a result of the electrochemical reaction that occurs when the alloy, which is made electrically positive (anode), is immersed in a water-based electrolyte.

3.2.1.4 Technical feasibility criterion 2: Chemical resistance

Chemical resistance refers to the ability of the component to withstand contact with fluids encountered in the service life of the part, such as lubricants, hydraulic fluids, greases, fuels, solvents, de-greasers, cleaning fluids, and de-icing fluids. Anodised aluminium is chemically inert to solvents and aircraft fluids. If additional chemical resistance is required, then it may be necessary to seal the anodic layer and/or apply a subsequent coating, such as a primer.

3.2.1.5 Technical feasibility criterion 3: Adhesion promotion (adhesion to subsequent coating or paint) of subsequent layer

Adhesion of organic coatings to anodised films is influenced by the sealing process. Unsealed anodised coatings typically have superior adhesive properties due to the presence of the pores, which allow for mechanical interlocking of the organic coating with the anodised layer. Some sealing processes, such

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[22] SAE (2022): AMSM45202: Magnesium Alloys, Anodic Treatment Of - SAE International

as nickel acetate sealing, produce copious deposits of low cohesive strength that block the pores but also extend over the adjacent anodised film, resulting in unacceptable paint adhesion. Hydrothermal sealing, with the addition of Cr(VI) compounds serves to strengthen the pore bases, narrow the pore walls, and infiltrate the pore region with corrosion inhibitive Cr(VI) compounds while allowing for some capillary infiltration of subsequent paint layers with acceptable adhesion.

3.2.1.6 Technical feasibility criterion 4: Layer thickness

Layer thickness is principally controlled by (i) the anodising solution (composition, pH, temperature, time) and (ii) the applied voltage. As stated above it is important to carefully control the thickness of the anodic layer. A thickness of up to 10µm is reported as typically achieved with CAA. As reported above, a characteristic of CAA is its self-limiting nature affecting oxide growth. This aspect of CAA is important to achieving target thickness range for components with narrow geometric tolerances, and those that are sensitive fatigue strength loss. Cr(VI) supports the oxidation of the substrate, in conjunction with the applied voltage, and formation of the metal oxide. Dissolution in chromic acid occurs at the same time competing with the oxide formation on the surface and contributing to the characteristic structure of the porous anodic layer. Thicker layers will preferentially benefit corrosion resistance. However, if the anodising process is difficult to control and becomes too thick, as stated, it may adversely affect the fatigue strength of the substrate alloy. For non-CAA anodic coatings, such as sulphuric acid anodising the layer thickness can be too thick due to non-thickness limiting nature of the oxide growth from this substitute, detrimentally impacting fatigue strength, or impacting geometric tolerances. Local current densities in anodising baths vary due to part geometries and voltage drops in the solution. The self-limiting property of oxide growth from the CAA process counters non-uniform anodise coating growth rates that would otherwise result from variations in local current densities in anodising baths. Where this self-limiting property is absent with test candidates, the impact of tighter control of operating processes, and any variation in arrangement of parts in the anodising solution, must be assessed before implementation.

3.2.1.7 Technical feasibility criterion 5: Wear resistance

Cr(VI) does not directly contribute to wear resistance, which is due to the composition and structure of the anodisation layer; aluminium oxide is a very hard substance. Combined with the cohesive and adhesive strength of the anodised layer, it is a wear resistant surface. The cohesion and adhesion properties of the anodic coating are related to its density, therefore controlling the density of the anodic coating influences its wear resistance.

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

With regard to the replacement of chromium trioxide in anodising, 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 anodised alloys 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: Potential A&D applications of anodising
(Rheinmetall – Systems & Products, n.d)

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 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 'anodising'. Potential alternatives to Cr(VI) in anodising are shown in Table 3-4. This list comprises all the alternatives that were reported in the parent AfAs. Note that not all test candidates reported in the parent AfAs have been the focus of research and progression by the members.

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

Test Candidate	AfA ID
Boric-sulphuric acid anodising (BSA)	0032-04
Sulphuric acid anodising (SAA)	0032-04; 0032-05
Thin film sulphuric acid anodising (TFSAA)	0032-04
Tartaric sulphuric acid anodising (TSA)	0032-04
Phosphoric acid-based anodising (PAA)	0032-04

Electrolytic paint[(b)]	0032-04
(a) (ECHA, n.d.-a) (b) AfA 0032-04 section 7.1.9.2 (applied with a thickness of 5µm)	

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 combined AoA/SEAs, e.g. the Global Chromates Consortium for Aerospace (GCCA), Chromium trioxide Authorisation Consortium (CTAC) and Chromium VI Compounds for Surface Treatment (CCST). However, this review focuses upon recognised collaborations which include research into the development of alternatives for anodising and identify additional relevant collaborations.

A short summary of the collaborations relevant to anodising 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). The project considered a range of alternatives to CT as well as new anodising methods and was followed by the SUSITICOAT project which continued work on alternatives to CAA.

- **Advanced Surface Engineering Technologies for a Sustainable Defense (ASETSDefense)** consists of SERDP (Strategic Environmental Research and Development Program) and ESTCP (Environmental Security Technology Certification Program) and is a US Department of Defense initiative. ASETSDefense aims to provide information on environmentally friendly surface engineering technologies, including chromate free alternatives to CAA. A range of potential alternatives were considered including thin film sulphuric acid anodising (TFSAA); boric acid; oxalic acid; tartaric acid; boric-sulphuric acid; phosphoric acid; Keronite (plasma electrolytic oxidation); and Tagnite;

- **The Aerospace Chrome Elimination Team (ACE)** were established in 1988, with members including: Boeing, Lockheed Martin, Northrop, Grumman, NASA, UTC, Pratt Whitney, Sikorsky, Raytheon, NAVAIR, AMCOM G4[23], ARL[24] and AFRL[25] (Lamb, 2014). The outcome of studies from within the group is restricted to the members only, and not in the public domain. However, it is known that anodising was one of four investigated uses;

- **The Clean Sky 1 Joint Technology Initiative** was launched in 2008 running to 2014. Clean Sky 2 Joint Undertaking launched in 2014 and is set to run until 2024 as a collaboration between private and public sectors. The project was established beforehand by industry members in

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[23] U.S. Army Aviation and Missile Command

[24] U.S. Army Research Lab

[25] U.S. Air Force Research Lab

2006, including numerous ADCR members. Since December 2021, Clean Aviation began, running alongside Clean Sky 2 which will end in 2024 (Clean Aviation, 2022). Under the Clean Sky initiative, the TARTASEAL (€100k in total funding), SAA-SEAL (€240k in funding), OptiSeal and ECOLAND projects have assessed alternatives to CAA for the purposes of protecting aircraft landing gear which utilise lightweight aluminium alloys. Results reported in 2020 were encouraging although only are TRL 5. To progress further researchers were seeking commercial partners (European Commission, 2020). These projects have resulted in some alternatives being identified for specific applications (certain grades of aluminium and types of parts);

- **Airbus 350 programme** (GCCA, 2016) describes multiple projects led by GE Aviation. Since 2010 tartaric sulphuric acid anodising rather than chromic acid anodising has been in use with the caveat that potassium/sodium dichromate was still required for anodise sealing and priming uses following the anodising step. Tartaric sulphuric acid anodising (TSAA) was reported as a promising candidate however lacking sufficient corrosion protection throughout the lifecycle of the product. Another potential issue is posed by the presence of tartaric acid which may promote microbial growth leading to the need for related control measures. Further details are not provided, however Belmar Technologies state that there is microbiological activity in both the TSAA solution and water rinses post anodising. Tartaric anodising solution is highly bioavailable (Belmar Technologies, n.d.);

- **NAPOLET project** is being part funded by CzechInvest (*TREND Programme - Research & Development in the Czech Republic*, n.d.). The project is focused on “Replacement of surface anticorrosive and sliding layers of aerospace materials with more environmentally friendly technologies” (may also be known as NAPOLET). The project will end in December 2022 and has as part of its focus (WP1) the replacement of CAA for use on a range of aluminium alloys.

- **TREND programme.** The TREND programme supports industrial research and development projects financed from the state budget by the Technology Agency of the Czech Republic and Ministry of Industry and Trade under ‘CzechInvest’. Projects encompass advanced production technologies, advanced materials, nanotechnology, industrial biotechnology), digital technologies (micro and nanoelectronics, photonics, artificial intelligence), and cyber technologies (security, connectivity) (*TREND Programme - Research & Development in the Czech Republic*, n.d.)

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 to identify examples of potential technologies related to anodising. The search was performed using Espacenet[26], the European Patent Office (EPO) open access search portal. Espacenet contains over 120 million patent documents held by patent offices around the world, including North America and Asia (EPO, 2020) .

Using Espacenet, a search carried out in October 2020[27] for “anodise”, “anodising”, “anodize” or “anodizing” which returned more than 80,000 results. Various modifications to the search terms were used to achieve a manageable but relevant list. The final search used was ("anodise" OR "anodize" OR "anodising" OR "anodizing") AND ("non-chromate" OR (“chromate" prox/distance<3[28] "alternative")) and applying main group classification filters C23 and C25; descriptions below, returned 43 results:

- 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

- C25: Electrolytic or electrophoretic processes; apparatus therefor

Eliminating from this list patents that were not relevant or were related to chemical conversion coating finally resulted in just four patents, of which only two had a priority date later than 2000. These are briefly discussed below.

US5954893A (1994) discusses a method for treating an aluminium substrate to provide corrosion resistance by creating a porous layer on the surface and then treating with a solution or gel comprising a metavanadate ion. The porous layer in the first step is an oxide layer produced by acid anodising using sulphuric, phosphoric, or oxalic acid.

JP2012522965A (2009) EP2414764A4 (2016) by Henkel discusses a method for making a ceramic coating on an aluminium heat exchanger by anodising in a solution an aqueous solution having at least one of a fluoride and oxyfluoride of elements selected from the group consisting of Ti, Zr, Hf, Sn, Al, Ge and B. The coating has a thickness of 1-5µm and provides a mist spray corrosion resistance of at least 4,000 hours according to ASTM B117-03.

CA2198548A1 by Boeing and the University of Virginia (1996) discusses a boric acid/sulphuric acid anodising process on aircraft aluminium alloys as a pre-treatment to a conversion coating process. The conversion coating mixture includes a continuous phase selected from organic polymeric compositions, or sol-gels, and a distributed phase including corrosion-inhibiting chromate-free salts.

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

[27] 10 October 2020

[28] prox/distance<3 refers to a search for the two terms on either side if they are three words or less distance from each other.

WO2016201935A1 (2015) discusses an anodising method to produce a gold-coloured coating on aluminium alloy. The anodising solution consists of potassium permanganate, sodium persulfate, sodium acetate and sodium chlorate in a sodium hydroxide solution.

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

3.4.3.2 High-level literature review

A representative non-exhaustive technical literature review was carried out using Science Direct [29] on-line service via keyword search. The purpose of this search was to identify examples of alternatives to Cr(VI) for anodising that have been investigated in the academic field or within industry. The high-level literature review compliments the parallel non-exhaustive patent search. These were filtered according to their ‘Open Access’ status; documents available to the public without payment of a licence fee

Keyword search criteria (“anodising” OR “anodizing”) returned over 400,000 results. Modifying the search terms to ("non-chromate") AND (anodising OR anodizing) returned 232 results.

A short discussion of the most relevant articles is presented below.

Silane/silicon alternatives

A chromate-free surface pre-treatment of aluminium alloy AA1050 by using a modified phosphoric acid anodising process, followed by an impregnation with a commercial SiO_2-nanoparticle dispersion, is an approach reported to offer corrosion protection and promotion of adhesive bonding (Anthes et al., 2018).

A study seeking to improve the mechanical strength, defect level and hence anti-corrosion performance of a silane film treatment used two-dimensional Ti3C2 sheets which were hybridized into a γ-glycidoxypropyltrimethoxysilane (γ-GPS) film on AA2024 aluminium alloy (Nie et al., 2020). Neutral salt spray tests showed that the corrosion resistance of the hybridized silane film was better than that of traditional chromate treatment.

Corrosion protection and paint primer adhesion of aluminium-coated Al alloys were achieved by using a DC cathodic polymerization of trimethylsilane (TMS) under conditions similar to ion vapour deposition. The plasma polymer and (non-chromated) primer showed corrosion performance that out-performed chromate conversion-coated controls after four weeks of SO_2 and 12 weeks cyclic accelerated salt spray tests (Yu et al., 2001).

Aircraft aluminium alloy AA2024-T3 was protected using a chromate-free hybrid coating using photoinduced sol–gel and cationic polymerization. A film of n-alkyltrimethoxysilane and dipoxy monomer were UV-irradiated to generate superacids which then induced the single step formation of

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

two inorganic and organic barrier networks. Used without chemical conversion coating or anodising, some films have passed 2000 h of salt spray testing (Ni et al., 2014).

Aluminium alloy AA2524 was anodised using a conventional tartaric/sulphuric acid bath, and then protected with a TEOS-GPTMS hybrid sol-gel coating. The anodised layer thickness plays an important role in the protection mechanism of the sol-gel layer. Salt-spray tests highlighted the significant contribution of the sol-gel distribution in the anodised layer (Costenaro et al., 2017).

Other

Matykina et al observe that the traditional chromic acid anodization is to be phased out and as a result, special attention is paid to sodium hydroxide anodising (Matykina et al., 2011).

Immersion in hot $Ce(NO_3)_3$ and $CeCl_3$ solutions followed by anodic polarization in sodium molybdate was used to treat Al6061 and Al6013 aluminium alloys (Mansfeld & Wang, 1995).

AZ91D magnesium alloy was anodised in a solution of sodium silicate and potassium fluoride which formed an anodic film with thickness in excess of 100µm (Li et al., 2006).

King discusses electropainting of aluminium. The most used process is anodic. For aluminium, anodic processes have the advantage of requiring none of the usual pre-treatment coatings based on chromates, or phosphates. With electropainting, as the aluminium is made the anode, a thin anodic coating is formed on the surface of the aluminium as the paint deposition progresses that provides a good key to the deposited paint coating (KING, 1988).

3.4.4 Shortlist of alternatives

3.4.4.1 Introduction

Test candidates to Cr(VI) in anodising are summarised in **Table 3-5**. This list comprises test candidates that were reported in the parent AfAs.

In addition to these test candidates, several proposed candidates were reported by members which were subsequently rejected. These were screened at an initial laboratory evaluation stage, below TRL 3 maturity, and rejected for failing to meet performance requirements and therefore failed to transition to test candidates.

Table 3-5: Anodising summary of test alternatives reported in parent AfAs			
No.	**Alternative**	**Status reported in parent applications**	**AfA**
1	Boric-sulphuric acid anodising (BSA)	Potential for regrettable substitution[(a)]	0032-04
2	Sulphuric acid anodising (SAA)	Qualification restricted to specific applications [(b)]	0032-04
3	Thin-film sulphuric acid anodising (TFSAA)	Tested and partially implemented; not universal. Further testing required.	0032-04
4	Tartaric-sulphuric acid anodising (TSAA)	Qualified by some OEMs. Paint adhesion results inconsistent, incompatibilities exist. Resistivity not equivalent, possible impact on design of TSAA based layer systems	0032-04
5	Phosphoric acid-based anodising	Qualified as pre-treatment for localised structural bonding. Corrosion protection insufficient for alloyed aluminium without sealing. Limited use if subsequent sealing required; phosphates inhibit sealing step [(c)]	0032-04
(a) Category 1B reproductive toxicant (*Brief Profile - ECHA*, n.d.) (b) Not suitable for components sensitive to fatigue or with low manufacturing tolerances (c) Inferior corrosion resistance used in isolation, must be combined with Cr(VI) paint systems			

Test alternatives listed in Table 3-5 have been the focus of development and progression by the ADCR members, based on an assessment of technical feasibility criteria and performance requirements for anodising. Short listed and reported test candidates are:

- Boric-sulphuric anodising (BSA);
- Sulphuric Acid Anodising (SAA);
- Thin film Sulphuric Acid Anodising (TFSA);
- TSA; TSA-LC (Tartaric Sulphuric Acid Anodising or Tartaric-sulphuric acid anodising Long- Cycle variant); and
- Phosphoric acid-based anodising (PSA/PAA)

These are discussed in more detail in Section 3.5.

3.4.4.2 Non-shortlisted proposed candidates

Table 3-6 sets out those candidates that have been rejected by members.

Table 3-6: Anodising summary of proposed candidates reported by Members	
Proposed candidate	**Reason for rejection**
Sol-gel	No standalone corrosion resistance
Sulphuric acid manganese sulphate	Failed technical feasibility requirements
Sulphuric acid-nickel sulphate sodium phosphate	Failed technical feasibility requirements
Sulphuric-phosphoric acid	Failed technical feasibility requirements
Proprietary aluminosilicate glass	Failed to meet corrosion resistance requirements
Electro-ceramic coating (ECC)	Failed to meet corrosion resistance requirements
Plasma electrolytic oxidation (PEO)	Failed to meet corrosion resistance requirements

It is reported that sol-gels exhibit poor corrosion resistance although adhesion properties are very good. A secondary process using a chromated primer is required to achieve corrosion resistance.

Another issue to resolve for sol-gels is inconsistent reproduction of the coating, as reported by (CTAC, 2015).

Both proposed candidates, ECC and PEO failed to meet basic corrosion resistance performance requirements falling short of the benchmark Cr(VI) legacy solution.

Other non-short-listed proposed candidates listed in Table 3-6 also failed to meet base-line corrosion resistance critical to performance requirements and hence development work ceased in preference to the short-listed candidates.

3.4.5 Performance requirements and testing

The technical feasibility criteria required of anodising are:

- Wear resistance;
- Corrosion resistance including ;
- Chemical resistance;
- Adhesion promotion (adhesion to subsequent coating or paint); and
- Layer thickness.

In support of initial screening, tests are conducted to assess performance of proposed candidates in the laboratory environment for each of the above functionalities, and where necessary for essential performance requirements attributed to the design for example fatigue strength and intergranular attack/end-grain pitting.

Specifications related to anodising are often proprietary to individual companies (AAC, n.d.). An example of a publicly available specification for anodising is MIL-PRF-8625, “Anodic Coatings for Aluminium and Aluminium Alloys”. This is a comprehensive specification divided into several ‘Types’ including chromic acid anodising, Type I, (conventional) and Type 1B (low-voltage method), and non-chromic acid anodising variant, sulphuric acid anodising, and thin film sulphuric acid anodising. This specification also captures the process of dyeing the anodic coating. Dyeing the anodic coating could be for aesthetic or practical purposes. For example, it may be required to help differentiate similar or identical designs used for different purposes that need to be segregated and not conflated for reasons of function, safety, or both. The use of dyes is another potential variable to address. It is important to ensure that all additives, including dyes, are compatible with the proposed or test candidate.

Technical feasibility criteria measured using MIL-PRF-8625 are corrosion resistance, adhesion to subsequent layer, wear resistance (abrasion resistance), and layer thickness (coating weight). Fatigue resistance, another important attribute required when assessing alternatives, is also described within the specification.

Standards are used to ensure consistency when measuring technical feasibility criterion detailed in specifications. Corrosion resistance for example can be assessed as part of early screening of proposed candidates and for quality control purposes. An example is ASTM B117 “Standard Practice for Operating Salt Spray (Fog) Apparatus”. This standard defines apparatus, procedures, and conditions required to reproducibly administer the test. Other examples of standards used to measure technical feasibility criteria are listed in **Table 8-1**.

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 quality control thresholds, the proposed candidate will not advance to test candidate status 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 routinely apply more stringent internal performance requirements as discussed in Section 3.2.1. In addition, achieving pass thresholds at the laboratory scale does not necessarily infer 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 and performance requirements within the anticipated extremes and variables of service conditions. This is achieved via the application of simulated environmental testing in purpose-built facilities as described in Section 3.2.1.2

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 simulated environmental test regimes are rigorous, exacting, and designed to give the best and most realistic information possible, there remains the chance that they will not fully replicate all exposure scenarios 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 replicating all potential operational environments, emphasises the need for the test candidates' performance to be at least as good as Cr(VI).

3.5 Progression reported by ADCR members

3.5.1 Introduction

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

Approval of the test candidate must include a complete understanding of the influence of the adjacent treatments to anodising within the process flow. This is to understand the influence of all processes representing the surface treatment 'system' including pre-treatments and anodise sealing. Evaluation of the technical feasibility of the test candidate for anodising should consider its behaviour in contact with different alloy substrates, as well as 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 anodising, 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 aligned with different part/design families. Different designs exhibiting varying

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[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

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;
- Safety considerations;
- Availability; and
- Suitability.

3.5.1.1 Suitability of a test candidate

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?

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

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[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

[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)

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 Boric-sulphuric anodising

3.5.2.1 Introduction

As reported in Table 3-7 boric-sulphuric anodising (BSA) was tested and partially implemented as a replacement to CAA in the aviation sector, however health issues relating to boric acid (which is classified as category 1B reproductive toxicant) (Brief Profile - ECHA, n.d.)(Brief Profile - ECHA, n.d.)(Brief Profile - ECHA, n.d.)(Brief Profile - ECHA, n.d.)(Brief Profile - ECHA, n.d.)(Brief Profile - ECHA, n.d.) suggest its use as an alternative could lead to regrettable substitution.

When BSA was applied in conjunction with a Cr(VI)-containing sealing or paint system, requirements could be met for certain applications however corrosion performance sometimes failed to meet requirements. A small number of BSA-primer combinations were reported as qualified and meeting performance requirements. A reported reason for rejecting BSA from certain applications was as a result of the corrosive properties of BSA electrolyte and its impact upon sensitive components and assemblies (CTAC, 2015).

3.5.2.2 Technical feasibility/Technical Readiness Level of Boric-sulphuric acid anodising

BSA is extensively used in the commercial sector and is comparable to CAA in terms of ease of control of operational parameters to avoid potential damage to the substrate This is a key attribute to reduce unintended damage from the application of the anodising treatment or quality issues resulting from the process drifting out of operational parameters if tolerable operational margins are too fine. An attribute of the anodising process is its influence on the fatigue strength of the treated part. It was reported that fatigue strength for BSA is not equivalent to CAA in all situations. Further testing is planned, however if fatigue results continue to be inferior then the use of BSA would not be technically feasible in conjunction with components requiring excellent fatigue strength properties, prohibiting universal adoption. In addition, further testing is required to assess technical feasibility for certain defence applications.

The TRL of BSA across the A&D sector is varied. Implementation and industrialisation across selected product lines has already been achieved by some members. However where not deemed technically feasible, for example in some defence applications and where fatigue properties are of particular concern, research continues. Where this is the case the TRL status varies from TRL 3 to TRL 7 - 8, with an expectation for some members to achieve TRL 9, where not currently industrialised, as early as 2025. The maturity of test alternatives is also dependent upon the type of alloy with some members reporting that BSA has yet to be identified as a proposed candidate in conjunction with anodising magnesium.

For maintenance and repair operations (MRO), BSA is approved for a limited number of components by some design owners. A restriction to the adoption of BSA for some members seeking to substitute Cr(VI) from the treatment system as a whole, is caused by the need to follow the anodising process with a dilute chromic acid seal. Attempts to replace this process have as yet not been successful.

Before Cr(VI) anodising can be substituted, it may be necessary to also approve a sealing process that is compliant with the Cr(VI) free anodising treatment. For this reason, development in parallel with anodise sealing alternatives may be required. This can be more efficient in the long-term reducing the potential for compatibility issues between elements of the treatment system as a whole; anodising, anodise sealing, and primers. Clearly however this approach introduces additional complexity and time to the development and implementation of test candidates.

3.5.2.3 Economic feasibility of boric-sulphuric acid anodising

Potential economic impacts affecting the application of BSA for anodising are given below:

- Raw material costs; expected to decrease in comparison to CAA;
- Equipment costs: Expected to be comparable to CAA. Transfer to BSA may only require minor or limited modification of existing lines used for CAA;
- Utilities costs; may increase depending on current facilities. Requires heating, cooling, although ventilation requirements may not be as high and counter part of this impact;
- If borate removal is required this may be more complex than the process for Cr(VI) removal incurring a cost increase; and
- Changes in risk management measures with decrease in PPE requirements and associated cost benefits.

Where fatigue strength testing is required for qualification purposes, in-house facilities may not be present or suitable and external service providers may be required. Costs attributable to fatigue testing can start from in excess of €10,000 for each plus any additional costs associated with preparation of samples.

As described in Section 3.5.2.2 it has been reported that there can be an adverse impact on the fatigue strength from the use of boric-sulphuric anodising. If this is outside acceptable boundaries, determined by the incumbent Cr(VI) process, then redesign of the affected parts(s) would be required, which may not be economically feasible.

The requirement for any equipment is comparable to CAA. Transfer to BSA may only require minor or limited modification of existing production lines. Nevertheless, operating costs will increase.

The operational costs will increase due to the following impacts:

- Energy Costs: Energy costs are expected to rise due to the requirement of heating, cooling, and ventilation; and

- Waste Disposal costs: Potential increases in the volume of waste and therefore disposal costs than current levels. This is due to the need for borate removal, which can be more complex than the process for Cr (VI) removal.

3.5.2.4 Health and Safety considerations related to Boric-sulphuric acid anodising

For the purposes of understanding the risks associated with the test alternative the key identifiers of the constituent elements of BSA are summarised in **Table 3-7.**

Table 3-7: Boric-sulphuric acid anodising test alternative general information

Substance	Index number	EC Number	CAS number	IUPAC Name
Boric acid	005-007-00-2	233-139-2	10043-35-3	Boric acid
Sulphuric acid	016-020-00-8	231-639-5	7664-93-9	Sulfuric acid
(*Information on Chemicals - ECHA*, n.d.)				

The hazard classification and labelling profiles of each constituent acid in BSA are given in **Table 3-8**.

Table 3-8: Summary of hazard properties of Boric-sulphuric acid

Substance	EC Number	CAS number	CLP Classification
Boric acid	233-139-2	10043-35-3	Repr.1B; H360FD
Sulphuric acid	231-639-5	7664-93-9	Skin Corr.1A; H314
Harmonised classification according to Annex VI of Regulation (EC) 1272/2008 (CLP) (*Source: ECHA – Search for chemicals (https://echa.europa.eu/home)*			

As described in Section 3.5.2.1 boric acid is classified as category 1B reproductive toxicant. Although a reduction in hazard profile compared to CAA, there is however the danger of regrettable substitution from the adoption of candidates utilising boric acid in the longer-term due to the inclusion of boric acid on the Candidate List of substances of very high concern for Authorisation (SVHC) (ECHA, n.d.-b).

3.5.2.5 Availability of Boric-sulphuric acid anodising

The constituent acids of BSA are available on the EU market. Members report that supply chains are in place, however this is based on current production requirements for qualified processes. As the scope of approval to use BSA increases then further capacity will be required which may place some strain on the supply chain if additional suppliers are hesitant to adopt BSA due to do the presence of boric acid, a SVHC. For this reason, broadening of the supply base may stagnate and fail to meet all capacity requirements across the A&D sector.

Boric-sulphuric anodising has progressed to industrialisation for some components of the A&D sector and achieved mature TRL 9 status for others. However, in the context of being available from a regulatory perspective; fulfilling the substitution process described in detail in Section **Error! Reference source not found.**, additional work and time to meet regulatory approval is required. Implementation has been delayed in order address fatigue strength for example and has yet to be determined if it is available as a proposed candidate for anodising magnesium and its alloys.

3.5.2.6 Suitability of Boric-sulphuric acid anodising

As summarised in Section 3.5.1.1 an alternative must be assessed against defined criteria to determine it can be viewed as 'suitable'. BSA is already approved and certified in various manufacturing lines within the A&D sector therefore considered technically and economically feasible in these specific applications for anodising. However, other applications, for example where excellent fatigue strength properties are required, have yet to be approved with BSA, and use with magnesium and magnesium alloys is at very early stages of evaluation within TRL 1.

The use of BSA does constitute a reduction in hazard profile in comparison to Cr(VI), however there is the potential for this to be negated if BSA were to be elevated from an SVHC to an Annex XIV substance in the future. As a consequence, some members that have industrialised BSA are conducting additional research with other test candidates, whilst other members report having re-focused resources away from research and development with BSA in light of potential future regulatory constraints. The above analysis indicates that the test candidate is not technically feasible or available in light of legal requirements to all downstream users of anodising. **Error! Reference source not found.**

3.5.3 Sulphuric acid anodising

3.5.3.1 Introduction

Sulphuric acid anodising (SAA) was reported in parent applications as qualified at certain companies for corrosion protection of both painted and unpainted aluminium alloys, but not for fatigue sensitive components and components of low manufacturing tolerances.

The layer thickness of SAA is significantly higher (10-20µm) than for CAA (reported to be in the range of 2-10µm). Consequently, it was expected that a significant reduction in fatigue strength might be observed precluding its use from those anodising applications where fatigue strength is an overriding requirement of the design.

Other areas of weakness compared to Cr(VI) were reported to be that SAA did not meet all adhesion and coefficient of friction requirements for most critical applications (CTAC, 2015).

Another operational issue observed is the influence of copper containing aluminium alloys. It was reported that these can deposit copper on electrodes necessitating the addition of process excipients to the SAA solution to mitigate this issue, which is reportedly not observed with the CAA process(CTAC, 2015). .

3.5.3.2 Technical feasibility/Technical Readiness Level of Sulphuric acid anodising

As discussed in Section 0, any test alternative must not decrease fatigue strength of the anodised part, beyond acceptable parameters achieved with Cr(VI). Fatigue may be measured via rotating bend type tests and axial strain life tests for example. SAA typically results in thicker anodic layers in comparison to Cr(VI) anodised layers. As reported in Section 3.2.1.6, layer thickness expected from CAA is in the order of 2 – 10µm, although it may be less than 2µm depending on requirements and process conditions. In contrast SAA anodic coatings are 10 – 20µm (CTAC, 2015) or more. Thicker anodic coatings from the use of SAA will in general enhance corrosion protection, at the expense of fatigue strength. Fatigue debit[34] can be in the order of double or more for SAA in comparison to that observed for CAA

If SAA leaves entrapped corrosive electrolyte residues post treatment there is potential to cause corrosion of the treated component. Chromic acid anodising in contrast does not leave such corrosive residues.

As an alternative to Cr(VI), SAA has been implemented for limited products. For example, it is approved for dip/immersion on aluminium alloys according to MIL-PRF-8625 where fatigue strength is not critical. Increasing the scope of implementation of SAA as an alternative to CAA is dependent upon modification of the process to control the layer thickness. An example of this is Thin Film Sulphuric Acid Anodising (TFSAA), discussed below.

For processes that allow the control of SAA anodic layer thickness, progression is in the range of TRL 3 - 7.

Before Cr(VI) anodising can be substituted, it may be necessary to also approve a sealing process that is compliant with the Cr(VI) free anodising treatment. For this reason, development in parallel with anodise sealing alternatives may be required. This can be more efficient in the long-term reducing the

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[34] The reduction of a component's fatigue strength due to surface treatment.

potential for compatibility issues between elements of the treatment system as a whole; anodising, anodise sealing, and primers. Clearly however this approach introduces additional complexity and time to the development and implementation of test candidates.

Masking hard anodising; hardcoat (Type III)

Hard anodising, a specific form of sulphuric acid anodising also referred to as hardcoat or Type III anodising is used where a harder more wear resistant anodic coating is required for certain engineering applications. In addition, hard anodising provides a more open pore structure which is more receptive to dyeing. Modified process conditions are employed to achieve the additional performance requirements, corrosion and wear resistance, from the anodic layer. When used in proximity to fatigue sensitive surfaces, it is necessary to protect these surfaces from the hard anodising process with a mask. Sealed CAA is an ideal maskant as it is resistance to the aggressive hard anodising process and prevents leaching of the hard anodise coating at the edges of the mask ensuring the whole fatigue sensitive surface is protected. Cr(VI) free maskants are available. These include wax, masking tape, and lacquers. However, these fail to demonstrate the reliability and versatility of a CAA based mask for hard anodising.

3.5.3.3 Economic feasibility of sulphuric acid anodising

Before implementation, where fatigue testing is required for qualification purposes, in-house facilities may not be present or suitable and external service providers may be required. Costs attributable to fatigue testing can start from in excess of €10,000, in addition to the costs associated with the preparation of samples for testing.

Equipment costs for the implementation of SAA are generally expected to be minimal or require minimal capital expenditure. The SAA process typically requires more frequent monitoring to ensure all parameters are maintained within acceptable tolerances. This can introduce additional costs compared to monitoring the CAA process. Cost from retraining staff to operate a new system(s) will be incurred, the extent of which will vary depending upon the complexity of the process changes. Constant maintenance of treatment baths or increased control and inspection frequency to ensure more narrow operational parameters are maintained, compared to CAA, may also result in incremental additional costs from staffing, solution analysis, and reagents used to monitor the anodising process.

Where processes are implemented to control layer thickness of the SAA, via an increase in staffing or additional training requirements, existing capacity and equipment could be utilised to help mitigate some of the above incurred costs. Waste disposal costs would be reduced as SAA is comparatively easy to treat compared to the need to process waste containing chromium compounds. Costs arising from risk management measures may also be reduced.

Costs to suppliers may result if the customer base does not transition away from Cr(VI) in parallel either due to not being at the same level of maturity of the new technology within respective substitution processes, or refusal by some design owners to adopt the test candidate.

3.5.3.4 Health and Safety considerations of Sulphuric acid anodising

For the purposes of understanding the risks associated with the test candidate the key identifiers of the sulphuric acid anodising are summarised in **Table 3-9**.

Table 3-9: Sulphuric acid anodising test candidate general information

Substance	Index number	EC Number	CAS number	IUPAC Name
Sulphuric acid	016-020-00-8	231-639-5	7664-93-9	Sulfuric acid
(*Information on Chemicals - ECHA*, n.d.)				

The hazard classification and labelling profile of sulphuric acid is given in **Table 3-10**. As shown, sulphuric acid represents a clear reduction in hazard profile compared to Cr(VI).

Table 3-10: Summary of hazard properties of Sulphuric acid

Substance	EC Number	CAS number	CLP Classification
Sulphuric acid	231-639-5	7664-93-9	Skin Corr.1A; H314
Harmonised classification according to Annex VI of Regulation (EC) 1272/2008 (CLP) (*Source: ECHA – Search for chemicals (https://echa.europa.eu/home)*)			

3.5.3.5 Availability of Sulphuric acid anodising

Sulphuric acid is commercially available in the EU. The test candidate SAA however is only approved and implemented in specific designs. It is reported that the international specification MIL-PRF-8625 for producing a fully Cr(VI) anodic coating, including anodise sealing, has not been adopted by all OEMs therefore restricting availability at present. Component designs that are vulnerable or sensitive to fatigue strength debit or require corrosion resistance properties comparable to those provided by CAA may not meet approval requirements when treated with SAA. Until further work is conducted to approve SAA for a more diverse range of designs subject to anodising, or to refine it via a modified process affording improved precision and control of the anodic layer thickness, SAA cannot achieve universal adoption for all component designs utilising Cr(VI) anodising. Achieving approval, i.e. certification, to be available to use by fulfilling the substitution process described in detail in Section **Error! Reference source not found.**, requires further research and testing to address the above deficiencies and meet regulatory approval requirements from EASA/MoDs. SAA is also yet to be determined as technically feasible and therefore potentially available as a test candidate for anodising other affected metals such as magnesium and its alloys, which is at a relatively immature stage of development compared to work with aluminium and its alloys.

3.5.3.6 Suitability of Sulphuric acid anodising

As summarised in Section 3.5.1.1 an alternative must be assessed against defined criteria to determine if it can be viewed as 'suitable'. SAA is already approved and certified in various manufacturing lines within the A&D sector therefore considered technically and economically feasible in these specific applications for anodising. However, other applications, for example where excellent fatigue strength properties are required, are outside the scope of the SAA process. In addition, it is reported that corrosion may occur from the entrapment of electrolyte residues from the SAA process which could limit its use were corrosion resistance is reduced; this property is not observed with Cr(VI) anodising processes.

The use of SAA does constitute a reduction in hazard profile in comparison to Cr(VI), with an associated reduction in costs a possible benefit. Economic impacts may vary depending on the degree of modification of the process if not transferable unmodified. If fatigue strength is a key attribute to be maintained, controlling the anodic layer thickness demands narrow process parameters and more frequent monitoring and analysis. Consequently, incremental increases in operational costs could result; to be assessed against any mitigating costs for waste disposal and risk management measures.

SAA as an alternative to CAA fails to meet all requirements under the defined criteria for suitability. Failure to meet technical feasibility requirements across all key functional criteria to the level delivered by CAA, coupled with limited availability in light of certification requirements, for all component designs, whilst noting adverse impact upon fatigue strength, are key deficiencies. Technical feasibility is reported to be viable and proven for certain applications within the A&D sector, although not with components that require excellent fatigue strength or where corrosion resistance may be inferior to CAA, due to entrapped electrolyte residues from the SAA process. Economic feasibility has potential to be comparable overall to Cr(VI) anodising and with options for cost reduction in areas such as risk management measures and waste disposal.

Referring to requirements stipulated within Regulation (EU) 2018/1139 (EU, 2018)and to Section 3.5.1.1, SAA is not considered widely available from a regulatory and certification perspective, and therefore not a suitable test candidate for all component designs currently using CAA processes.

3.5.4 Thin Film Sulphuric Acid Anodising (TFSAA)

3.5.4.1 Introduction

As reported in section 3.5.3.1, sulphuric acid anodising (SAA) is incompatible with fatigue sensitive components or designs. For this reason, the standard SAA process is not suitable as a universal alternative for all applications of chromic acid anodising. To mitigate these deficiencies Thin Film Sulphuric Acid Anodising (TFSAA) is a modification to the standard process that seeks to control the thickness of the anodic layer and reduce impact on fatigue strength.

(CTAC, 2015) reported similar issues as discussed above for SAA. For some components this process was already in use, whilst further testing was required before TFSAA could be adopted for other components.

3.5.4.2 Technical feasibility/Technical Readiness Level of Thin Film Sulphuric Acid Anodising

Members confirmed that the TFSAA process was already approved and implemented by some OEMs, although not universally across the sector. TFSAA coatings are not self-limiting and can exhibit local variations in thickness. This can have an impact on fatigue sensitive components and assemblies and therefore be an impediment when using TFSAA for certain applications such as legacy parts. Therefore, TFSAA is restricted to non-fatigue sensitive applications in these circumstances.

Before Cr(VI) anodising can be substituted, it may be necessary to also approve a sealing process that is compliant with the Cr(VI) free anodising treatment. For this reason, development in parallel with anodise sealing alternatives may be required. This can be more efficient in the long-term reducing the potential for compatibility issues between elements of the treatment system as a whole; anodising, anodise sealing, and primers. Clearly however this approach introduces additional complexity and time to the development and implementation of test candidates .

The issue of entrapment of corrosive electrolyte residues, as described for SAA in section 3.5.3.6, is not reported for components with non-complex geometry. The extent by which TFSAA can cause entrapment of corrosive residues in components with complex geometry, was not reported.

However, entrapment needs to be ruled out for any at risk or sensitive components, for example those with narrow channels or blind passages.

As discussed, the TFSAA process is a modification of SAA. Intellectual property associated with this process modification has been published covering the European region. The Mercaprotec patent describes a novel modification to the SAA process to yield a claimed anodic layer of 3 – 5µm.[35] which is more closely aligned with that achieved with CAA. For those members without access to the IP, work is required to develop and test bespoke versions of the TFSAA process. This must be compliant with international patent regulations and not infringe existing patents, meet all performance requirements delivered by anodising, and be compatible with all applications including fatigue sensitive components and legacy uses.

Where not already introduced for specific applications, TFSAA has achieved TRL 4 - 7 for other impacted components. Members reported that for those component families sensitive to fatigue strength loss, substitution cannot be conducted on the assumption that test results will be replicated for similar components as not all component families can be expected to behave identically to the introduction of the TFSAA system. Each family of components will need to be assessed separately either in parallel or sequentially depending upon resources and internal priorities, or in order of risk of failure.

3.5.4.3 Economic feasibility of Thin Film Sulphuric Acid Anodising

Section 3.5.4.2 reports that TFSAA is capable of delivering anodic coating layer thickness comparable with the CAA process provided process parameters are carefully controlled. Intellectual property (IP); has been published covering the TFSAA process. An ADCR member without the necessary expertise may be reliant upon third party IP and have to purchase a licence or enter into some other commercial arrangement with the patent holder, if operating within a region covered by the IP. Alternatively, resources may be made available to develop a non-infringing TFSAA process. Development costs include legal fees to defend TFSA based processes as not infringing existing IP, before entering into production. This economic burden may be coupled with additional time impacts to meet all performance requirements expected from the anodising process.

Raw material costs for the anodising step are reported to be comparable or lower than CAA. An impact would be from the selection of the subsequent sealing process required following TFSAA. Members reported that if a Cr(VI) free anodise/anodise sealing process is implemented as a combined treatment system, the sealing process required in conjunction with TFSAA would add complexity and cost due to additional steps required to deliver the treatment system. A sealing process approved for use with TFSAA includes hydrogen peroxide in its composition. Use of hydrogen peroxide necessitates process controls and integrated cooling systems to prevent excessive evaporation which is in addition to costs from extra processing tanks required for the treatment system as a whole.

In comparison to CAA, as with sulphuric acid anodising waste treatment processes for TFSAA will typically be comparable or less complex as the chromate reduction process is removed. Personal protective equipment, and utilities costs to run the TFSAA process were reported as broadly similar to CAA.

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[35] EP2812467B1 available at Espacenet – search results, accessed 13 December 2022

3.5.4.4 Health and Safety considerations of Thin Film Sulphuric acid Anodising

For the purposes of understanding the risks associated with the test candidate TFSA the key identifiers and hazard phrases of sulphuric acid are summarised in Section 3.5.3.4, **Table 3-10**. As stated above sulphuric acid demonstrates a reduction in hazard profile compared to the incumbent Cr(VI).

3.5.4.5 Availability of Thin Film Sulphuric acid Anodising

As reported in section 3.5.3.5, sulphuric acid is readily commercially available on the market. A point of difference of the TFSAA process over conventional SAA is the reduction in the anodic layer delivered by the process. This attribute increases the scope of use with fatigue sensitive components that may be intolerant to conventional SAA. As described within section 3.5.4.2, reduction in layer thickness requires modification of the parameters used to generate the anodic layer via the SAA process. Activity in this field has led to novel solutions some of which have been published in patents within the EU. However, intellectual property (IP) patents, block some members from using the technology in the patented form if a commercial arrangement, such as licence agreement cannot be obtained. For those members, resources are required to develop their own non-infringing TFSAA solution. Provision of additional resources is not a guarantee of success. Until a bespoke TFSAA solution is developed and proven to not infringe existing IP it cannot be progressed within the substitution process without risk of being withdrawn as a viable candidate. For the above reasons, whether due to the need to develop IP compliant technology, or a restriction in the number of commercial partners able to offer TFSAA, availability of suppliers can also be restricted whilst they are attaining qualification to meet requirements of public and internal specifications related to the use of the alternative.

3.5.4.6 Suitability of Thin Film Sulphuric acid Anodising

The transition to TFSAA represents a reduction in risk when compared to the existing process, and it has been successfully implanted by OEMs as an alternative to anodising with Cr(VI) for a number of components. It is also identified as the most promising test candidate in a number of substitution plans. Despite this, it is not a process which is technically feasible for all components and has particular limitations when applied for legacy uses with specific anodic layer thickness requirements as defined by the component design. In addition where entrapment of corrosive electrolyte residues is a concern this must be thoroughly evaluated.

Resolving the considerable and complex challenges arising from developing a non-infringing process independent of existing IP is time consuming, demands considerable internal resources, and therefore incurs significant costs that have to be met before the test candidate can be implemented. For those members without such expertise and/or resources, there may still be increased costs associated with access to third party IP via commercial arrangements such as licensing, although it should be noted that such arrangements may not be agreed by the licence holder. As a consequence, existing IP is likely to encumber or prevent access to the relevant technology for some members. Suitability of TFSAA is restricted to specific members operating within aforementioned technical feasibility parameters and able to operate in compliance with any commercial arrangements or IP controlling access to the technology.

3.5.5 Tartaric-sulphuric acid anodising and tartaric-sulphuric acid (Long-cycle) anodising

3.5.5.1 Introduction

Tartaric-sulphuric anodising (TSA) was already qualified as a CAA-replacement by some OEMs and suppliers for providing adequate corrosion resistance in anodising of certain Al alloys and Cr(VI) sealed, or subsequently coated components for certain applications, although this did not meet the requirements of the A&D sector as a whole. Not all Cr(VI) painting or sealing systems were considered compatible with TSAA. Therefore a relatively small number of TSAA – Cr(VI) combinations were qualified limiting wider adoption of TSAA. In general, TSAA provides less corrosion resistance than CAA although TSAA had successfully replaced CAA for certain applications where compatible sealing options were available. TSAA was being implemented as the new process replacing CAA in several Airbus facilities and deployed within the supply chain on certain aluminium alloys (CTAC, 2015).

Adhesion results for TSAA were reported as inconsistent. Some organic coating adhesion incompatibilities exist, depending on the application.

Layer thickness of TSAA is reported as comparable to CAA. It is thinner than SAA, resulting in less impact on fatigue properties compared to SAA (CTAC, 2015).

Electrical resistance of TSAA is not equivalent to CAA. This was reported as a consideration of design owners and how it might impact on the design of TSA-based layer systems.

For local repair applications, numerous trials were performed. Variability in performance was high depending on the formulation of the anodising solutions and the time before exposure in the salt spray chamber, which made it difficult to interpret the process performance. Refining the cleaning step before anodising was reported to potentially lead to improvements if a suitable Cr(VI)-free sealing solution can be added after anodising (CTAC, 2015).

3.5.5.2 Technical feasibility/Technical Readiness Level of Tartaric-sulphuric acid anodising

Tartaric-sulphuric acid anodising (TSA) has been developed as a test candidate to substitute CAA. A variant of TSAA with adjusted process parameters has also been developed referred to as Tartaric-Sulphuric Acid anodising Long-Cycle (TSA-LC). This modification was made to try to increase the scope of applications and performance of the test candidate; improve corrosion resistance.

Comparable results have been reported for key functionality, corrosion resistance, chemical resistance, and adhesion requirements for bonding processes for some applications on certain alloys, but not all. Touch-up anodising using TSAA (brush anodising) as part of a treatment system has been evaluated and demonstrated positive results in line with expectations. For some applications, corrosion resistance may need to be supplemented with the use of a subsequent coating, such as a primer, with adequate adhesion depending upon the criticality of this function.

It may be necessary to approve a sealing process that is compliant with the Cr(VI) free anodising treatment. For this reason, development in parallel with anodise sealing alternatives may be required for some ADCR members. This can be more efficient in the long-term reducing the potential for compatibility issues between elements of the treatment system as a whole; anodising, anodise sealing, and primers. Clearly however this approach introduces additional complexity and time to the development and implementation of test candidates.

However, for certain legacy cases, TSAA fatigue strength properties are reported as inferior to CAA. Further testing is required to establish if reduction in fatigue strength from the use of TSAA can be mitigated or overcome. Due to the part organic nature of TSAA, there is the potential for microbial growth attributed to the presence of tartaric acid in the solution. This needs to be fully evaluated and quantified as a risk to the process, where it could occur in the equipment/line, and what if any impact it may have on the key functions delivered by TSAA. If a biocide is required this will need to be compliant with the Biocidal Products Regulation and not adversely impact the anodising process.

Solution control, and hence stability, is reported as more difficult to maintain for TSAA compared to CAA. This can influence the number of qualified suppliers able to administer this process. Due to process control considerations, reported to be more complex than for CAA, there is also scope for variability of components produced from different facilities, albeit these will all be subject to the same stringent specification and certification requirements implemented by the design owner.

3.5.5.3 Economic feasibility of Tartaric-sulphuric acid anodising

Economic factors to consider for the test candidate tartaric-sulphuric acid include cost of raw materials. These may be up to twice the cost of the Cr(VI) initially as supply chains are consolidated, with the potential for reduction in cost as more designs/components transition and consumption of the raw materials increase, although this is not a certainty. Additional costs are incurred from solution analysis and maintenance of the treatment process which is more frequent than the Cr(VI) process.

Infrastructure costs may be incurred if facilities are not already fully equipped with the necessary tanks and controls required to maintain the optimum processing conditions required for TSA. Expenditure may include installation of additional tanks and pipework for treatment and rinsing additional or revised effluent waste treatment processes. These may require additional treatment reagents, controls, staff training process development and qualification, which results in additional costs. These ancillary processes and modifications represent increases in production costs.

Microbial control measures to prevent fungal growth for example within immersion tanks or pipework would require appropriate qualification within the process, with inherent costs. In addition to the cost of the biocide used, targeted risk management measures and staff training may be required before the biocide can be deployed into the treatment system.

3.5.5.4 Health and Safety considerations of Tartaric-sulphuric anodising

For the purposes of understanding the risks associated with the test candidate the key identifiers of the tartaric-sulphuric acid anodising are summarised in **Table 3-11** .

Table 3-11: Tartaric-sulphuric acid anodising test candidate general information

Substance	Index number	EC Number	CAS number	IUPAC Name
Tartaric acid	N/A	201-766-0	87-69-4	(2R,3R)-2,3-dihydroxybutanedioic acid
Sulphuric acid	016-020-00-8	231-639-5	7664-93-9	Sulfuric acid

(*Information on Chemicals - ECHA*, n.d.)

The hazard classification and labelling profile of tartaric-sulphuric acid is given in **Table 3-12**. As shown, sulphuric acid represents a clear reduction in hazard profile compared to Cr(VI).

Table 3-12: Summary of hazard properties of Tartaric-sulphuric acid anodising

Substance	EC Number	CAS number	CLP Classification
Tartaric acid	201-766-0	87-69-4	Eye Dam. 1; H318[a]
Sulphuric acid	231-639-5	7664-93-9	Skin Corr.1A; H314[b]

(a) Based on classification presented in REACH Registration dossier
(b) Harmonised classification according to Annex VI of Regulation (EC) 1272/2008 (CLP)
(*Source: ECHA – Search for chemicals (https://echa.europa.eu/home)*

As shown in **Table 3-12**, both tartaric acid and sulphuric acid represent a clear reduction in hazard profile compared to Cr(VI) and neither has a classification linked to chronic exposure. However, as described in Section 3.5.5.2 a biocide may also be used as a direct consequence of using TSA, which may impose an additional health and safety consideration.

3.5.5.5 Availability of Tartaric-sulphuric acid anodising

Tartaric and sulphuric acids are commercially available in the EU. The test candidate TSAA however is only approved for implementation with specific designs. Supply chain capacity of this relatively new process is restricted as more suppliers need to be qualified to use this more complex process.

Part designs that are vulnerable or sensitive to fatigue strength debit or require enhanced corrosion resistance properties, comparable to those provided by CAA, may not meet all requirements when treated with TSA. Until further work is conducted to approve TSAA across a more diverse range of designs, TSAA cannot achieve universal adoption for all component designs utilising Cr(VI) anodising. Achieving legal approval to be available to use and fulfilling the substitution process described in detail in section 3.1.2, requires further research and testing to address the above functional deficiencies and meet regulatory approval requirements from EASA/MoDs. TSAA is yet to be determined as technically feasible, and therefore available as a test candidate for anodising for all affected metals such as magnesium and its alloys. These additional metal alloys are reported as at a relatively immature stage of development compared to using TSAA with aluminium and its alloys.

3.5.5.6 Suitability of Tartaric-sulphuric acid anodising

As summarised in Section 3.5.1.1 assessment against defined criteria seeks to determine if a test candidate can be viewed as 'suitable'. TSAA is approved and certified for production of selected components and designs within the A&D sector and therefore considered technically and economically feasible in these specific applications for anodising. However, other applications, for example where excellent fatigue strength properties are required, have yet to be approved with TSA. Economic impact from implementation and industrialisation may vary depending upon the level of infrastructure that is required. Adoption of process controls, required for maintenance of the more complex TSAA process, brings with them associated incremental costs from staffing and reagents used for routine analysis of the TSAA solution. Existing capacity to deliver TSAA is limited by the number of suppliers qualified and willing to implement the process. Increasing the number of qualified suppliers is required to expand the adoption of TSAA and widen its availability, to match CAA capacity. This will allow transition to TSAA across a wider array of component designs, subject to meeting all technical feasibility criteria.

TSAA constitutes a reduction in hazard profile in comparison to Cr(VI). If layer thickness control, and hence fatigue strength requirements are paramount, frequent process control as a consequence would cause incremental increases in operational costs although this is mitigated by the expectation of lower costs for waste disposal and risk management. The above assessment fails to meet all requirements under the defined criteria for suitability. The above analysis indicates that the test candidate, TSAA, is not always technically feasible or available, in light of legal requirements, to all downstream users of anodising within the A&D sector.

3.5.6 Phosphoric acid based anodising

3.5.6.1 Introduction

It is reported that in general phosphoric acid-based anodising processes cannot be used as an alternative to CAA if the anodic coating has to be sealed. Therefore components need to be primed where this is a requirement. Phosphoric-sulphuric anodising (PSA) and phosphoric acid anodising (PAA) were used and qualified as pre-treatments for structural bonding of Al alloys as a replacement CAA within the aviation sector. PSA and PAA are not used in sealed conditions for unpainted components as they provide less corrosion resistance than CAA. Consequently application of PSA, PAA processes are limited and often only used in combination with Cr(VI) containing subsequent coatings; paints for example. A further limitation of use included requirements of certain military specifications, for example MIL-A-8625 which excluded phosphoric acid based anodising processes (CTAC, 2015).

For local repair applications combining sulphuric and phosphoric acids similar limitations are seen. Development to optimise the ratios of the acids was reported as still required in order to resolve corrosion performance requirements on a 6µm non-sealed oxide layer. Additional R&D to develop the sealing process and investigate higher oxide thicknesses was identified as a further step

Localized PAA has been approved for bonding for several years when applied in the form of a gel (PANTA process) (CTAC, 2015).

3.5.6.2 Technical feasibility/Technical Readiness Level of phosphoric acid-based anodising

PSA has been certified as a replacement for CAA when used prior to specific bonding applications. However, in contrast PAA is reported as failing to meet all performance requirements when used in place of CAA prior to certain bonding applications. Other members report that adhesion promotion is facilitated by PAA due to the properties of the anodic coating.

As reported in Section 3.5.6.1, the PAA coating is too porous and does not delivery corrosion resistance, unlike the CAA coating. Therefore, as indicated above, for some applications corrosion resistance may need to be supplemented with the use of a subsequent coating, such as a bonding primer/protective primer, according to the relevant functionality of the treated component. As a consequence of not delivering corrosion resistance and failing certain other bonding applications, the technical readiness level of phosphoric acid-based anodising is not always deemed sufficient to fulfil all key functions delivered by CAA.

3.5.6.3 Economic feasibility of phosphoric acid-based anodising

Economic factors to consider for the test candidate PAA include cost of raw materials. These may be up to twice the cost of the Cr(VI) initially as supply chains are consolidated, with the potential for reduction in cost as more designs/components transition and consumption of the raw materials increase, although this is not a certainty. Additional costs are incurred from solution analysis and maintenance of the treatment process which is more frequent than the Cr(VI) process.

Infrastructure costs may be incurred if facilities are not already fully equipped with the necessary tanks and controls required to maintain the optimum processing conditions required for PAA. Expenditure may include installation of additional tanks and pipework for treatment and rinsing additional or revised effluent waste treatment processes. These may require additional treatment reagents, controls, staff training process development and qualification, resulting in additional costs. These ancillary processes and modifications incur increased production costs.

3.5.6.4 Hazard considerations of phosphoric acid-based anodising

For the purposes of understanding the risks associated with the test candidate phosphoric acid based anodising the key identifiers and summary of hazard properties of are summarised in **Table 3-13** and **Table 3-14** below

Table 3-13: Phosphoric acid based acid anodising test candidate general information

Substance	Index number	EC Number	CAS number	IUPAC Name
Phosphoric acid	015-011-00-6	231-633-2	7664-38-2	Phosphoric acid
(*Information on Chemicals - ECHA*, n.d.)				

Table 3-14: Summary of hazard properties of phosphoric acid based anodising

Substance	EC Number	CAS number	CLP Classification
Phosphoric acid	231-633-2	7664-38-2	Skin Corr.1B; H314
Harmonised classification according to Annex VI of Regulation (EC) 1272/2008 (CLP) (*Source: ECHA – Search for chemicals (https://echa.europa.eu/home)*)			

The hazard classification and labelling profile of phosphoric acid is given in **Table 3-14**. As shown, phosphoric acid represents a clear reduction in hazard profile compared to Cr(VI).

3.5.6.5 Availability of phosphoric acid-based anodising

Both phosphoric and sulphuric acids are commercially available with supply chains in place within the European market. No supply issues are reported amongst the ADCR members. From a regulatory approval perspective PSA/PAA based anodising fails to meet technical feasibility and performance requirement criteria delivered by CAA. For this reason, it is also not regarded as available from a regulatory perspective.

3.5.6.6 Suitability of phosphoric acid-based anodising

Due to the limitations of phosphoric acid-based anodising, it cannot provide the key functions delivered by the CAA process, in particular, it does not provide sufficient intrinsic corrosion resistance. Members reported that a principal application is for the preparation of surfaces prior to bonding processes and does not provide the variety of benefits from CAA. Due to these limitations, phosphoric acid-based anodising is only considered for niche applications for example adhesion promotion; certain bonding applications.

3.6 Conclusions on suitability of short-listed alternatives

The short-listed test candidates described above fulfil individual roles in the substitution of CAA across the multitude of components and alloys subject to anodising, and in turn the wider treatment system, which must be accounted for when choosing an alternative. It is recognised that none fulfil the same universal application facility provided for CAA, but rather aim to fulfil this requirement collectively.

Table 3-15 provides an overview of each of the criteria used to assess the short-listed test candidates and their overall suitability as a test candidate. To confirm, in all cases 'high' represents an acceptable level of compliance, moderate, represents a partial level of compliance, and low, a poor level of compliance with the individual criteria.

Table 3-15: Conclusions on suitability of short-listed anodising alternatives

Alternative	Technical feasibility	Economic Feasibility	Hazard reduction	Availability	Suitability
Boric-Sulphuric acid anodising	Moderate	High	Low	Moderate	Low/Moderate
Sulphuric acid anodising	Moderate	High	High	Moderate	Moderate
Thin-film sulphuric acid anodising	High/moderate	Moderate	High	Moderate/Low	Moderate
Tartaric-sulphuric acid anodising	Moderate	Moderate	High	Low/Moderate	Moderate
Phosphoric acid based anodising	Low	High/Moderate	High	Low/Moderate	Low

Boric-sulphuric acid anodising technical feasibility is reported to be viable and proven for certain applications within the A&D sector, although not with components that require excellent fatigue strength where to date BSA has exhibited inferior performance to Cr(VI) anodising. Economic feasibility is expected to be comparable overall to CAA with potential for cost reduction in areas such as risk management measures and waste disposal. Due to certification requirements, BSA is not available to all members for selected applications of anodising whilst approval and certification requirements are outstanding. Suitability of BSA is considered to be low/moderate. This is justified as although available to some downstream users of anodising it is excluded from certain applications due to deficits in technical feasibility and therefore is not available from a regulatory standpoint. In addition, there is the medium to longer-term risk of regrettable substitution. The commercial decision not to resource the maturation of BSA as a universal alternative for all applications of CAA is appropriate if there is the likelihood of its regulatory status changing due to the addition of boric acid to Annex XIV; Authorisation list

Sulphuric acid anodising technical feasibility is proven for certain applications within the A&D sector. However, it is not appropriate with components that require excellent fatigue strength or where corrosion resistance may be inferior to CAA due to entrapped electrolyte residues from the process. Economic feasibility has potential to be comparable overall to CAA with options for cost reduction in areas such as risk management measures and waste disposal.

Tartaric-sulphuric acid anodising is implemented as an alternative within the A&D sector, although not with components that require excellent fatigue strength or enhanced corrosion resistance is a prerequisite. Legacy uses where a specific anodic layer thickness is required to meet the performance requirements of the legacy design were identified as a limitation for TSAA for example. Further testing is required to determine if this limitation of the use can be resolved. If entrapment of corrosive residues from the use of sulphuric acid is a concern, this may limit the range of components compatible with this test candidate. Economic feasibility has potential to be comparable overall to Cr(VI) anodising with options for cost reduction in areas such as risk management measures and waste disposal. Due to the organic nature of tartaric acid, there is the potential for microbial growth within the processing apparatus, tanks, and pipework. If present in the treatment solution this growth could contaminate component surfaces. Consequently, control measures may be required, either physical/external, for example UV lamps, or via dosing biocide. Any change or addition to the process must not adversely impact its performance or compatibility with treated components. Aside from possible unintended consequences impacting performance, control measures may also introduce additional costs. Modifications to the line, additional tanks, pipework, revised effluent waste treatment processes, treatment reagents, staff training and qualification of a new process are amongst the costs reported from implementation and ongoing support of the TSAA process.

Thin film sulphuric acid anodising is implemented for several applications by OEMs. However, as with TSAA, and SAA limitations are reported for those legacy uses with specific anodic layer thickness requirements as defined by the component design. If entrapment of corrosive residues from the use of sulphuric acid is a concern, not all components may be compatible with this test candidate. Non-fatigue sensitive components are reported as a lower risk in terms of adopting TFSAA. To supplement corrosion resistance were required, parallel development of post anodising processes such as sealing, and primers is often conducted to ensure compatibility across the processes forming the treatment system. This reinforces the requirement to consider the treatment system as a whole in the development of an alternative for anodising. A consequence of parallel development with other parts of the treatment process is a greater chance of success in the longer-term, set against added complexity and opportunities for compatibility issues between the non Cr(VI) alternative and non-Cr(VI) adjacent processes in the treatment system. If a completely Cr(VI) free process is to be adopted, these issues need to be resolved before the anodising alternative can be implemented.

Development of TFSAA has driven innovation in the form of intellectual property (IP); patents. The commercial impact of a patented system can restrict availability of the technology across the sector. Some companies without access to a licence or other commercial arrangement to use patented processes are compelled to develop bespoke modifications of the TFSAA process which do not infringe existing IP before progressing further with substitution activities. This adds complexity, time, and cost to the substitution process.

Phosphoric acid based anodising processes are reported as delivering good adhesion performance but insufficient intrinsic corrosion resistance. These systems are not readily sealed, and therefore only suitable where either sealing is not a requirement or priming is permitted/feasible. Therefore, although these systems represent a clear reduction in hazard profile compared to CAA, they fail to meet the other criteria required to be considered suitable alternatives for the global CAA process.

3.7 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*);
- 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 cost 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 anodising, and its relevant pre-treatments. They require continuous review and monitoring to ensure that the substitution plan progresses through its phases and all changes are clearly documented. Monitoring of progress markers associated with the substitution plan includes a timetable of steps and targeted completion dates, assessment of the highest risks to progression, and how these risks can be reduced (if possible), which may not always be the case.

3.7.1.2 Substitution plans within individual members

Each ADCR member has a substitution plan to remove Cr(VI) in anodising that is uniquely reflective of their individual situation. Additionally, an individual member often has multiple substitution plans for anodising, 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, and type of alternative. 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 test candidate and prioritisation of certain types of component or substrate.

3.7.1.3 Interplay with pre-treatments and post-treatments

Development of substitution plans for alternatives to Cr(VI) for anodising are fundamentally related to and impacted by uses in the treatment system; pre-treatment and post-treatment processes. In the case where members are using Cr(VI) in other parts of the treatment system, there is often a requirement to develop these Cr(VI)-free processes in parallel with the Cr(VI)-free anodising to ensure compatibility between the different elements of the treatment system. The progression and success of the development of alternatives to Cr(VI) in anodising depends on the successful development of test candidates in adjacent uses within the system. Any unexpected technical failures in the development Cr(VI)-free test candidates in these supporting uses, will impact the timing of the substitution plan for anodising. Often it is not technically feasible to implement an alternative for anodising in isolation.

In some cases, a member will target substitution of Cr(VI) from all inter-related uses, in addition to anodising, at the same time.

3.7.2 Substitution plan for ADCR in anodising

3.7.2.1 Substitution plans

Multiple test candidates to replace Cr(VI) in anodising have been investigated by members and have been progressed to various stages, with variation arising from different types of components and substrates. In general, the most developed are sulphuric acid anodising (and its thin film variants) and tartaric-sulphuric acid anodising.

The expected progression of ADCR members' substitution plans to replace Cr(VI) in anodising is shown in **Figure 3-9** below. The progressive stages of the substitution plan (development, qualification, validation etc.) as shown in the diagram are described in detail in section 3.1.2. Implementation and progression of substitution plans ultimately leads to reduced Cr(VI) usage. MRL 10 is the stage at which manufacturing is in full rate production and is therefore where significant reduction in Cr(VI) use due to replacement with an alternative is expected.

The data in **Figure 3-9** shows the expected progress of 47 distinct substitution plans for Cr(VI) in anodising, covering different plans across different members, and also multiple plans within individual members. These data have been aggregated to present the expected progress of the substitution of Cr(VI) from anodising for the ADCR consortium as a whole.

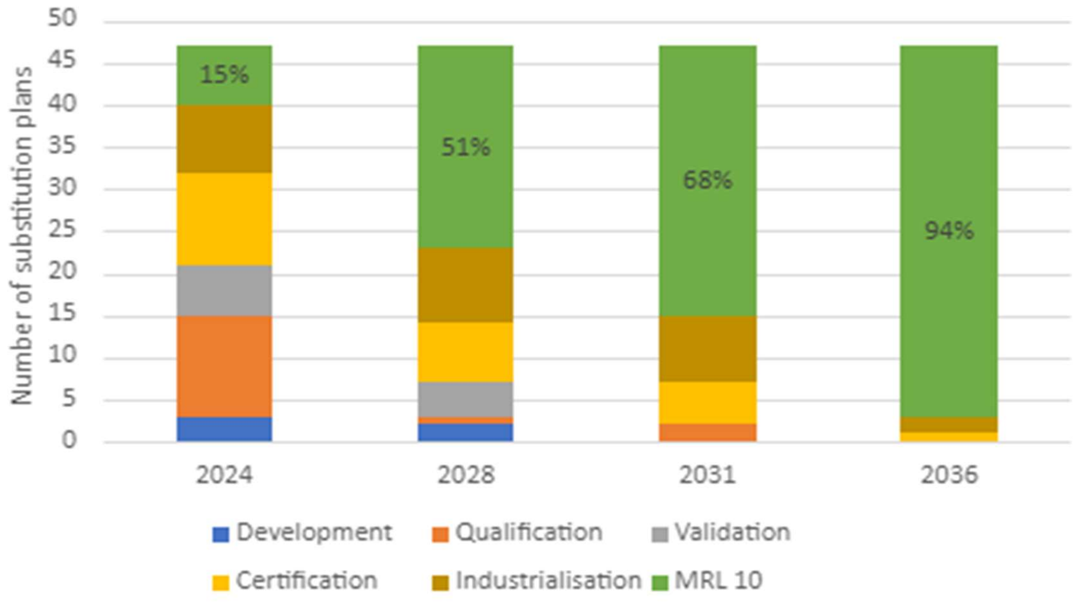


Figure 3-9: Expected progression of substitution plans for the use of Cr(VI) in anodising, by year. The vertical axis refers to number of substitution plans (some members have multiple substitution plans for anodising). The percentage value shown on each of the green bars indicates the proportion of substitution plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which there is expected to be a significant reduction in Cr(VI) usage.
Source: RPA analysis, ADCR members

The above summary shows:

- Variation in the status of different substitution plans in each of the years (this variation is due to issues such as technical difficulty, types of substrates, types of component (performance requirement considerations e.g., impact on fatigue strength); 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 or more years from now could be different to our expectations today.

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

There are many issues that limit members' progression of the substitution plans beyond the stages indicted in **Figure 3-9**. Technical issues include failures on some types of components and substrates (particularly fatigue debit), including legacy parts, with uncertainty on whether all of these issues can be resolved. Direct replacement of Cr(VI) may not be possible on these components, necessitating a complete re-design which has uncertain practicality and viability; not practical for legacy applications. The move to a new anodising process, combined with the most appropriate sealing method, requires considerable development and associated engineering work. There are a limited number of suppliers and insufficient supply chain capacity for some of the Cr(VI)-free anodising test candidates, with uncertainty on when this may be resolved. Process issues include for example the need for a large and diverse range of customers (including Ministries of Defence) to approve all changes, requiring extensive and time-consuming testing. There are interlinked and interdependent workstreams, where the transition to Cr(VI)-free anodising needs to be coordinated with the transition to Cr(VI)-free candidates in other main treatments such as sealing, primers and conversion coating which often need to take place in unison as each is an individual step in the treatment system. For anodising there are also significant IP considerations impacting the implementation of test candidates across all members.

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 anodising, 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 significant proportion are not expected to have achieved MRL 10 and are expected to be predominantly at the certification or industrialisation stages. For these substitution plans (which are from several member companies), there is still expected to be a need for the use of Cr(VI).

As a result of the individual members' substitution plans summarised above, **the ADCR requests a Review Period of 12 years for the use of Cr(VI) in anodising**.

4 Continued Use Scenario

4.1 Introduction

Section 3 provided an analysis of the alternatives with respect to the technical feasibility, economic feasibility, availability and suitability of alternatives, as well as the substitution plan. The assessment highlights the importance of CAA and its application to aluminium and magnesium alloys and the fact that for the ADCR members supporting this application there are no suitable alternatives that are generally available.

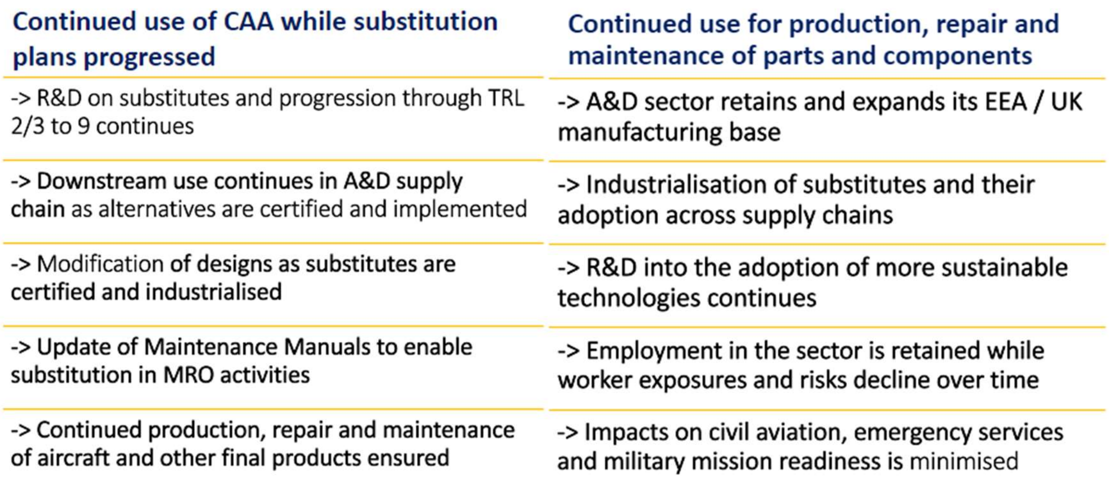
Although some of the companies supporting this use have implemented alternatives at the industrial level for some of their components, this is not across all components. As noted in Section 3.6.1, each ADCR member that acts as a design owner has one or more substitution plans in place to remove Chromium trioxide in anodising; these are unique to their individual situations. The different substitution plans are segmented by factors such as type of substrate and type of alternative. The substitution plans are being progressed simultaneously but can have different timings with respect to the anticipated achievement of each TRL level, due to the technical difficulty of introducing the alternative and prioritisation of certain types of components and substrates.

Until alternatives which are also compatible with pre- and post-treatment steps (as relevant), and which deliver an equivalent level of functionality (as required) on aluminium and its alloys or magnesium alloys, and are tested, qualified, validated and certified for the production of components and products, use of the chromium trioxide in anodising will continue to be required; its use is essential to meeting airworthiness and other safety and reliability requirements. As a result, and taking into account the differences in performance requirements across components; this is why there are no alternatives which can be considered “generally available” in the context of A&D.

In some cases, issues may remain with legacy spare parts and maintenance where certification of components using alternatives is not technically feasible or available due to design control being held by MoDs, who will not revisit older designs in the near future.

Nevertheless, the OEMs and their suppliers are working hard and maintaining a strong focus on the development and certification of alternatives.

The continued use scenario can be summarised as follows:



Continued use of CAA while substitution plans progressed	Continued use for production, repair and maintenance of parts and components
-> R&D on substitutes and progression through TRL 2/3 to 9 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 aerospace and defence markets;
- Annual tonnages of chromium trioxide used in CAA, including projected tonnages over the requested review period;
- The risks associated with the continued use of chromium trioxide.

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 all members and their supply chains. The continual re-visiting of supply chain requirements fed into the narrowing of the substance-use combinations requiring re-authorisation compared to the original applications for authorisation. This has led to only chromium trioxide being supported for anodising because members and their supply chains have been able to eliminate use of the other chromates for this purpose in the EEA and UK.

Furthermore, the scope of this RR is driven by A&D qualification, validation, and certification requirements, which can only be met by the use of the substances/formulations 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 chromium trioxide in anodising until alternatives can be qualified and certified across all the relevant components. The choice of substances to be used is further affected by the fact that they form part of a process flow (see Figure 2-2), which has been developed over time to meet specific performance requirements as part of ensuring airworthiness.

4.2.2 Overview of the European aerospace and defence sector

In 2020, the European A&D industry comprised over 3,000 companies of all sizes and employed over 880,000 highly skilled employees (with these figures including the UK[36]). As noted by the European Commission, the aerospace 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

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

domain"[37]. **Figure 4-1** provides details of turnover and employment for the industry in 2020, based on the Aerospace, Security and Defence Industries Association of Europe (ASD) publication "2021 Facts & Figures".[38] These figures are lower than the comparable figures for 2019, at around 405,000 jobs and €130 billion in revenues[39], with these leading to exports amounting to around €109 billion.

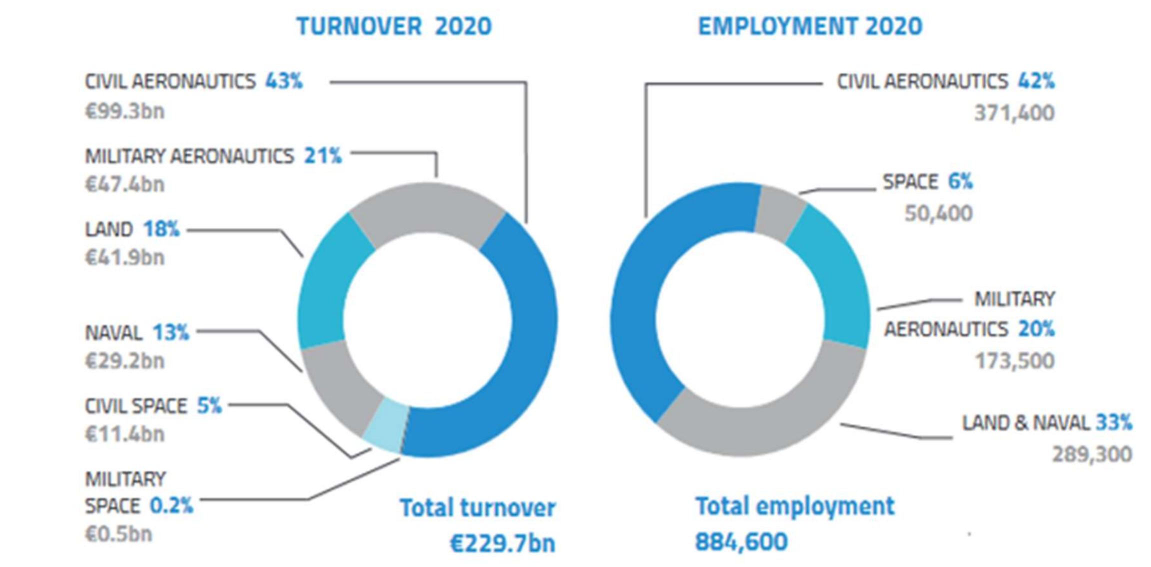

Figure 4-1: Turnover and Employment for the European Aerospace and Defence Industry in 2020
Based on ASD, 2021, available at: https://www.asd-europe.org/sites/default/files/atoms/files/ASD_Facts%26Figures_2021_.pdf

As can be seen from **Figure 4-1**, civil and military aeronautics alone accounted for 64% of turnover and 75% of employment for the sector in 2020.

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

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

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

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

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

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

- Aircraft and other A&D products remain in service over long time periods. For example, the Boeing 747 first entered service in 1970, and continues to be flown and produced in 2022 (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 long periods after the first aircraft or military products were placed on the market.

- A&D technologies take many years to mature. Product development is a five to ten-year process, and it can take 15 years (or more) before the results of research projects are applied in the market. As part of the development and roll-out of new A&D products, OEMs must be ready to demonstrate fully developed technologies, or they risk losing contracts that may have a lasting effect on business;[40]

- 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 critical uses of chromium trioxide. As indicated below with respect to R&D activities, research on substitution of chromium trioxide has been underway for several decades, with the substitution of the chromates in chromic acid anodising processes proving one of the most difficult tasks, in part due to its process flow (see Figure 2-2) and relationship with other surface treatment.

- 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 chromium trioxide, in particular 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 chromium trioxide where this is mandated by the original equipment manufacturers.

4.2.3 Economic characteristics of Companies undertaking chromic acid anodising

4.2.3.1 Overview of uses and downstream users

CAA constitutes a widespread and critical use of chromium trioxide in the corrosion protection and wear resistance of aluminium and other alloys. As a treatment, it is therefore likely to be carried out across a significant number of aerospace and defence sites within the EU and within the UK. This includes in-house use by the major OEMs, as well as use by BtP suppliers, and to a lesser degree DtB suppliers and MROs. As part of the overall process involving CAA, it is often preceded by a pre-treatment such as deoxidising/etching/pickling and may be followed by anodise sealing or inorganic finish stripping. These pre- and post-treatment process may be Cr(VI)-based or Cr(VI)-free depending on the OEM's performance requirements and the associated EASA certifications and military qualifications.

CAA is therefore relevant to production, repair, maintenance and overhaul of a range of different parts. As noted above, it is particularly important for protection of aluminium and its alloys but may

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

also be carried out on other substrates such as magnesium. Examples (non-exhaustive) of the types of components treated with CAA include:

- Aircraft engines;
- Fuselage skins and bulkheads;
- Wing skins, panels and covers;
- Stabilisers; and
- Wheels and landing gear links.

SEA questionnaire responses were provided by 50 aerospace and defence companies undertaking CAA (57 if considering the EU and UK separately), with these companies operating across 43 sites in the EU and 21 sites in the UK (64 out of a total of 126 sites operated by these respondents). It is important to note that these figures exclude sites operated by MoDs, which identified sites reliant on use of CAA but due to the nature of their activities did not otherwise provide socio-economic data.

Table 4–1 provides an indication of numbers by role in the supply chain by size of company. As might be expected by the composition of the ADCR and the companies that are its members key suppliers, 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). The number of responses covering MROs also is low compared to what might be expected. This could reflect the reduced relevance of CAA to most repair and maintenance activities (although it has been identified as part of repair and overhaul by military MROs).

Table 4–1: Numbers of SEA respondents undertaking Chromic Acid Anodising

Role (and total number of companies)	**Number of companies/sites undertaking CAA***				**Company Size**[41]	
	EEA		**UK**		**EEA**	**UK**
	Companies	**Sites**	**Companies**	**Sites**	**Companies**	**Companies**
Build to print (31 in total)	19	19	12	12	2 small 7 med 10 large	7 small 4 med 1 large
Design and build (9 in total)	5	5	4	4	2 medium 3 large	1 medium 3 large
MRO only (5 in total)	4	4	1	1	1 medium 3 large	1 large
OEM (8 in total)	8	15	4	4	1 medium 7 large	4 large
Total *	36	43	21	21		

*Some of the OEMs members have sites in both the EU and UK. In total, 50 companies provided a response, but some reported for the purposes of both EU 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.

4.2.3.2 Economic characteristics

Table 4–2 provides a summary of the number of companies identifying their activities as falling against different NACE codes, which are used to develop the econ

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

Table 4–2: Economic characteristics of "typical" companies by NACE in sectors involved in Chromic Acid Anodising (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	31	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	5	57.20	65,000	43,200	9.7%
C2599 - Manufacture of other fabricated metal products n.e.c.	11	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%
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	11	1214.65	98,000	76,400	11.2%
C3040 - Manufacture of military fighting vehicles	5	1214.65	99,000	64,800	9.8%
C3316 - Repair and maintenance of aircraft and spacecraft	17	71.33	85,000	56,400	8.4%
Other: please specify	0	NA	NA	NA	NA
Total count	88				

Companies may have indicated more than one NACE code as being relevant to their activities, such that the number of relevant NACE code counts is higher than the number of SEA responses relevant to CAA 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 and average GOS as a percentage of turnover. 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 chromic acid anodising and taking into account the size distribution of the companies[42] that are involved in such activities. GVA per employee, numbers of employees, and average personnel costs are generally 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[43] (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 the 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 64 sites for which data were collected via the SEA questionnaire represent an estimated €26 billion in turnover and €2.8 billion in GOS as a proxy for profits. Across all 210 sites estimated as undertaking anodising in the EEA and UK, these figures rise to over €43 billion in turnover and €4.7 billion in GOS.

Table 4–3: Key turnover and profit data for market undertaking chromic acid anodising (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% avg. GOS) € million
43 EEA Sites	20,145	2,216
21 UK sites	6,023	663
Extrapolation to all sites involved in chromate-based CAA in the EEA or UK		
180 EEA sites	35,255	3,878
30 UK sites	7,796	858

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

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

[43] 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).

4.2.3.3 Economic importance of Chromic Acid Anodising to revenues

CAA will only account for a percentage of the calculated revenues, GVA and jobs given in the above table.

To understand the importance of CAA 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 chromium trioxide in anodising.

As the supply chains covered by this SEA vary from manufacturers of small components to producers of much larger components (e.g. fuselage skins and bulkheads), the responses vary significantly across companies. Of key importance is that for design owners, CAA continues to be a critical surface treatment, the loss of which would result in loss of all turnover due to the inability to meet airworthiness and military safety requirements, even though as a process it accounts for only a very small percentage of production costs.

In addition, responses to the SEA questionnaire highlight that the combination of pre-treatment, anodise sealing and/or inorganic finish stripping (for rework or repair) using the chromates may 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 pre-treatments (deoxidising, etching, pickling) relevant to CAA, as well as anodise sealing as a post-treatment. This includes both Cr(VI)-based and non-Cr(VI) based pre- and post-treatments as part of a certified component. Of note is the fact that over 40 of the 64 companies also undertake Cr(VI)-based pre-and post-treatments, with some of these same companies using chromate-free treatments where this is permitted under the design owners (e.g. the OEM's) performance requirements and EASA certifications/military qualifications for the component.

The pre-treatments and inorganic finish stripping may also be relevant to other uses; however, they are a common part of the anodising process flow. Similarly, not all CAA will be followed by chromate-based anodise sealing, and not all chromate-based anodise sealing may be preceded by CAA. As already stated, the need for CAA will depend on the component certifications in place and the extent to which a feasible alternative has been developed, qualified and certified for that component and has then gone through industrialisation.

Table 4-4: Number of companies undertaking relevant pre- and post-treatments to CAA

Role	Number of companies also undertaking pre-treatments		Number of companies undertaking anodise sealing		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	18	14	22	16	22	16
Design to build	4	1	3	2	3	2
MRO only	4	0	3	0	3	0
OEMs	5	3	6	4	6	4
Total	**31**	**18**	**34**	**22**	**34**	**22**

Given the importance of CAA to protecting metal substrates such as aluminium and magnesium for corrosion; the loss of CAA 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, CAA, anodising sealing and inorganic finish stripping combined. However, we have taken the combination of these activities as the relevant process flow for assessing economic impacts, regardless of whether the pre-treatments, anodising sealing and/or inorganic finish stripping are chromate or non-chromate based, as it is the series of processes and profits and employment linked to them as an overall activity that is relevant for this SEA.

Nevertheless, it is relevant to consider the extent to which the production costs at different companies/sites relate to these three activities. Responses to the SEA questionnaire reveal the following (based on 50 company responses – no split between the EU and UK):

- For around one half of the companies (26 or 52%), pre-treatment is highlighted as accounting for less than 30% of production costs (14 at <5%, 12 at 6% to 30%). It only accounts for more than 50% of costs for 6 of the companies (12%), but in some of these cases the remainder of the share of production costs was explicitly linked to anodising (16 companies – 32% did not provide a response).

- Anodising itself was identified as accounting for over 50% of production costs by 22% of companies, with 4 that it accounted for 31% - 50% and 27 (54%) indicated that it accounted for less than 30% (and 8 non-responses).

- Anodise sealing accounted for over 50% of production costs for 6 companies (12%), and less than 30% for 26 of the remaining companies (17 non-responses).

When considered together as a process flow, the responses indicate that the three processes will generally account for between 30% to 50% of production costs for most companies but will constitute over 50% for more than one third of companies and over 75% for 15% of companies. These figures are assumed to translate also to the site level.

Even where anodising and its pre-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, chemical resistance, wear resistance, layer thickness and layer adhesion properties of aluminium, titanium and other metal substrates. By way of example, one of the MROs' responses related to a site that undertook repairs on landing gear. Although CAA (as well as chromate-based deoxidising/ etching/pickling and anodise sealing) were reported as only accounting for <5% of production costs, the response made it clear that "the use of chromates in CAA forms an essential step in the overhaul of landing gear". Thus, loss of CAA could affect all of their revenues 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 combined set of processes, as relevant to each company. As can be seen from this table, 25 of the 50 companies indicated that over 50% of their revenues were linked to anodising and the related processes. Of note is the fact that three of these were OEMs, whose main sources of revenues will be the sale of large assemblies or of finished aircraft/hardware; one would, therefore, expect the processes to account for low percentages of total revenues.

Although only eight of the ADCR OEMs undertake CAA themselves, 14 of the 24 ADCR members falling into this category have indicated that CAA treatments carried out by their suppliers are critical to their systems/final products. All aviation-related OEMs highlighted the critical importance of CAA to a wide range of final products and the impossibility of certifying an aircraft as meeting airworthiness requirements without the use of chromate-based CAA against existing design specifications for those components without certified alternatives.

Table 4–5: Number of SEA respondents indicating percentage of revenues generated by or linked to chromate using processes based on SEA responses

	<10%	10% - 25%	25% - 50%	50% - 75%	>75%	No response
Build-to-print	2	4	3	4	16	2
Design-to-build	2	2	0	1	1	1
MROs only	0	1	0	2	1	0
OEMs and Tier 1*	3	3	0	0	0	2

*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 the DtB and BtP companies will use chromate-free processes in the manufacture of their components/products where they are able to under their customer's mandated requirements and the associated EASA certifications/military qualifications. They also reflect the fact that some of these companies will carry out surface treatment activities for sectors other than aerospace and defence. This includes producing components and assemblies for machinery, food manufacturing, medical equipment, automotive uses, oil drilling and electrical equipment, which may or may not also involve the use of chromium trioxide (e.g. for automotive uses).

It is also of note that two military MROs have highlighted the importance of CAA to their military forces. Should this use not be allowed to continue, there could be significant impacts on their ability to maintain current aircraft and military equipment.

4.2.3.4 Investment in alternatives, risk management measures and monitoring

OEMs

OEMs have carried out R&D into the substitution of the chromates for over 30 years, but as detailed in the AoA technical difficulties remain in substituting the use of chromium trioxide in CAA. Although some have developed, validated, qualified and are currently certifying alternatives for use in the manufacture of their final products, others are still in the testing and development phase. These differences are driven by factors including operating performance requirements, for example impact of test candidates on fatigue strength of components, and other variables such as substrates utilised across final products, and inter-relationship with adjacent uses in the production process

Examples of R&D expenditure outside the larger joint programmes referenced in Section 3.4 is provided below, together with some of the data provided on capital investments related to anodising activities that have taken place in the last 7 years:

- Investment of €1.8 million to modernise the CAA line so as to reduce emissions;
- R&D expenditure into new test lines, equating to around €190,000 in expenditure;
- R&D expenditure of around €100,000 into the influence of anodising on the lifetime of components to better understand performance required parameters;
- R&D expenditure of around €1.8 million into new technologies to replace the existing surface anticorrosive protection of aerospace materials, including verified technologies for surface protection of aluminium.

One of the companies also notes that, between the period 2018 to 2021, they spent €5.9 million on the certification of alternatives for use in the manufacture of components where substitution was established as able to meet performance requirements and EASA certification could be achieved.

More generally, the OEMs spent around €6.6 million on R&D into chromate replacement efforts, including replacement in anodising. See Section 3.4 for further details.

Design-to-build suppliers

None of the design-to-build suppliers have undertaken capital investments relevant to the continued use of CAA (although investments relevant to other chromate-based surface treatments have been undertaken). NADCAP accreditation costs are identified by one of the DtB companies, with these being €400,000 for accreditation of their chromate using processes – including CAA; these costs relate to only the production of small parts, which excludes a significant proportion of their work for the aerospace industry.

Four companies have, however, carried out investments relevant to the substitution of the chromates, with two of these explicit to substitution of CAA:

- Investment of €500,000 in a Tartaric process line in 2018 to enable anodising via a chrome-free process for a subset of components where it has been certified alongside their CAA process line for those components not yet having certified alternatives (which they expect to continue carrying out past 2030);
- Investment in a pilot facility with repurposed tanks to enable testing of chromate-free alternatives, also as part of this company's involvement in various of the large scale, collaborative R&D projects.

The other two companies identify investment in new air filtration and exhaust equipment as well as various production equipment, process development activities and testing; it is not clear what proportion of the expenditure on these is relevant to CAA.

The costs being incurred by one of the larger DtB companies in moving to chromate-free anodising processes in the manufacture of components for defence products will be significant. In total, between €25 - €40 million will be spent in process development, installation of new capital equipment and re-qualification and certification of the end product. Once the process changes have been fully implemented (estimated not until after 2032), the company will be able to switch all anodising to the use of alternatives.

Build-to-print suppliers

Eleven of the build-to-print companies carried out investments in the period from 2010 to 2021 relevant to their use of the CAA. Examples include:

- €600,000 investment in a new anodising line 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. 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 chromate-free operations to be carried out alongside the chromate-using plant;
- Construction of a new hall in 2017 to accommodate a new anodising line, 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 a TSAA line to supplement the CAA line (until the latter can be phased out);
- Investment in a TSAA line at a cost of €552,500 in 2018 to enable chromate-free anodising where this is technically feasible (i.e. allowed under customers' certifications);
- £800,000 investment in 2015 (25-year expected life) in a new anodising line and a new passivation line 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 (APACA, ECOCONV and NEPAL), have worked with their OEM or have carried out own research into alternatives. One company (which also has some DtB roles but identifies as a BtP) cites own R&D at a cost of €1 million and use of a dedicated engineering team. Another reports costs of around €250,000 working with an OEM on testing and trials using TSAA production as an alternative to CAA for a particular set of components; a further £60,000 was spent on producing test pieces.

The six companies also include a GB-based company that carried out R&D into TSAA as an alternative to CAA including the installation of a TSAA trial line to allow testing; this company has an installation plan and made a commitment to install a TSAA line once its main OEM customer certifies the use of TSAA on the components in produces (and assuming the trials on the components are successful).

It should also be noted that some of these suppliers will have to be NADCAP[44] qualified and will be subject to audits (AeroSpace (AS) and/or International Standards Organisation (ISO)) of their CAA processes, to secure and hold accreditations/OEM-specific certifications for their customer and industry approvals. This expenditure varies by company size, with related costs quoted as varying from e.g. €60,000 to €100,000 per company for those involved in CAA.

MROs

The MROs have undertaken significant investments into new equipment related to their use of the chromates, including for waste management and emissions reduction. Investments specific to CAA activities 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 (in tandem with a design owner) aimed at reducing or eliminating the use of the chromates. One of the four MROs 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

Under the continued use scenario, companies will continue financing the R&D, testing and development of potential alternatives to CAA but will also have the finance needed to carry out such activities for the substitution also of other SVHC and the development of more environmentally sustainable products. Current R&D projects being carried out with EEA/UK research institutes and

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[44] National Aerospace and Defence Contractors Accreditation

Universities, working to develop alternatives and other novel technologies, would also continue helping to keep the EEA and UK at the forefront of technological development.

A small number of companies also identified a range of other potential benefits under the continued use scenario as they completed their substitution programmes:

- Better relations with authorities, including reduced regulatory compliance costs;
- Better shareholder and community relations; and
- Potentially, increased worker job motivation and satisfaction, and less absenteeism and illness.

4.2.4 End markets in civil aviation and defence

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

Because the use of chromium trioxide in anodising cannot be fully substituted at present, it plays a critical role in ensuring the reliability of aircraft and of safety standards. Thus, although the economic importance of chromium trioxide in anodising 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 in Section 2 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 cannot be quantified in the same manner, however, the involvement of MoDs in supporting this combined AoA/SEA through the provision of information demonstrates the critical nature of chromic acid anodising to on-going mission readiness. In particular, the continued use of CAA as part of MRO activities is relevant to military organisations located in the EEA (multiple countries) and UK, as well as to companies servicing them.

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

4.2.5.1 Civilian aircraft

Demand for new civilian aircraft is expected to grow into the future, as illustrated in Figure 4-2. Projected global compound annual growth rates (CAGR) for different aircraft classes for the period 2020-2031 are given in the figure below[45], with this suggesting a CAGR from 2020 to 2031 of around 2.5%.

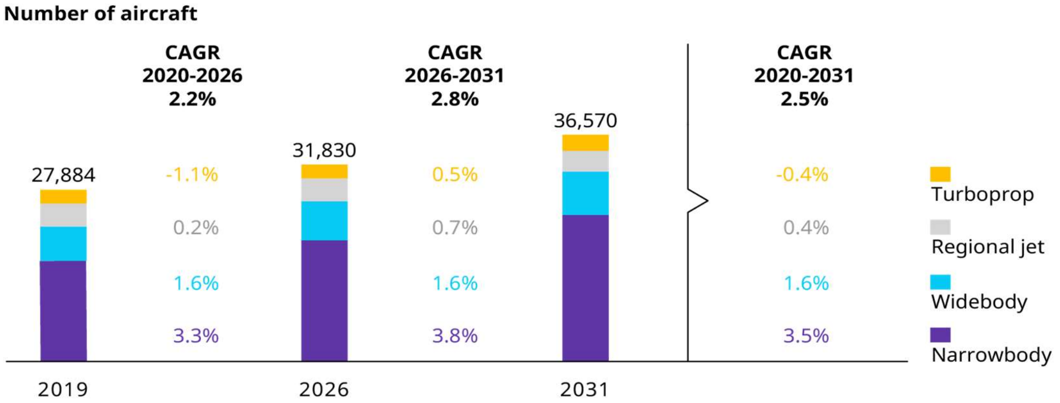

Figure 4–2: Global fleet forecast by aircraft class, 2020-2031
***Source*: *Oliver Wyman analysis, 2021*[19]**

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 in particular.[46]

Boeing's 2022 Commercial Market Outlook[47] indicates a similar level of increase, noting that the global fleet will increase by around 80% through to 2041 with the forecast value of new airplane deliveries at around US $7.2 trillion (based on a slightly higher growth in traffic at around 3.8% CAGR.

Based on figures publicly available on Airbus' website, the demand for new aircraft will progressively shift from fleet growth to accelerated replacement of older, less fuel-efficient aircraft. This will mean a need for over 39,000 new passenger and freighter aircraft, delivered over the next 20 years - around 15,250 of these will be for replacement of older less fuel-efficient models. By 2040, the vast majority of commercial aircraft in operation will be of the latest generation. Projections based on generic

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

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

[47] https://www.boeing.com/commercial/market/commercial-market-outlook/index.page

neutral seating categories (100 plus seater passenger aircraft and 10 tonnes plus freighters) are given in **Table 4-6** below.

Table 4-6: Airbus Global Market Forecast: projected new deliveries 2021-2040

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

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

When considering these figures, it is important to recognise that the European aerospace sector is a global exporter of aircraft, and A&D products make a significant contribution to the overall balance of trade. For example, France and Germany alone had export markets totalling over US$ 57 billion (€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.[48]

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 EU/UK with a consequent loss in Gross Value Added (GVA) to the EU and UK economies, with significant impacts also on employment.

4.2.5.2 The MRO market

Not only would the manufacture of new aircraft in the EEA and UK be impacted but anticipated growth in the aftermarket parts segment would also be affected. The aircraft spare components/final products market encompasses the market for both new and used rotable[49] 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.

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

[49] 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.

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 5 to 10 years. Globally, the market is expected to have a CAGR of over 3% over the period from 2022-2027, as illustrated in the figure below.[50, 51]

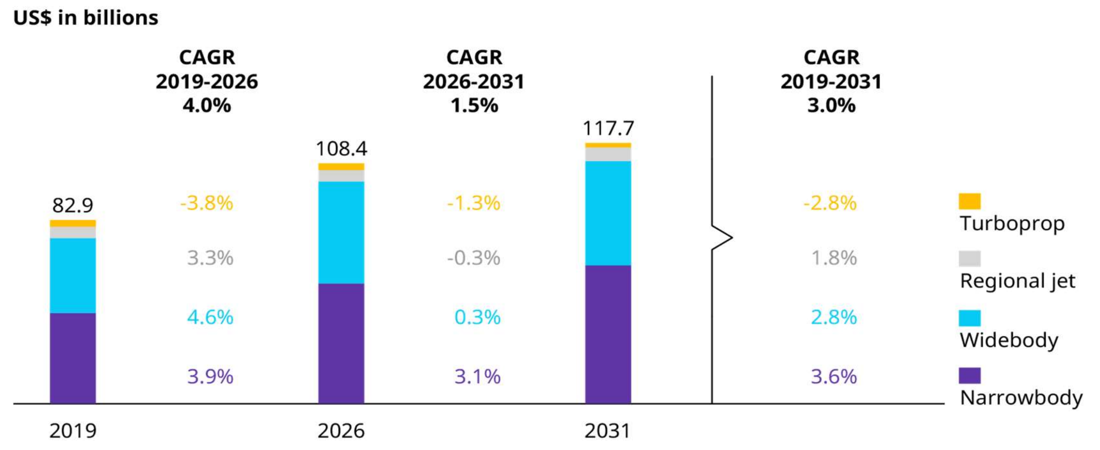

Figure 4–3: MRO market forecast by aircraft class, 2019-2031
Source: Oliver Wyman analysis

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 requirements; and 3) Increases in fleet sizes over the next 5 years will also lead to a continued growth in demand for maintenance and repair activities.

4.2.5.3 The Defence market

The war in Ukraine has led to several EEA countries and the UK to revisit their defence expenditure. In particular, several countries that are NATO members and which previously did not meet the target of spending 2% of GDP on defence are now committed to meeting that target. This compares to Eurostat figures for total general government expenditure on defence in 2020 of around 1.3% of GDP for the EU[52]. 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

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

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

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

commitments announced in October 2022 aiming for a target of 3% of GDP by 2030[53]. This equates to an increase in spending of around £157 billion between 2022 and 2030.

Such investment, which will include new spending on existing technologies, may also result in a continued reliance on the use of the chromates for CAA 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%.[54]

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 a set of their key suppliers. This work included collection of data on the tonnages of the chromium trioxide used in CAA per site. The tonnages assumed in the CSR range from 0 to 1,040 kg Cr(VI) per year per site:

- based on 0 to 2000 kg of CT being used per year per site.

4.3.2 Consultation for the SEA

The consultation carried out for the SEA verifies that the figure of 2000kg of CT being used in CAA represents a maximum figure, with most SEA respondents (not just those included in the CSR work) indicating levels in the region of tens of kg per annum to around 1000kg for some of the companies identifying CAA as more important to their turnover.

Based on the expected number of sites undertaking CAA and the SEA responses, it is estimated that the most likely range for consumption of CT in anodising is between 75 and 150 tonnes per annum in the EEA and between 10 and 35 in the UK. This equates to a range of between 300kg to 500 kg per site on average.

It is most likely that the total volume is towards the lower end of this range, taking into account the range of SEA questionnaire responses, and the fact that responses come from a population made up disproportionately of medium and large sized companies.

Trends in use by role are reported below.

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[53] 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

[54] https://www.prnewswire.com/news-releases/at-4-61-cagr-aircraft-mro-market-is-expected-to-reach-usd-97-12-billion-to-2028---exclusive-report-by-brandessence-market-research-301500861.html

4.3.2.1 OEMs

Use of chromium trioxide in anodising by the OEMs was impacted in 2020 by COVID-19, with the impacts varying across sites and resulting in reductions in the use of between 5% and 50%. No significant changes in consumption compared to 2019 levels are foreseen up to 2024, while consumption is expected to continue decreasing between 2024 and 2032.

As noted in Section 3, the OEMs are progressing their substitution plans. The picture is mixed, however, in terms of changes in consumption of chromium trioxide in anodising over time by the OEMs. On the one hand, the increased production and delivery of aircraft and other products may lead to an ongoing need for CAA for some components, while on the other hand substitution efforts have led to significant increases in the use of alternatives, with this continuing into the future, as these are qualified and certified for other components.

Importantly, however, some of the OEMs (in particular, those producing final products for military use) may require the use of CAA for an extended period, albeit with the quantities needed decreasing post 2032.

4.3.2.2 Design-to-build suppliers

Across the seven design-to-build companies undertaking CAA, all but one reported that the use of the chromates had remained steady in terms of volumes over the past seven years. The one outlier company reported that use had increased by around 4% over this period. This company attributes over 75% of its production costs and its revenue to CAA in combination with anodise sealing, with deoxidising/etching/pickling contributing a further 5-10%.

Four of the seven companies indicated that they were impacted by COVID-19, with this leading to between 10% and 60% reductions in chromate usage. All these companies expected their levels of activity to return to normal by the end of 2023.

With respect to expected changes in consumption over time, five of the companies indicated their expected their use of the chromates would continue to decrease up to September 2024, resulting in decreases in consumption of between 10% and 80%. Further reductions were expected by 2030, including a complete phase-out of use for two companies. After 2030, additional companies expected to phase-out their use of the chromium trioxide for consumption to reduce further (e.g. by up to 60%). This includes one of the companies with the highest number of workers involved in anodising activities.

All these companies indicated that CAA is currently necessary in order to meet customers' performance requirements and/or as part of their customers' certifications. In addition, five indicated that they may be required by their own processes which hold certifications, 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).

4.3.2.3 Build-to-print suppliers

As a result of COVID-19 and its impacts on the aerospace industry, most SEA respondents indicated that their sites experienced between a 10% to 25% decrease in their utilisation rate for CAA activities. These included decreases from previous utilisation rates at 100% capacity or more commonly around 75% of capacity to lower levels. In some cases, however, companies were already operating at fairly low levels of capacity (e.g. 35%), as they shifted production to chromate-free solutions where these were technically feasible and available (e.g. qualified and certified for the manufacture of their components).

Companies were also asked whether the use of the chromates had been impacted by COVID-19. Twenty of the 31 build-to-print companies indicated that it had had an impact, with responses indicating that use of the chromates across all activities fell during this period, from as little as a 10% reduction to as much as a 70% reduction. Note that this covers all chromate-using activities not just CAA. Of these 20 companies, 15 expected levels of use to return to normal by the end of 2023 as production levels increased again.

More generally, 11 of the 31 companies indicated that use of the chromates had remained steady over the past seven years, with a further 11 indicating that use had reduced over the last seven years as substitution took place as alternatives were newly qualified and certified. Eight of the companies expected further reductions to take place between 2021 and 2024, with this typically being by 20-30% but also by as much as 75% lower compared to current consumption.

Looking to the longer term, 19 of the 31 companies responded “Don’t know” to questions regarding how consumption of the chromates might change between 2024 and 2028. Such a response was expected given that these companies are unable to substitute until alternatives are implemented by their OEM and DtB customers. BtP suppliers will often have no knowledge of their customers’ R&D or substitution plans. As a result, one would expect that their use of CAA will decrease at the same rate as for the OEMs and DtBs.

This is verified by the fact that when asked to indicate the key reason for using the chromates, 28 indicated that it was required by their customers’ specifications as part of certification requirements, with the remaining three (filling multiple supply chain roles) indicating that it was due to requirements set out in Maintenance Manuals which had to be adhered to (legal requirement) in the repair, maintenance and overhaul of parts and products.

4.3.2.4 MROs

The picture for MROs is more complicated. Two of these companies indicated that use of the chromates has remained steady over the past seven years, while the other two reported small increases in consumption of up to 10% due to increases in the number of aircraft requiring servicing.

For the period from 2024 to 2032, the MROs expect the use to continue in line with aircraft and military product requirements, with the potential for reductions in use depending on updated requirements in Maintenance Manuals. It is important to recognise that these operators are unable to move to use of substitutes until the Maintenance Manuals have been revised, as they are legally obliged to follow the maintenance and repair requirements set out in the Manuals.

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 263 notifications relating to the REACH Authorisations listed above covering 357 sites across the EU-27 (and Norway) for the main set of dossiers focused on surface treatment by the aerospace industry. These figures are given in Table 4-7. Note that Authorisations 20/18/21-25 may also be of relevance for aeroderivative uses of chromium trioxide for anodising but including these notifications would double-count the number of EEA sites relevant to the A&D industry. As is clear from the table, some notifications clearly cover more than one site.

Table 4–7: Article 66 notifications to ECHA

Substance	Authorisation	Authorised Use	Notifications	EEA Sites
Chromium trioxide	20/18/14-20	Surface Treatment for aerospace	263	357

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

It is important to stress that these notifications relate to 'surface treatment' which covers several more processes than anodising.

As noted in Section 2, around 25 of the notifications appear to include specific reference to anodising (of aluminium components for aerospace applications). In these specific cases, the chromium trioxide consumption is generally indicated as between 0.1-1 t/yr.

More generally, it worth noting that 70% of site notifications[55] that report tonnage figures indicate a chromium trioxide consumption in total of less than one t/yr. This supports an estimated range for the annual consumption of chromium trioxide in anodising as a maximum of around 300kg – 500kg per site per year.

Care is required though in use of the notifications data. Provision of tonnage data is not a legal requirement under Article 66. As a result, consultation with individual notifiers as part of preparation of this combined AoA/SEA indicates that some notified volumes may be very approximate.

Similar data are not publicly available for the UK.

4.3.4 Projected future use of the chromates

The A&D sector is actively working to phase out the use of all chromates in metal surface treatments. It will take further time however to qualify, validate and certify alternatives across all components and products for the A&D industry. Individual companies are at different points along this path, although this also varies by specific aircraft/defence application and across different types of components and final products.

Where possible, the use of CAA in new designs is being phased out, however, products that require its continued use remain in production. As discussed above, increasingly new planes will be replacing older models, reducing the on-going need for the use of CAA where alternatives have proven to meet performance requirements or the need for use of the CAA has been designed out. As a result, by 2036, the main uses should relate to any on-going MRO /legacy parts requirements for in-service aircraft.

Responses to the SEA questionnaire indicate a downward future trend in the use of the chromates over the review period, although it is also clear that almost half of the respondents will require a further 12 years to finalise R&D, development, testing, qualification, component certification and implementation of alternatives at an industrial level, where the latter also includes making changes to process specifications, drawings and maintenance manuals.

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[55] Specific to Authorisations REACH 20/18/14 – 20, which includes parent AfAs that are no covered by this combined AoA / SEA.

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

- "*Time is required due to the high numbers of parts that require testing and validation of the alternatives, re-qualification of the parts with chrome free alternatives, and the commissioning by suppliers of any new equipment needed for the new process(es)*".

- *"Even after an alternative has been found and the component re-certified against its use, the industrialisation of an alternative alone is likely to take up to 6 years across the supplier base".*

- *A 12-year review period is required to ensure that alternatives can be implemented whilst also allowing for a short contingency period. We have worked for twenty-five years to replace chromic acid anodising with little success, and the current proposed alternatives have still not met all technical performance requirements.*

Ten to 12 years is required by 50% of the OEMs and DtBs to roll-out substitution across their entire ranges of components and products. This includes the time needed to qualify and certify components using the alternatives, as well as to implement them through their supply chain. It also includes a contingency period of one year to allow for setbacks in the testing and qualification of alternatives. In particular, MROs who are dependent on design owners' certifying alternatives, will require the use of CT for anodising for the full 12 years, given the time periods required by the design owners to finish certification activities and to update Maintenance Manuals following EASA certification or MoD approvals of a component using an alternative.

There is the potential that MROs and MoDs undertaking maintenance and overhaul activities, as well as DtB and BtP companies producing spare components (including for military final products), will require the use of CAA beyond the 12 years and for up to 20 years due to the long lifetimes of A&D final products and the infeasibility of gaining new certifications for products that have been in service already for long periods of time.

Phase-out of the use of CT in CAA will therefore be gradual under the continued use scenario, as components are certified for use of alternatives and the alternatives are then implemented throughout supply chains. As noted by some of the BtP companies, once their customers' have certified components using alternatives, they will need time to implement them at their site(s), also recognising that different customers have different requirements and are at different points in the substitution process. The time needed by the BtPs will be driven by having to raise the necessary finance, source and install any new equipment, and become qualified against the new alternative and process changes by customers.

4.4 Risks associated with continued use

4.4.1 Classifications and exposure scenarios

4.4.1.1 Human health classifications

Chromium trioxide was included into Annex XIV of Regulation (EC) No 1907/2006 due to its intrinsic properties. It 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.

The hazard evaluation follows recommendations given by RAC (ECHA, 2015)[56]:

- For assessing carcinogenic risk, exposure-risk relationships are used to calculate excess cancer risks.
- 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 anodising within the ADCR value 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 and organisational measures are in place to reduce workplace exposures. The sites adhere to best practices to reduce workplace exposures and environmental emissions to as low as technically and practically feasible and use automated processes to the maximum extent possible. The 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 CAA 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 chromium trioxide in surface treatments (including CAA), additional risk management measures were implemented by A&D companies, involving significant investment. A full summary of these conditions is provided in the CSR that accompanies this combined AoA/SEA.

Due to the different levels in the supply chain that a company may operate as, and the variation in the sizes of the sites, the conditions under which the use is carried out can be variable. The conditions of use cover small sites and repair shops up to large sites with high throughput, and thus, a low to high level of automation for specific activities. This variability was also observed in extensive consultation processes during the preparation of the CSR.

Table 4-8 lists all the exposure scenarios (ES) and contributing scenarios assessed in the CSR.

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[56] 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 number	ES Title	Environmental release category (ERC)/ Process category (PROC)
ES1	Anodising using chromium trioxide in the aerospace and defence industry and its supply chains	
Environmental contributing scenario(s)		
ECS 1	Anodising using chromium trioxide in the aerospace and defence industry and its supply chains	ERC 5
Worker contributing scenario(s)		
WCS 1	Line operators	PROC 5, PROC8b, PROC 9, PROC 10, PROC 13, PROC 28
WCS 2	Storage area workers	PROC 5, PROC 8b, PROC 9, PROC 28
WCS 3	Laboratory technicians	PROC 9, PROC 15
WCS 5	Maintenance workers	PROC 28
WCS 6	Machinists	PROC 21, PROC 24
WCS 7	Incidentally exposed workers	PROC 0
Exposure scenario for industrial end use at site: ES1-IW1		

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 chromium trioxide in CAA. 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 4.2 below, which presents the excess lung cancer risks to workers involved in CAA treatment related activities. The risks are calculated using a combination of measured inhalation data and modelling for different SEGs (Similar Exposure Groups). The SEGs include:

- WCS1: Line operators who may be involved in a range of activities including immersion of parts into a treatment bath, sampling of the treatment baths and selective (swab) anodising.
- 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 may be involved in sampling of treatment baths and laboratory analysis of treatment bath solutions.
- WCS4: Maintenance and/or cleaning workers who carry out maintenance and cleaning of equipment and handling of solid wastes.
- WCS5: Machinists who carry out machining operations on anodised parts.
- 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** also indicates the number of workers on average that may be exposed per typical site, with this figure taken into account in estimating the total number of workers exposed across all 180 EU sites and 30 UK sites that would continue to carry out CAA anodising.

Table 4-9: Excess lifetime cancer risk for workers by SEG

#	SEG	Number of workers and number of shifts	Excess lifetime lung cancer risk [1/υg/m^3)
WCS1	Line operators	1-3 per shift, 4 per day on average; up to 3 shifts at larger sites	2.36E-03
WCS2	Storage area workers	1-2 per shift, 4 per day on average; up to 3 shifts (only 1-2 per shift)	7.60E-05
WCS3	Laboratory technicians	1-5 per site	NA
WCS4	Maintenance and/or cleaning workers	1-5 per shift, 3 per day on average; up to 3 shifts per day	3.84E-04
WCS5	Machinists	1-15 per site, 5 per day @ 40% of time; up to 3 shifts per day	8.21E-04
WCS6	Incidentally exposed workers	0-15 per shift, 3 FTE per day; up to 3 shifts	1.00E-03

Source: Information from CSR
Note: Excess lung cancer risk refers to 40 years of occupational exposure

4.4.2.2 Humans via the environment

Excess lifetime cancer risks

The assessment of risks for humans via the environment presented in the CSR has been carried out for the general population at the local level only. No regional assessment has been carried out as it can be assumed that Cr(VI) from any source will be reduced to Cr(III) in most environmental situations and therefore the effects of Cr(VI) as such are likely to be limited to the area around the source, as described in the EU Risk Assessment Report for chromates (see CSR for further details). The approach to not perform a regional assessment for human Cr(VI) exposure via the environment as part of AfAs for chromate uses was also supported in compiled RAC and SEAC (Socio-economic Analysis Committee) opinions, as described for example in the *Opinion on an Application for Authorisation for Use of Sodium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites and sealings of anodic films* (ID 0043-02). This reference states that regional exposure of the general population is not considered relevant by RAC[57].

The assessment presented in the CSR is based on measured data for emission to air and wastewater. For this assessment combined exposure of humans via the inhalation (air) and the oral (uptake of water and fish) route is considered. Data were available from 21 sites undertaking CAA to act as the basis for estimating exposure concentrations and associated risks. The resulting 90th percentile risk estimates are presented in the table below.

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[57] RAC/SEAC "Opinion on an Application for Authorisation for Use of Sodium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites and sealings of anodic films", consolidated version, 2016; https://echa.europa.eu/documents/10162/658d42f4-93ac-b472-c721-ad5f0c22823c

Table 4-10: Excess lifetime cancer risk estimates for humans via the environment (general population, local assessment)

Inhalation		Oral		Combined lifetime risk (90%)
Local Cr(VI) PEC in air [µg/m3]	**Inhalation risk**	**Oral exposure [µg Cr(VI)/kg x d]**	**Oral risk**	**Combined risk**
1.03E-03	2.98E-05	1.26E-03	1.01E-06	**3.16E-05 (range: 5.81E-09 to 7.9-E05**

a) RAC dose-response relationship based on excess lifetime lung cancer risk (see CSR): Exposure to 1 µg/m3 Cr(VI) relates to an excess risk of 2.9×10^{-2} for the general population, based on 70 years of exposure; 24h/day.

b) RAC dose-response relationship based on excess cancer risk for tumours of the small intestine (see CSR): Exposure to 1 µg/kg bw/day Cr(VI) relates to an excess risk of 8×10^{-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 chromium trioxide is summarised in **Table 4-11** below for those Authorisations relevant to continued use in CAA by the A&D sector. 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 the original CTAC parent authorisations is presented here.

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, Passivation of stainless steel, chemical conversion coating and anodising and anodise sealing	1107

Number of workers based on SEA questionnaire data

Responses to the SEA questionnaire indicate that some 740 workers (Full time equivalent) are directly involved in CAA across the 64 sites covered by responses. The breakdown for these is given in **Table 4–12** below by role in the supply chain, and as extrapolated out to the 180 EU sites and 30 UK sites.

Table 4–12: Number of employees undertaking CAA across the EU and UK

Type of company	Number of sites EEA	Number of sites UK	No of employees EEA	No of employees UK	Total
Number of workers 64 sites involved in chromic acid anodising					
Build-to-print	19	12	177	103	280
Build to design	5	4	128	64	192
MRO only	4	1	130	5	135
ADCR Members	15	4	115	20	135
Total 64 sites	**43**	**21**	**550**	**192**	**742**
Average per site			**12.8**	**9.1**	**11.6**
Number of workers at 180 EU sites and 30 UK sites involved in chromic acid anodising					
Build-to-print	130	13	1,211	112	1,323
Build to design	20	7	512	112	624
MRO only	10	5	325	25	350
ADCR Members	20	5	153	25	178
Total 210 sites	**180**	**30**	2,201	274	2,475

In total, this translates to a potential 2,200 exposed workers in the EU and around 275 in the UK, or between nine to 13 per site. These figures are considered consistent with the CSR assumptions on the number of workers exposed to the chromates under WCS1 to WCS3, which totals to 13 per site on average excluding machinists and incidentally exposed workers.

The average figures assumed in the CSR are adopted here for consistency and extrapolated out to the total numbers of sites to give the figures set out in **Table 4–13** as the number of workers exposed under each WCS.

Note that WCS3 related to laboratory technicians is not considered further here as the handling of substances in laboratories for quality control purposes under controlled conditions and in amounts below one tonne per annum 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.

Table 4–13: Number of employees undertaking CAA across the EU and UK				
Worker Contributing Scenarios		**Average No. Exposed from CSR**	**180 EU sites**	**30 UK sites**
WCS1	Line operators	4	720	120
WCS2	Storage area workers	4	720	120
WCS3*	Laboratory technicians	2	360	60
WCS4	Maintenance and/or cleaning workers	3	540	90
WCS5	Machinists	5	900	150
WCS6	Incidentally exposed workers	6	1,080	180
Total		**24**	**4,320**	**720**
Excluding WCS3		**13**	**3,960**	**660**
***Not considered further**				

4.4.3.2 Humans via the Environment

The relevant local population for humans via the environment has been estimated based on the following information:

- Number of downstream user sites in total and then as assumed in terms of their distribution across the EU/UK;
- The population density per km^2 for each relevant EU country and the UK;
- The relevant distance from sites for the local assessment, taken as the default assumption of a 1000m radius (or 3.14 km^2).

A 1000m 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 and are only higher for two of the 21 anodising sites used as the basis for the CSR; in these cases inhalation risks were lower than average. 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 EU and UK. The total number of humans exposed via the environment in the EU is estimated at just over 83,300, with the UK figure being around 40,000 (the UK figure appears disproportionately high due to the UK's high population density).

Table 4–14: General public, local assessment exposed population from CAA across the EEA and UK

Countries with DUs	No. Sites per country	Population density per km^2	Exposed local population within 1000m radius
France	45	118	16682
Germany	30	232	21865
Italy	17	200	10681
Spain	17	92	4913
Poland	17	123	6569
Czech Republic	10	135	4241
Sweden	10	23	723
Finland	5	16	251
Netherlands	5	421	6613
Belgium	5	376	5906
Denmark	2	135	848
Hungary	2	105	660
Norway	2	14	88
Romania	2	82	515
Bulgaria	2	64	402
Ireland	2	69	434
Greece	1	82	258
Lithuania	2	43	270
Portugal	2	112	704
Slovakia	2	111	697
Total EEA	**180**		**83,321**
UK	**30**	**424**	**39,961**

4.4.4 Residual health risks

4.4.4.1 Introduction

Under the Applied-for-Use Scenario, use of chromates in CAA will continue up to the end of the requested 12 year review period.

In December 2013, the Risk Assessment Committee (RAC) agreed lifetime (i.e. for 40 years and 70 years of exposure) mortality risk estimates associated with carcinogenicity for workers and humans via the environment exposed to Cr(VI) substances[58]. 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.

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[58] 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[59] cancer cases were derived from the Cancer Today database, see Table 4-15 below.

Table 4-15: Estimated incidence and mortality of cancers across the EU-27 and the UK, both males and females (in 2020)

Type of cancer	Cases	Deaths	Survivals
Lung	370,310	293,811 (79%)	76,499 (21%)
Colorectum (intestinal)	393,547	177,787 (45%)	215,760 (55%)

Source: Source: http://gco.iarc.fr/today/home (accessed on 20/02/2022)
Note: Percentages have been rounded

To calculate the number of additional non-fatal lung cancer cases, a ratio of deaths to survivals is applied to the number of additional fatal lung cancer cases, as shown below:

(1) $(0.21/0.79) \times \pi = \sigma$

where π is the number of additional fatal lung cancer cases and σ is the number of additional non-fatal lung cancer cases.

In a similar fashion, the figures from Cancer Today reported above are applied to the estimates to calculate the total number of additional fatal and non-fatal intestinal cancer cases[60].

(2) $(0.55/0.45) \text{ x } \delta = \eta$

where, δ is the number of additional fatal intestinal cancer cases and η is the number of additional non-fatal intestinal cancer cases.

Note, however, that the CSR provides combined excess risk estimates. To err on the side of conservatism, the fatality versus morbidity ratio for lung cancer has been adopted for valuation of risks to humans via the environment (HvE).

4.4.4.3 Predicted excess cancer cases with continued use: workers directly exposed

Total excess cancer risk cases are based on the excess lifetime risk estimates derived in the CSR for the different worker contributing scenarios (WCS as presented in **Table 4-9**). These risk estimates reflect the additional safety measures that have been implemented due to the conditions placed on continued use by the initial authorisations. The number of excess risk cases is calculated by multiplying the number of workers assumed to be exposed in each task by the value of the excess cancer risk given above adjusted for the requested review periods, i.e. over 12 years. This value is then multiplied by the number of workers exposed in each WCS to calculate the total excess cancer cases arising from the continued use of chromates in CAA. **Table 4-16** and **Table 4-17** provide a summary of the results across all WCS for EU and UK workers.

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

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

Table 4-16: Number of excess lifetime cancer cases to EU 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	720	2.36E-03	**1.70**	**1.34**	**0.36**
WCS2	720	7.60E-05	**0.05**	**0.04**	**0.01**
WCS4	540	3.84E-04	**0.21**	**0.16**	**0.04**
WCS5	900	8.21E-04	**0.74**	**0.58**	**0.16**
WCS6	1080	1.00E-03	**1.08**	**0.85**	**0.23**
		Years - Lifetime	**40.00**	**2.56**	**2.99**
		Years - Review period	**12.00**	**0.77**	**0.90**
		Years - Annual	**1.00**	**0.06**	**0.07**

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	120	2.36E-03	**0.28**	**0.22**	**0.06**
WCS2	120	7.60E-05	**0.01**	**0.01**	**0.00**
WCS4	90	3.84E-04	**0.03**	**0.03**	**0.01**
WCS5	150	8.21E-04	**0.12**	**0.10**	**0.03**
WCS6	180	1.00E-03	**0.18**	**0.14**	**0.04**
		Years - Lifetime	**40.00**	**0.50**	**0.13**
		Years - Review period	**12.00**	**0.15**	**0.04**
		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 as humans via the environment as given in **Table 4–14** is multiplied by the excess cancer risk estimates to calculate the total excess cancer cases arising under the continued use scenario. The results are given in **Table 4–18**. The basis for estimating the number of people exposed per country is the percentages of Article 66 notifications made to ECHA per country, as described in Section 4.2 plus some adjustments based on SEA responses and the location of suppliers to the ADCR OEMs and DtB companies (and taking into account military sites).

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
France	45	118	16682	3.16E-05	5.27E-01	**0.42**	**0.11**
Germany	30	232	21865	3.16E-05	6.91E-01	**0.55**	**0.15**
Italy	17	200	10681	3.16E-05	3.38E-01	**0.27**	**0.07**
Spain	17	92	4913	3.16E-05	1.55E-01	**0.12**	**0.03**
Poland	17	123	6569	3.16E-05	2.08E-01	**0.16**	**0.04**
Czech Republic	10	135	4241	3.16E-05	1.34E-01	**0.11**	**0.03**
Sweden	10	23	723	3.16E-05	2.28E-02	**0.02**	**0.00**
Finland	5	16	251	3.16E-05	7.94E-03	**0.01**	**0.00**
Netherlands	5	421	6613	3.16E-05	2.09E-01	**0.17**	**0.04**
Belgium	5	376	5906	3.16E-05	1.87E-01	**0.15**	**0.04**
Denmark	2	135	848	3.16E-05	2.68E-02	**0.02**	**0.01**
Hungary	2	105	660	3.16E-05	2.08E-02	**0.02**	**0.00**
Norway	2	14	88	3.16E-05	2.78E-03	**0.00**	**0.00**
Romania	2	82	515	3.16E-05	1.63E-02	**0.01**	**0.00**
Bulgaria	2	64	402	3.16E-05	1.27E-02	**0.01**	**0.00**
Ireland	2	69	434	3.16E-05	1.37E-02	**0.01**	**0.00**
Greece	1	82	258	3.16E-05	8.14E-03	**0.01**	**0.00**
Lithuania	2	43	270	3.16E-05	8.54E-03	**0.01**	**0.00**
Portugal	2	112	704	3.16E-05	2.22E-02	**0.02**	**0.00**
Slovakia	2	111	697	3.16E-05	2.20E-02	**0.02**	**0.00**
Total	**180**		**83,321**	**3.16E-05**	2.63	**2.08**	**0.55**
			Years – Lifetime cases		**70.00**	**2.08E+00**	**3.20E-01**
			Years - Review period		**12.00**	**3.57E-01**	**9.48E-02**
			Years - Annual		**1.00**	**2.97E-02**	**7.90E-03**
UK	30	424	39,961	3.16E-05	1.68E+00	**1.00**	**0.27**
			Years – Lifetime cases		**70.00**	**9.98E-01**	**2.65E-01**
			Years - Review period		**12.00**	**1.71E-01**	**4.55E-02**
			Years - Annual		**1.00**	**1.43E-02**	**3.79E-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 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[61]. It has been assumed that the levels of exposure to Cr(VI) for workers and members of the general population remains constant throughout the length of the review period, even though this is a very conservative assumption. In fact, downstream users will gradually reduce the amount of Cr(VI) consumed as the transition to alternatives 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[62] 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[63]. 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[64]. 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 .

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

[62] 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.

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

[64] 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[65]			
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)[66]			
Luo et al (2010)	2000 (assumed)	US$29,196	€36,230
Lang et al (2009)	2006	US$28,626	€31,740
York Health Economics Consortium (2007)	2004	£8,808	€12,180
York Health Economics Consortium (2007)	2004	£12,037	€16,410

The average cost across the four lung cancer studies is €17,314 per annum (2021 prices). The average cost figures reported for intestinal cancer are based on figures produced for colon, rectal and colorectal cancer in the US and UK. The US 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 €14,853 per case in 2021 prices, taking into account price inflation.

These average medical costs are annual figures and apply to survivors over the period of time that they continue to be treated. With respect to lung cancer morbidity cases, we have taken a percentage survival of 32% after one year since diagnosis, 10% after five years, 5% after ten years[67]. With respect to intestinal cancer morbidity cases, we have taken a percentage survival of 76% after one year since diagnosis, 59% after five years, 57% after ten years. Based on these time periods, the NPV of average future medical costs per lung cancer case is estimated at €30,110 in 2021 prices, using a 4% future discount rate. The NPV of average future medical costs per intestinal cancer case is estimated at €82,620 in 2021 prices. It is noted that a large percentage of people survive intestinal cancer after a period of 10 years and any stream of health care costs incurring after that is not incorporated in our calculations. However, such costs are not likely to be relevant considering that those surviving after such a long period of time can either be considered as definitely cured or probably only in need of a small degree of medical attention.

The valuations of mortality and morbidity were multiplied by the estimated number of additional cancer cases, fatal and non-fatal, that can occur in the Applied for use scenario. The basic calculations for the value of an excess cancer case are presented below:

(3) $(\pi \times (€\ 3{,}920{,}000)) + (\sigma \times (€\ 460{,}000 + €\ 30{,}840) =$ Total lung cancer costs

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[65] 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.

[66] 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.

[67] https://www.cancerresearchuk.org/health-professional/cancer-statistics/statistics-by-cancer-type/lung-cancer/survival.

(4) $(\delta \times (€\ 3{,}920{,}000)) + (\eta \times (€\ 460{,}000 + €84{,}790))$ = 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 **€1.31 million for the EU and €217,900 for the UK**, based on the assumption that chromate-based CAA 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 latency)

	EEA Workers		UK Workers	
	Mortality	Morbidity	Mortality	Morbidity
Total number of lung cancer cases	8.96E-01	2.38E-01	1.49E-01	3.97E-02
Annual number of lung cancer cases	7.47E-02	1.98E-02	1.24E-02	3.31E-03
Present Value (PV, 2024)	€ 1,267,706	€ 39,544	€ 211,284	€ 6,591
Total PV costs	**€ 1,307,250**		**€ 217,875**	
Total annualised cost	**€ 301,791**		**€ 50,298**	

Source: Derived estimates from responses to the SEA questionnaire, Article 66 data, Eurostat data and CSR

4.4.5.3 Predicted value of excess cancer cases with continued use: man via the environment

Table 4-21 applies the economic value of the associated health impacts to the additional statistical cases of cancer for 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 roughly **€522,000 for the EEA and €250,200 for the UK**, based on the assumption that CAA 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 latency)				
	EU General Population		UK General Population	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cancer cases	3.57E-01	4.55E-02	1.71E-01	4.55E-02
Annual number of cancer cases	2.97E-02	7.90E-03	1.43E-02	3.79E-03
Present Value (PV, 2024)	€ 504,558	€ 17,189	€ 241,987	€ 8,244
Total PV costs	**€ 521,748**		**€ 250,231**	
Total annualised cost	**€ 120,450**		**€ 57,768**	
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 aluminium and other surfaces following CAA has been accounted for in the worker estimates presented above.

4.4.7 Environmental impacts

Releases to the environment are governed by, and comply with, local worker and environmental regulatory requirements.

Releases of wastewater containing Cr(VI) may occur from:

- Bath solutions (depending on the site and the Cr(VI) concentration) when they are renewed
- Rinsing water from rinsing tanks
- Cleaning water (e.g., from bath cleaning, cleaning of empty chemical containers, general/workplace cleaning, cleaning of equipment)
- Liquid from secondary containment pits
- Water from wet scrubbers
- Liquid hazardous waste from samples processed in the laboratory

At all sites wastewater is collected and then treated by one or more of the following three options:

- Sending it to an external waste management company where it is treated as hazardous waste;
- Recycling and evaporation in an on-site evaporation system; the residue is discharged as hazardous solid waste;
- Discharge into a special treatment facility.

The special treatment facility is in most cases located on-site but may also be external where the water is transferred via underground pipes. Typically, contaminated water is either disposed as hazardous waste by an external company or conveyed to the special treatment facility. Wastewater from the other sources listed above is usually either collected and mixed together for treatment at the treatment facility or recycled and then led to the evaporation system. In the special treatment facility, the Cr(VI) in wastewater is reduced to Cr(III) by addition of a reducing agent (e.g. sodium bisulfite or ferrous sulfate) in excess. Following the reduction step, the wastewater pH is neutralized, and Cr(III) is precipitated. After monitoring of the Cr(VI) concentration in the reduced wastewater, usually the wastewater is mixed with other (non-Cr(VI)) containing waste solutions. The wastewater is then discharged to an external municipal wastewater/sewage treatment plant for further treatment prior to discharge to receiving waters (river, canal, or sea).

Exhaust air is released via stacks, and emitted air is treated in scrubbers or by air filters before being released to the ambient air. There are no direct releases to soil and solid waste materials containing Cr(VI) are classified and treated as hazardous wastes according to EU and national regulations. Any solid or liquid waste is collected and forwarded to an external waste management company (licenced contractor) for disposal as hazardous waste.

4.4.8 Summary of human health and environmental impacts from Continued Use

Table 4-22 provides a summary of the economic value of the human health impacts across the worker and local populations. When considering these figures, it should be remembered that they relate to use of the CAA across the EEA or UK, rather than risks associated with activities at a single site.

Furthermore, the workers undertaking CAA may also be using chromates as part of pre- or post-treatment activities, or other main process activities. As a result, their monitoring data could be an aggregation of these exposures and therefore risks may be over-represented for CAA alone.

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, starting 2024, figures rounded)

	EEA		UK	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cancer cases	1.25	0.28	0.32	0.09
Annual number of cancer cases	0.10	0.03	0.03	0.01
Present Value (PV, 2024)	€ 1,772,264	€ 56,734	€ 453,271	€ 14,835
Total PV costs	**€ 1,828,997**		**€ 468,106**	
Total annualised cost	**€ 422,241**		**€ 108,067**	

Source: Derived estimates from responses to the SEA questionnaire, Article 66 data, Eurostat data and CSR

5 Socio-Economic Impacts of the Non-Use Scenario

5.1 The Non-use scenario (NUS)

5.1.1 Summary of consequences of non-use

The inability of companies to undertake CAA on aluminium and other alloys across the EEA and in the UK would be severe. This use is critical to corrosion protection across a broad range of components and products. It is important to the protection of aluminium and its alloys and magnesium and its alloys, which are estimated as making up around 80% of a modern-day aircraft and up to 90% of spacecraft. Aluminium and magnesium alloys are used extensively in the construction of A&D products due to their good weight to strength to cost ratio, predictability as a material and resistance to UV damage. Different aircraft grades of aluminium alloys find different uses, but they include the fuselage, wing skins, aircraft structures and structural components, cowls, and fuel tanks.

As noted in Section 2 and 3, CAA is often preceded by some form of pre-treatment and is frequently followed by anodise sealing, with the latter taking place within a matter of hours to ensure corrosion protection. As a result, the inability to undertake CAA will have consequential impacts on other manufacturing activities, in such cases. This is important in the context of the non-use scenario.

If CAA was no longer authorised, where qualified and certified alternatives are not available according to the definition of “generally 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 consequent effects for other parts of the A&D value chain, as summarised below.

If the Applicants are not granted an Authorisation, the critical corrosion protection, chemical resistance, layer adhesion, layer thickness and wear resistance benefits associated with CAA would be lost to aerospace and defence downstream users in the EEA/UK

⇩

Due to certification and airworthiness requirements, downstream users in the A&D value chain would be forced to undertake CAA activities outside the EEA/UK or shift to suppliers outside of the EEA/UK

⇩

OEMs would shift production and assembly activities outside the EEA/UK as it would be too inefficient and costly to transport parts and assemblies for CAA only

⇩

Design-to-build suppliers may have more flexibility and be able to shift only part of their production activities outside the EEA/UK resulting in the loss of profits and jobs

⇩

BtP suppliers in the EEA/UK would be forced to cease CAA and linked treatments, leading to loss of contracts and jobs due to relocation of customers outside the EEA/UK

⇩

MROs would have to shift some of their activities outside the EEA/UK, where CAA is an essential part of maintenance, repairs and overhaul activities

⇩

Relocation of MRO activities outside the EEA/UK would cause significant disruption to the A&D sector itself

⬇

Ministries of Defence would face logistical difficulties in maintaining aircraft and other equipment, severely impacting on mission readiness. Service agreements would need to be reached with non-EEA countries

⬇

Civil aviation, passengers, freight shippers and emergency services would face reduced flight availability and routes, as well as increased costs

5.1.2 Identification of plausible non-use scenarios

Consultation was carried out with the applicants, OEMs, the build-to-print, design-to-build suppliers and MROs to establish what the most likely non-use scenarios would be due to the non-Authorisation of CAA. These included discussions surrounding the subsequent effects from the loss of CAA, 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 and how this impacts on why they use chromium trioxide, past investments and R&D, and the most likely impacts of a refused re-authorisation. This information 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. Producing components overseas, shipping them back to the EEA/UK and then warehousing them was ruled out due to logistic difficulties and economic feasibility.
Table 5-1 below presents the choices presented in the SEA questionnaire and a count of the number of companies selecting each (out of the 50 companies in total, covering the 64 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 demonstrate the differences that exist within the aerospace supply chain and hence how the most plausible scenarios will vary by role.

Further details on the non-use scenario for the different types of companies are provided below, starting with OEMs as the main design owners, followed by DtBs, BtPs and MROs.

Table 5-1: Responses to SEA survey on most likely non-use scenarios

	OEM/Tier 1	Build-to-print only	Design-to-build only	MROs – only
The decision is up to our customer		10	1	
We may have to cease all operations as the company will no longer be viable	2	9		4
We will focus on other aerospace uses or on non-aerospace and defence uses		3	1	
We will shift our work outside the EEA/UK	4	1	1	
We will stop undertaking use of the chromate(s) until we have certified alternative	2	7	4	
Number of responses (companies)	8	30*	7	4

*One response left blank

5.1.2.1 OEMs

In discussions, the OEMs and all stressed that the aim is replacement of chromium trioxide in anodising to a qualified and certified alternative . In some cases, a candidate alternative has been identified, but more time is required for testing, qualification, validation and certification using the alternative across the entire supply chain (particularly where a significant number of suppliers may be involved in undertaking CAA of structural parts). In other cases, the companies have been trying to find a suitable replacement for over 25 years (e.g. in their defence applications) and have been unable to as of yet, although R&D continues.

With respect to the plausibility of the different non-use scenarios identified above, the following are clear from the consultation based on the choices provided in the SEA questionnaire.

- **We will shift our work involving Chromates to another Country outside the EEA/UK.** This is the most plausible scenario for half (4 of 8) of OEMs directly involved in the use of CAA. It would not be possible for the OEMs (or divisions of them) to maintain manufacturing activities that did not involve CAA inside the EEA/UK while transferring CAA outside the EEA/UK. This would result in huge numbers of transfers of component manufacturing outside the EEA/UK, which would not be economically feasible. Furthermore, given the importance of CAA to the protection of aluminium and magnesium alloys, it is also the most likely response for those OEMs who are supporting the continued use of CAA in their supply chains. In addition, the ability to shift CAA activities outside the EEA/UK for defence supply chains may be restricted for security reasons.

- **We will stop using the chromates until we have certified alternatives:** In most cases substitution activities and especially the industrialisation phase of moving to alternatives will not be completed for at least seven years and for a significant number of components/products for 12 years (or potentially longer). Two of the OEMs indicated, however, that this would be their most plausible scenario as they believe they are close to substitution for their products. One would cease production in the short term while it developed a case-by-case strategy to enable production to restart. Losses in turnover in the short term, e.g. two years, would be up to 100%. This company produces components and products for both civilian aerospace and defence. For the other OEM identifying this as the most plausible scenario, losses in turnover would be between 40 - 60%. For the other companies, the potential duration of such a production stoppage would not be economically feasible and they would relocate or cease manufacturing.

- **We may have to cease all operations as the company will no longer be viable.** If shifting CAA work outside the EEA/UK is not economically feasible, nor is stopping production on a temporary basis until alternatives are certified, then companies will cease their operations. It is important to note that this includes a cessation of A&D production within the EEA/UK, with consequent reductions in revenues from both component production and product assembly operations. The loss of this turnover would result in other operations (R&D, Engineering, Sales, etc.) also becoming non-viable with the final outcoming being a shut-down of all activities within the EEA/UK. This option was identified by two of the large OEMs who not only manufacture products but also carry out repair and maintenance activities involving CAA.

It is not technically nor economically feasible for aerospace and defence OEMs to switch all or most of their focus to other sectors, as their sole areas of expertise reside in the aerospace field and/or defence fields. As a result, this is not a plausible option for any of the companies.

For the majority of OEMs, the **most plausible response under the non-use scenario would be to relocate all or some of their manufacturing activities outside of the EEA/UK** (even if this would not be ethically agreeable as risks can be better controlled within the EEA/UK) **or to a total cessation of operations for the OEM or divisions within them**.

The extent to which companies would move all or only some of their manufacturing outside the EEA/UK depends on the integrated "system" of activities undertaken at individual sites. CAA is not undertaken across all sites of the larger OEMs companies that may operate over more than ten sites; however, it may be critical to certain divisions or carried out by suppliers to those sites. Consultation indicates that these companies' sites may each be supported by up to 20 suppliers undertaking CAA regionally (with this figure used in generating the number of sites in total assumed to be carrying out CAA in the EEA in particular). In terms of impacts on individual companies, the estimated loss of production and turnover ranges from around 20% (i.e. impacts on a particular division or site) to 100% of current levels, with production expected to stop completely at a significant percentage of sites where CAA is a core activity, or the operations of a division are reliant upon it. These impacts would be experienced by sites involved in civil aviation and/or defence manufacturing. Because aircraft manufacturing and MRO activities represent the largest share of the OEMs' activities, the impact on the European economy would be considerable, especially as their response would drive the responses of their suppliers.

The OEMs stress that it is not feasible to only cease undertaking CAA treatments; all activities related to the anodising process flow, including the manufacture of the relevant components and products would need to be moved outside the EEA/UK.

In the A&D industry, reliance on proven corrosion prevention systems means that Cr(VI) and non-Cr(VI) operations/processes normally exist side-by-side, are inter-reliant and non-separable. This is one of the reasons the aerospace industry has a very complex and interrelated supply chain. For several essential components, only one designated supplier exists. Typically, this supplier will have worked in close partnership with its customer(s) for decades to develop a product. Critical suppliers often take occupancy on, or adjacent to, the premises of their customers. Therefore, relocation will often be based on strategic decisions, e.g. if the customer relocates then the suppliers might do the same to keep proximity.

From an operational perspective, surface treatment using Cr(VI) substances is a small element of the overall process flow in most mixed facilities, with the combination of machining, finishing, assembly, testing and inspection dominating overall. However, as noted above, they cannot be separated from one another. The impacted operations, and therefore socio-economic impacts to industry in the non-use scenario, go far beyond the specific process directly using Cr(VI) and have substantial implications for non-Cr(VI) processes that are indirectly affected.

For the majority of the components that require CAA, the process is carried out at a key stage in the production process, and the timing of the pre- and post-treatment steps is critical. All steps in the anodising process sequence need to be performed one after the other without letting the components dry in between (e.g. degrease/clean, etch/deoxidize, anodise, seal), so individual parts of this process cannot be moved – only the entire process. Anodise sealants may be applied to a wet anodised component, while primers may be applied to wet or a dry, unsealed anodised component. The logistical issues are similar, however, as the sealant or primer has to be applied within a certain time window after anodising (typically less than a day but could be extended in some circumstances). If this window is not met, then the components have to be stripped and reprocessed.

Hypothetically, CAA could be moved, and parts shipped outside of the EEA and then be brought back. Excessive handling of an anodised component, however, can lead to contamination and the need for reprocessing. This drives the need for components to be treated at a single location with minimal handling. In addition, sub-contracting overseas production would drastically undermine the competitiveness of EEA component suppliers. By adding extra transportation, lead-times, and risk of additional handling-related damages, suppliers in the EEA would be put at a massive disadvantage compared with non-EEA suppliers in their bids/services. Furthermore, if manufacturing activities using CAA were separated from other production activities (including use of primers), the huge logistic requirements of managing the flow of components and the level of transportation required would have a dramatic impact on resources and the environmental footprint of the sector.

Note that this argument also applies to the case where a Cr(VI)-free alternative is successfully qualified and certified by an OEM for one or more, but not all, components. Being able to move to an alternative for a subset of components would not change the overall impacts as the entire supply chain must be able to move to alternatives to produce an aircraft. If only one component cannot be produced according to type certification, the manufacture of the entire aircraft is jeopardised.

Particular difficulties would be faced by companies in the defence sector. Possibilities for relocating some activities outside the EEA/UK are limited due to 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 potential responses identified by design-to-build companies include:

- Await a decision from their customers;
- Focus on other surface treatment activities for the aerospace or other sectors;
- Stop carrying out anodising until components are certified based on use of an alternative; or
- Shift operations outside the EEA/UK.

Only one of these companies indicated that they currently carried out anodising using a non-chromate alternative for some components and products, noting that alternatives are not qualified and certified for use in the production of other components and products.

As a result, those companies that indicated they would “focus on other surface treatment activities” or “stop undertaking CAA until a certified alternative is available” would face reductions in turnover and levels of employment, as well as eventual qualification and certification costs if they were able to continue operating:

> One noted that: “the development, testing, deployment and certification of components and products based on replacements is and will continue to be very costly for our company”, while another identified the “high-costs” of requalification;

- Another commented: “We plan to remove as many of the uses of these chromates as possible by the end of 2024”. More specific to anodising, which makes up 50-75% of their production costs and is relevant to a range of small, medium and large components, “the work could be put on hold or outsourced to another country” depending on how close any component was to being certified for production using an alternative and their customers’ demand for the components.

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 could face closure or would be forced to also move some or all of their operations. Sub-contracting to companies outside the EEA/UK was not viewed as feasible given the logistics involved in shipping and warehousing components, as well as the issues regarding the potential for rework, etc.

Of the remaining two companies, one’s response depended on the actions of their customers, while the other company would move outside the EEA/UK. This second company that indicated that it would shift their activities outside the EEA/UK.

With respect to turnover losses, half of the companies indicated losses of between 30-60%, while the other half indicated losses of between 80-100%; the respondent who indicated it was up to their customers answered, “don’t know”.

5.1.2.3 Build-to-print

Around half (15/31) of the build-to-print companies noted that their customers had certified chromate-free alternatives for anodising some components but not for others. As a result, they could not shift to an alternative for anodising all components until their OEMs had qualified and certified alternatives for those components. (Note that this does not mean that they do not require the use of the chromates for other steps in the process flow, as some do). This is the case for some of the companies. Furthermore, there was no significant distinction between the half that currently carry out some anodising using an alternative to chromium trioxide with those that do not in terms of their likely response to the non-use scenario:

- Half of those who would “focus on other aerospace and non-aerospace activities” or would stop undertaking CAA “until a certified alternative was available” currently also carry out anodising for some proportion of their production using an alternative; however, they still required the use of CAA for some proportion of their A&D production, where no alternatives have been qualified and certified by their customers. As a result, the non-use scenario would lead to a consequent reduction in turnover and numbers of employees;

- Around half (five of the nine) of the companies that indicated they may have to “cease operations” or that they would “shift operations outside the EEA/UK” currently carry out anodising for some part of their production activities using a certified alternative; and

- Half (five out of the 10) of those who indicated that the decision was “up to their customers” are also currently able carry out anodising on some components using an alternative where this is an “available option”, i.e. the component has been qualified and certified by their customers based on the alternative.

Additional comments included that “if the components do not have a certified alternative then the company will not be viable”. Another responded that: “The effects of loss of authorisation would be massive for our company. This would likely lead to significant redundancies and a large drop off in turnover.”

In terms of turnover losses, eight (of 31) companies indicated that they would lose up to 40% of their turnover under the non-use Scenario (6 of these were between 30 - 40%); two indicated losses of between 41 – 60%; seven indicated losses of 80% to 100%; 12 responded “don’t know” as the decision rested with their customers (and two provided no response).

A range of countries were identified as possibilities for relocation. Four BtPs already have facilities outside the EEA (with one having facilities in the UK as well as elsewhere) and UK. These companies would shift production activities to such facilities if this was feasible rather than cease operations or stop production activities while they wait for an alternative to be qualified. They noted however that this was unlikely to be acceptable to their EEA/UK customers due to the risk of rework and the logistic issues.

5.1.2.4 MROs

For companies that operate as MROs only, there is less choice. They do not undertake manufacturing per se, only the overhaul, repair and maintenance of different A&D components, which can differ in size and complexity (ranging from the overhaul of a complete aircraft to maintenance of a single defence 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 (e.g. from pre-treatment to CAA to anodise sealing as a “system”) 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 minutes to several days. Within these process flows, even if CAA is only required to a very limited extent, it may remain essential as part of the maintenance and repairs carried out to ensure that airworthiness regulations are met.

The inability to undertake CAA as part of maintenance, repair and overhaul activities may make such services unviable for those MRO sites where this is carried out. There is no scope for them to operate outside the requirements detailed in the OEMs' service Manuals. Where these requirements mandate the use of chromium trioxide, then the MRO must use chromium trioxide as instructed unless the Manuals also list a qualified alternative.

As a result, those MRO businesses which are based on the re-implementation of CAA would no longer be viable and would have to cease in the EEA/UK. All four MROs responding to the SEA questionnaire indicated that they would have to cease their EEA/UK operations, which would be neither practical nor feasible for their defence customers or civil aviation customers.

With respect to turnover losses, these ranged from 20 - 100% losses. However, the company indicating that direct losses would be around 20% also noted that this could have a knock-on effect leading to a further 50% loss due to impacts also 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.

As noted by one of the MROs: "*The effect of a refused authorization is enhanced due to tie-in business - business models that rely on the implementation of the upstream Cr(VI)/CrO3 and downstream process steps. The remaining business would not be viable anymore, operations would have to be ceased*".

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[68] and MoDs, or from an engineering perspective taking airworthiness safety requirements into consideration.

Under such a scenario, OEMs would be forced accept an alternative that is less efficacious in delivering corrosion protection where no alternative has been proven to provide an equivalent level of performance to CAA on a particular component or product. This use of a less effective alternative would downgrade the performance of the final product, and the reduction in the benefits conferred by CCA would give rise to several unacceptable risks/impacts:

- The highly likely risk of EASA (the airworthiness authorities) and MoDs not accepting a downgrade in component/product 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.

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[68] 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.

Corrosion and other issues likely would not appear suddenly, but over time they may affect hundreds of A&D components entered into in-service. Further, potential decreased corrosion protection performance from Cr(VI)-free coatings would necessitate shorter inspection intervals to prevent failures. Flight safety obligations preclude the aerospace industry from introducing inferior alternatives in the production of components and products.

In the purely hypothetical case where decreased or loss of corrosion protection, chemical resistance and wear resistance is introduced to aircraft, the following risk mitigation actions may be required:

- Substantial increase in inspections – both visual checks and non-destructive evaluations, such as ultra-sound crack tests, etc. Some inspections are very difficult or hazardous to perform (e.g. inside fuselage/wing structures). All aircraft using less effective materials in repair/overhaul and/or unproven materials across the operating lifetime of an aircraft would be subject. A very conservative inspection frequency would be set to ensure safety until adequate in-service performance experience is obtained.
- Increased overhaul frequency or replacement of life-limited components. Possible early retirement of aircraft due to compromised integrity of non-replaceable structural parts.
- Whole fleets may be grounded until a repair/replacement plan is in place for the whole aircraft fleet (e.g. grounding Boeing 787 fleet due to battery problems).
- Due to similarity of technologies and aircraft uses, a fleet grounding event in such a scenario could impact many or all aircraft fleets. An 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.

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 Analyse (MSG-3), specifically developed for corrosion. MSG-3 provides a system for Original Equipment Manufacturers (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 chromate-free system cannot be highly rated. Consequentially, a significant reduction to the maintenance interval would be required, potentially cut in half. For cases with no long-term experiences or correlation to in-service behaviour, which is normally the case, a further reduction to the maintenance interval 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 alternatives with equivalent performance to CAA on the affected components This objective cannot be achieved, however, without sufficient testing and flight (or other) data surrounding the use of alternatives. Without such data, the necessary approvals cannot be gained as the safety risk becomes too great, whether related to civil aviation or military aircraft. The corrosion resistance and corrosion inhibition benefits provided by chromic acid anodising are crucial to minimising any corrosion related risks and hence to the manufacture of components in the EEA/UK; if there are no qualified alternatives certified for 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 by spare components (which would run counter to the sectors drive towards increased sustainability).

The reasons why holding increased inventories is not a feasible option compared to maintaining and repairing damage include, but are not limited to, the following considerations:

- If no certified alternative is currently 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 projects/R&D, etc. The inventory costs would also have to be added to product costs and would therefore reduce competitiveness for operations in the EEA/UK.

- The costs of building adequate warehouse facilities in the EEA and the UK would be prohibitive and would not be economically feasible. In the UK, an industrial warehouse without climate control (which would be required for the storage of some A&D inventory) costs around €1000 per m^2 to construct (a conservative estimate). Its assumed here that warehouses that would act as a hub for storing inventory would be around 10,000 m2 as a minimum, given the range of parts that would need to be stored. This implies a total build cost of around £10 million as a minimum, not taking into account the costs of land purchase, site preparation, design, construction, etc. which could easily add a further 25% even after taking into account any potential economies of scale in pricing due to the large size of the warehouse.[69] If such facilities are required at around 100 sites across the EEA and UK (to cover civilian and military requirements), then warehousing costs alone would lead to €1 billion in expenditure. These costs would be on top of the losses in profits that would occur from the need to subcontract manufacture to companies located outside the EEA/UK and the consequent profit losses and increased costs of shipping, etc.

- Facilities do not have enough production capacity to build up multi-year inventories, while also meeting current demand. Even if production capacities could be increased and adequate quantities of standard components be produced, there would be idle inventories for years beyond their need, which would in turn increase product costs for years. Importantly, the need to store this inventory under optimum conditions to avoid corrosion or damage over extended periods of stockpiling, would lead to further increases in costs.

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

- Existing facilities are not sized to store the amount of multi-year inventories required. Companies will need to build/invest in additional secure, high-quality warehouses to store the inventory. However, it is important to recognise that this scenario is not feasible at all for many parts, such as wing and fuselage skins, because these components are not removed from the aircraft; these parts only allow MRO activities in-situ. Therefore, the entire aircraft would need to be transported to a non-EEA country for repair. If the plane is not airworthy, the effort and cost relating to transportation alone (e.g. from Belgium to Egypt) would be overwhelming.

- 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. Furthermore, this would run contrary to the EU's New Industrial Strategy[70], which identifies the A&D industry as one of the industrial ecosystems that requires support to ensure innovation, competition and a strong and well-functioning single market.

- 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 parts in the EEA/UK anymore (if CAA is still required). Consequently, it is clearly not possible to rely on a long-term stock of spare parts that would fit all situations.

- It is impossible to hold a stock of all spare components at every airport. This would affect schedules, especially overnight stops as aircraft cannot be readily repaired and maintained. As a result, these aircraft would not be available for services next day and delays or flight cancellations would likely occur.

- Cost and environmental impacts of managing and disposing of waste components that could not be reused would be high. This seems to be inconsistent with the emphasis on waste reduction as a part of circular economy.

It is 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. Furthermore, for certain types of components, increasing stock inventory is not feasible at all.

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 countries. It can also be expected that future investment in associated industries and technologies will be most efficiently located alongside these activities.

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

Given the above, this scenario was not considered plausible by the OEMs and MROs in particular due to the need for CAA to be followed within a short period of time by either anodise sealing or inorganic finish stripping and/or a primer.

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 and DtBs as design owners to a refused authorisation. They are the companies 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 equipment and risk management measures to enable them to move to the alternative.

As a result, the most plausible scenario for the OEMs drives the most likely non-use scenario for the sector as a whole. The most likely scenario is as follows:

1. EEA and UK suppliers of chromium trioxide and its formulations would be impacted by the loss of sales, with the market relocating outside the EEA/UK. In the short term at least, i.e. 2 – 4 years, this would result in a loss of revenues and profits from sales in the EEA/UK. Over the longer term, as alternatives are certified some of the A&D market for formulated alternatives may return to the EEA/UK, but the extent to which and timeframe are highly uncertain.

2. OEMs directly involved in CAA would move a significant proportion of their manufacturing (if not all) outside the EEA/UK, with the consequent loss of significant levels of turnover and employment. In particular, they would move those manufacturing activities reliant on the use of CAA where there is no qualified alternative or where implementation across suppliers after qualification and certification have been achieved is expected to require several years after the end of the current review period (e.g. 2-4 years after qualification). The losses to the EEA/UK would range from 30% of manufacturing turnover for some sites to 100% of manufacturing turnover at others. There would be a significant loss of jobs directly related to CAA, as well as across other manufacturing activities. On average, responses suggest losses of around 70% of turnover for the affected companies in the EEA/UK. The above response is regardless of whether some warehousing is created in the EEA/UK, as this would only be relevant to smaller parts and components.

3. OEMs who do not carry out CAA treatments themselves would move some of their manufacturing operations outside the EEA/UK due to the need for other production activities to be co-located with key BtP and DtB suppliers (i.e. to form clusters). This would facilitate the integration of manufacturing activities and associated maintenance and repair activities. As a result, there would be losses in turnover and employment associated with these companies also relocating.

4. As OEMs shift their own manufacturing activities outside the EEA/UK, they will have to carry out technical and industrial qualification of new suppliers or 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.

5. In some cases, these newly located supply chains would be developed using DtB (and BtP) suppliers who have moved operations from the EEA/UK to other countries in order to continue supplying the OEMs. As the DtB companies undertake anodising (and other surface treatments) for sectors other than A&D, and using non-chromate based alternatives where these are certified, they 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. For these companies, based on the SEA data and discussions with key design owners, it has been assumed that there would be a 40% loss of turnover. It must be recognised that this level of turnover loss implies that some companies losing such a high percentage of turnover would still be able to cover their fixed costs and to remain financially viable.

6. A significant proportion of the existing BtP companies involved in CAA – estimated at 70% – will cease trading in the EEA as they do not also 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 CAA only until a certified alternative was available or that they would shift to other activities. On average, these companies would lose between 20 - 50% of turnover within the EEA/UK. Overall, the data indicate turnover losses across the BtP suppliers of around 60% for the affected companies in the EEA/UK.

7. MROs will also be severely impacted, and the larger operators indicated that they would move operations outside the EEA, due to the need to maintain vertical integration across the surface treatment processes that they are able to carry out. On this basis, it is estimated that between 30 - 50% of current relevant MRO activities would cease in the EEA/UK. The economic assessment assumes that 45% of turnover would be lost based on the responses of the larger MROs who services a large proportion of the civil aviation fleet.

8. The re-location of MRO activities will have consequent impacts for civil aviation and military fleets, as well as for the maintenance of defence products and aero-derivative products. It would also run contrary to the EU's New Industrial Strategy[71], which identifies the A&D industry as critical to innovation, competitiveness and the single market.

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

10. 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.

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

The justification for this NUS takes into account the following factors. The justification for this NUS takes into account the fact that OEMs and DtBs will not have all components with certified alternatives which have been fully implemented across their supply chains until after 2031.

Although OEMs are working on substitution of CAA, and in several cases expect to be able to phase out its use in the next four to seven years, not all OEMs will have certified alternatives across all their components by September 2032. Many OEMs 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"[72].

As noted previously, because of the complexity of the supply chain, and the close working partnerships that exist, a decision by an OEM or DtB to relocate will result in their suppliers relocating to keep proximity. Such relocation would involve not just CAA, but all associated pre- and post-treatment activities due to the potential for corrosion of unprotected surfaces during transport to another place.

The impacted operations and socio-economic impacts to industry under the non-use scenario will therefore go far beyond the specific processes directly reliant on CAA. **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 CAA 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.

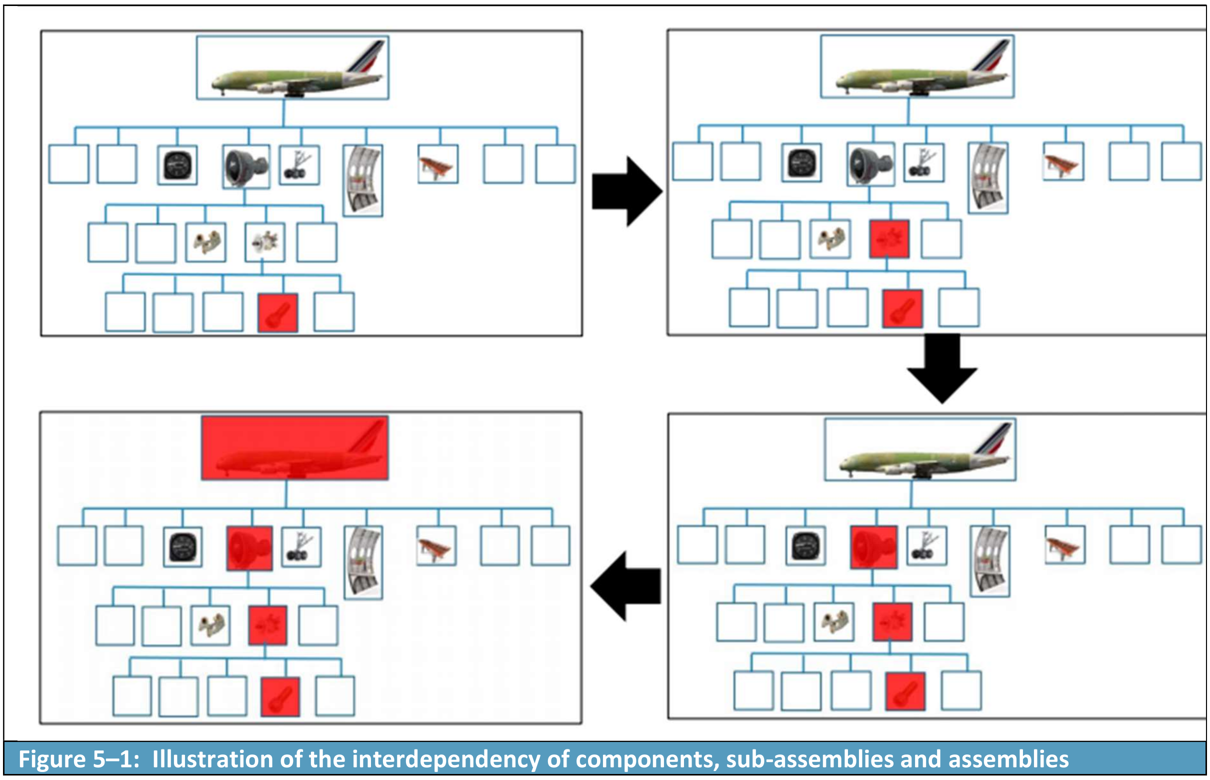

Figure 5–1: Illustration of the interdependency of components, sub-assemblies and assemblies

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[72] 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)

MROs will be similarly affected. It is technically not possible (or economically feasible) to carry out repairs to large components outside the EEA/UK, and then ship it back for reassembly in a final product in the EEA/UK. Apart from the fact that the surface of the component could be damaged during transport, adding to the technical infeasibility of this situation, the very tight turnaround times and budgets are impossible to hold in such a scenario.

Finally, although this is considered the most plausible scenario, OEMs note that the obstacles that would have to be overcome may make it overly optimistic. The infrastructure of the sector is based in part around manufacturing clusters or hubs (see also Error! Reference source not found.**2**), 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 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 hence the OEMs would be likely to cease manufacturing activities until the new industrial facilities were in place and ready to operate outside the EEA/UK.

5.2 Economic impacts associated with non-use

5.2.1 Economic impacts on applicants and formulators

Under the non-use scenario, all suppliers of anodising products would be impacted by the loss of sales of chromium trioxide or of imported formulations containing the chromates for use in anodising.

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 downstream formulators. Over time, as consumption of CT reduces in line with companies' substitution plans, sales and hence revenues will continue to decrease.

No quantitative estimates for these losses are included in this SEA. These impacts are captured in the combined AoA/SEA for formulation.

5.2.2 Economic impacts on A&D companies

5.2.2.1 Introduction

It would be theoretically possible to move CAA activities outside the EEA/UK due to already existing supply chain sites in other countries, for example, the USA, Canada, or China, and to outsource manufacturing as the supply chain is spread around the world.

There are several obstacles to such a scenario, however, which would make this economically unattractive even if it is the most plausible scenario. Firstly, the due diligence principle will continue to apply to the supply chain and would be exacerbated in case of relocation out of EEA/UK. Secondly, when activities are shifted to another site, there is an inevitable phase of technical and industrial preparation and qualification to ensure the sustainability of these activities including assessment of 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, these two aspects are not realistic and would require a huge economic investment that would significantly affect businesses with detrimental economic impacts. As a result, OEMs have indicated that they probably would be forced to stop manufacturing activities until the new industrial facilities and infrastructure are in place and ready to operate outside of the EEA/UK. Given the current levels of civil aviation and anticipated growth, this would be catastrophic for aviation in the EEA/UK and globally.

5.2.2.2 Approach to assessing economic impacts

As noted in Section 1, the ADCR has been created as a sectoral consortium and downstream user members include competitors, which may also act as suppliers to each other; the larger companies also share many of the same BtP and DtB suppliers (an estimated 15-25% overlap in suppliers exists across some OEMs). These interlinkages have been taken into account in the estimation of economic impacts, which have been calculated separately for the OEMs, DtBs, their associated BtP suppliers and MROs.

Two separate approaches have been used to estimate the magnitude of the potential economic impacts. Both are based on responses to the SEA questionnaire, with one taking as its starting point the number of jobs that would be lost while the other considers losses in turnover and what these imply in terms of losses in profits. Both approaches are used as a greater number of responses provided estimates of jobs lost than of the likely impacts on turnover (in percentage or actual terms).

1. **Estimates based on loss of jobs**: The first approach takes as its starting point the number of jobs that would be lost at the sites of SEA questionnaire respondents, based on their most likely response to the non-use scenario. This includes loss of jobs directly linked to use of chromium trioxide 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 (based on 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 of these approaches provide proxy estimates of profit losses based on current levels of employment and turnover. They do not account for foregone future turnover under the continued use scenario due to the inability of the EEA/UK A&D sector to respond to growth in the global demand for air traffic or to increased military and defence spending as a result of either a cessation in manufacturing activities or their relocating outside the EEA/UK.

The two approaches have been applied to account for uncertainty in the data available from the SEA questionnaire responses. Together they provide an interval, with one estimate acting as an upper bound and the other as a lower bound to the economic impacts.

5.2.2.3 Estimates based on loss of jobs (and GVA lost)

The SEA questionnaire collected data on the number of employees who would lose their jobs under the NUS which are directly linked to CAA. Information was also collected on the number of jobs related to pre-treatments and anodise sealing as part of a process flow. Information was also sought on the number of jobs that could be affected due to a cessation of production activities or due to companies moving outside the EEA.

For the purposes of this assessment, we focus on the numbers of jobs that would be lost should CAA activities not be re-authorised, as well as losses stemming from the cessation of other linked surface treatment and manufacturing activities, including the manufacturing and assembly of aircraft and military equipment more generally as direct effect of the non-authorisation of chromic acid anodising.

The job losses reported by respondents to the SEA questionnaire cover 43 sites in the EEA and 21 sites in the UK and have been extrapolated to provide estimates for the expected 180 EEA and 30 UK sites undertaking CAA.

Both sets of figures are presented in **Table 5-2** below, with this including jobs that would be loss directly due to the loss of CAA as well as jobs that would be lost in linked pre- and post-surface treatments and manufacturing of components/or assembly across product lines and/or to the cessation of MRO services, including as a result of companies moving operations outside the EEA.

Across all 210 sites expected to be affected, the losses are estimated at almost 47,000 jobs:

- Around 32,900 jobs at the 180 sites in the EEA, and
- 14,100 jobs at the 30 sites in the UK.

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. Instead, they represent those jobs that are linked to or dependent upon CAA, including downstream machining, manufacturing and assembly activities. In addition, the figures do not include impacts on military MROs, given that these would not necessarily translate to "lost jobs".

Although these figures appear high, they should be seen within the context of the roughly 890,000 employees (2019[73]) within the European A&D sector and taking into account the critical importance of the chromates in CAA and the protection of aluminium and other substrates from corrosion.

It is important to note that these estimates do not assume a cessation of activities across all affected DU companies. In particular, it is assumed that at least one third of the BtP companies undertaking CAA at present and more than half of the DtB companies would continue operations in the EU, either with a reduced number of jobs or by shifting to the manufacture of components for other sectors. In addition, the number of jobs lost at OEMs is only a very small proportion of the total number of jobs at the affected sites. The estimates also exclude the impacts on suppliers of services to the various aerospace and defence companies.

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

Table 5-2: SEA survey responses and extrapolations on numbers of jobs lost under the non-use scenario						
	No. Sites		Job losses for workers undertaking CAA only		Job losses due to a cessation of manufacturing/MRO activities	
	EEA	UK	EEA	UK	EEA	UK
Build-to-print (31 sites)	19	12	177	103	1,155	1,952
Design-to-build (9 sites)	5	4	128	64	1,245	3,915
MROs (5 sites as "only")	4	1	130	5	1,979	495
OEMs (19 sites)	15	4	115	20	11,311	2,106
Total 64 sites	**43**	**21**	**550**	**192**	**15,690**	**8,468**
Job losses - Extrapolation of job losses under the non-use scenario to the estimated 210 sites undertaking CAA treatments						
Build-to-print (143 sites)	130	13	1,211	112	7,903	2,115
Design-to-build (27)	20	7	512	112	4,980	6,851
MROs (15 sites)	10	5	325	25	4,948	2,474
OEM (25 sites)	20	5	153	25	15,081	2,633
Total sites (210)	180	30	2,201	274	**32,911**	**14,072**
Notes: Totals may not exactly match sums of column entries due to rounding						

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 CAA jobs € million		GVA lost per annum due to a cessation of manufacturing/MRO activities - € million	
	EEA	UK	EEA	UK	EEA	UK
Build-to-print (31 sites)	59,964	59,964	10.6	6.2	69.26	117.05
Design-to-build (9 sites)	59,964	59,964	7.7	3.8	74.65	234.76
MROs (5 sites as "only")	85,000	85,000	12.8	0.5	194.93	48.73
OEMs (19 sites)	98,500	98,500	9.8	1.7	961.44	179.01
Total 64 sites (rounded)			40.9	12.2	**1,300**	**579**
GVA losses - Extrapolation of job losses under the non-use scenario to the estimated 210 sites undertaking CAA treatments						
Build-to-print (143 sites)	59,964	59,964	72.6	6.7	474	127
Design-to-build (27)	59,964	59,964	30.7	6.7	299	411
MROs (15 sites)	85,000	85,000	32.0	2.5	487	244
OEM (25 sites)	98,500	98,500	13.0	2.1	1,282	224
Total sites (210)			148.4	18.0	**2,542**	**1,005**

Notes: 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 EEA/UK as available.

Notes: Totals may not exactly match sums of column entries due to rounding

Table 5-4: Operating surplus losses due to a cessation of manufacturing/MRO activities under the Non-Use Scenario

	Total personnel costs associated with lost CAA jobs - € millions per annum		Implied operating surplus losses for lost CAA jobs € millions per annum		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	
	EEA	UK	EEA	UK	EEA	UK	EEA	UK
Build-to-print (31 sites)	6.94	4.04	3.67	2.14	45.29	76.54	23.97	40.51
Design-to-build (9 sites)	5.02	2.51	2.66	1.33	48.82	153.52	25.83	81.24
MROs (5 sites as "only")	7.33	0.28	5.47	0.21	111.62	27.90	83.32	20.83
OEMs (19 sites)	8.12	1.41	1.66	0.29	798.56	148.68	162.88	30.33
Total 64 sites	27.41	8.24	13.46	3.96	1,004.28	406.65	**296.00**	**172.90**
Operating surplus losses - Extrapolation to the estimated 210 sites undertaking CAA treatments								
Build-to-print (143 sites)	47.49	4.38	25.13	2.32	309.88	82.92	163.99	43.88
Design-to-build (27)	20.08	4.39	10.62	2.32	195.28	268.66	103.34	142.17
MROs (15 sites)	22.95	1.77	9.07	0.70	349.29	174.65	138.04	69.02
OEM (25 sites)	8.65	1.41	4.39	0.72	850.59	148.47	431.33	75.29
Total sites (210)	**99.16**	**11.94**	**49.21**	**6.05**	1,705.04	674.70	**836.69**	**330.36**

Notes: 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 EEA/UK as available.

Notes: Totals may not exactly match sums of column entries due to rounding

These predicted job losses have been combined with 2018/19 Eurostat data on Gross Value Added (GVA) per employee to the EU/UK economy as part of calculating the economic losses under the non-use scenario. The GVA used by role is reported in **Table 5-3** above. The GVA data presented earlier in **Table 4–2** is used to derive a weighted average for build-to-print and design-to-build companies due to the number of SEA respondents indicating multiple NACE codes as being relevant. The GVA figures used for OEMs and MROs are specific to their NACE codes. The resulting estimated losses in GVA are given in **Table 5-3**.

The estimated losses in GVA equate to:

- €2,542 million per annum for the 180 EEA sites; and
- €1,005 million per annum for 30 UK sites

respectively due to the cessation of CAA and related pre- and post-surface treatments and related assembly and manufacturing activities.

In order to convert these GVA losses to an estimate of lost operating surplus (as a measure of lost profits), personnel costs associated with 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 all BtP and DtB sites; the Eurostat figures on personnel costs for OEMs and MROs are adopted in these cases.

The estimated operating surplus losses equate to:

- €837 million per annum across the 180 EEA sites; and
- €330 million per annum across the 30 UK sites.

5.2.2.4 Estimates based on lost turnover

The SEA questionnaire also asked companies to provide information on the impacts that a refused authorisation would have on turnover/revenues. Fewer companies provided a response to this question, although the information provided together with the most likely NUS for the DtBs, OEMs and MROs enables estimates of likely percentages of turnover lost by role to be developed. These estimates take into account the number of companies indicating that they also carry out activities other than chromate-based CAA for the aerospace sector, as well as surface treatment and other processes for other sectors.

Total revenue estimates are based on Eurostat data by NACE code with weighted averages used for BtPs and DtBs and NACE code specific data used for OEMs and MROs. Note that the weighted averages exclude micro-enterprises as few suppliers to the sector will fall into this size category. Gross operating surplus losses are then calculated using Eurostat data by NACE code. The resulting losses in profits or GOS are given in **Table 5-5**, with these equating to around €870 and €131 million per annum for the EEA and UK respectively.

Table 5-5: Turnover and GOS losses under the Non-Use Scenario (based on Eurostat GOS data)					
	% turnover lost	Revenues lost per annum € millions		GOS losses per annum € millions per annum	
		EEA	UK	EEA	UK
Build-to-print (31 sites)	60%	779	492	98	62
Design-to-build (9 sites)	40%	137	109	17	14
MROs (5 sites as "only")	60%	2,186	547	214	54
OEMs (19 sites)	70%	749	200	72	19
Total 64 sites		3,851	1,348	402	149
Extrapolation to the estimated 180 EU and 30 UK sites undertaking CAA					
Build to print (143 sites)	60%	5,329	533	674	67
Design to build (27 sites)	40%	547	191	69	24
MROs (15 sites)	60%	321	160	31	16
OEM/Tier 1 (25sites)	70%	999	250	95	24
Total sites (210)		7,195	1,134	870	131
Notes: 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 EEA/UK as available. **Notes: Totals may not exactly match sums of column entries due to rounding**					

5.2.2.5 Comparison of the profit loss estimates

For comparison purposes, the two approaches result in the following upper and lower bound estimates of losses in gross operating surplus/profits:

- Losses in GVA and hence gross operating surpluses:
    - Losses of €837 million per annum for the EEA
    - Losses of €330 million per annum for the UK

- Losses in turnover and hence gross operating surpluses:
    - Losses of €870 million per annum for the EEA
    - Losses of €131 million per annum for the UK

The two sets of figures are used here to provide lower and upper bound estimates of losses in producer surplus.

Offsetting profit losses and impacts on rival firms

Associated with the above losses would be the premature retirement of some 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, and 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.

Consultation indicates that a shift to an alternative form of anodising is likely to require investment in new equipment for some sites and repurposing of existing equipment for other sites, depending on the alternative. For some companies there may also be a need to run two lines to accommodate customers (i.e. OEMs or DtBs) with different requirements. However, it is not possible at the sectoral level to determine what level of new investment would be required. As a result, no costs associated with investment in new equipment are included here. Where equipment has been made redundant due to successful substitution efforts, consultees indicate that it has not been able to repurpose it due to its previous use having been based on the chromic acid; this reduces market demand for refurbishment.

Given the potential scale of impacts on aerospace manufacturing activities from a refused Authorisation, particularly if more than one use fails to be authorised, any possible market for redundant equipment is likely to swamped by the number of sites ceasing CAA and related processes (e.g. pre-treatment baths and anodise sealing equipment as a minimum). It is also not possible to estimate the magnitude of the potential scrappage value given the sector-wide effects that would occur. As a result of the above factors, the analysis presented here does not include any offsetting of profit losses against the potential resale or scrappage value of the sector's tangible EU and UK assets.

Nor is it possible to estimate the costs to the OEMs of moving their own and their supply chains' production activities outside the EU. This would include identifying new locations, constructing new facilities, moving transportable capital assets and undertaking any site clean-up or remediation at EU facilities.

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 anodising 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 members of the ADCR include competitors; they also act as suppliers to each other, and the larger companies share many of the BtP and DtB suppliers (an estimated 15-25% overlap in suppliers based on lists of suppliers provided to the consultants and the views of industry experts). In addition, relationships between the OEMs and DtB companies with their suppliers 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 specific processes, parts and components. As a result, rival suppliers cannot readily step in and replace their production activity.

Economic losses are therefore based on consideration of losses in operating surplus/profits only. These have been estimated over three time periods in line with SEAC's new guidance for those cases where there are not suitable alternatives available in general. Discounted losses over 1, 2, 4, 7 and 12 years are given in **Table 5-6**.

As discussed earlier, these losses are based on Eurostat turnover figures for 2018 (most recently available). 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 given the importance of the EEA in the global manufacture of aerospace and defence products, as highlighted by the publicly available forecasts from Airbus and Boeing of the demand for new aircraft cited earlier.

Table 5-6: 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	
	EEA	UK	EEA	UK
1-year profit losses (2025)	870	131	837	330
2-year profit losses (2026)	1,640	247	1,578	623
4-year profit losses (2028)	3,157	476	3,037	1,199
7-year profit losses (2031)	5,220	787	5,022	1,983
12-year profit losses (2036)	8,162	1,231	7,852	3,100

5.2.2.6 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 EU /UK, leading to a second wave of negative impacts on the EEA market. These impacts have not been quantified here but would include as a minimum:

- Cancelled future orders and loss of contracts for new products if supplies are significantly interrupted;
- Customer penalties for late/missed delivery of products;
- Extended durations of maintenance, repair and overhaul operations for products in service leading to e.g. “aircraft on the ground” (AoG) and other out-of-service final products, with consequent penalties and additional impacts on turnover;
- Increased logistical costs; and
- Reputational damages due to late delivery or cancelled orders.

5.2.3 Economic impacts on competitors

5.2.3.1 Competitors in the EEA/UK

This combined AoA-SEA has been prepared so as to enable the continued use of CT in anodising across the entirety of the EEA and UK aerospace and defence sectors. It is non-exclusive in this respect. It has been funded by the major (global) players in the EEA and the UK, with additional support provided by their suppliers and by MoDs, to ensure the functioning of EEA and UK supply chains for their operations.

As a result, there should be no economic impacts on competitors, especially as the major global OEMs and DtBs act as the main design owners, which determine the ability of all suppliers to move to an alternative. As design owners, the validate, qualify and certify components with new alternatives and gain new approvals (e.g. a new type approval from EASA or an approval from an MoD). Once these design owners have certified new alternatives in the manufacture of parts and components, these alternatives will be implemented throughout their value chain.

5.2.3.2 Competitors outside the EEA/UK

Under the NUS, it is likely that a significant proportion of the A&D supply chains reliant on CAA in the manufacture of parts would move outside the EEA/UK, creating new supply chains as part of this process. This would be to the advantage of competitors outside the EEA/UK and to the detriment of existing EEA/UK suppliers but to the advantage of competitors outside the EEA/UK. Competitors would gain a competitive advantage due to their ability to continue to undertake CAA 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' manual under airworthiness and military safety requirements. Where maintenance or overhaul activities would require CAA, 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 dis-assembled and transported outside EEA/UK for repairs, with dramatic financial and environmental impacts.

Should MRO facilities be relocated outside the EEA/UK, airlines will also experience additional delays to routine aircraft maintenance due to transport requirements and capacity constraints at MRO facilities outside the EU. Indeed, it may take some time to build up capacity to accommodate additional demand from EU-based operators, potentially resulting in a large number of aircraft being grounded until maintenance checks can be completed.

As a result, airlines would need to have additional spare components/engines/planes to account for the added time that aircraft would be out of commission due to extended MRO times. Airports may also have to build up large inventories of spare components to replace products (including e.g. Spare engines, aircraft)that currently can be repaired, with this going against the desire to ensure sustainability within the sector.

The need to have maintenance carried out outside the EEA/UK would also lead to additional operational costs being incurred through increased fuel use. Small planes (e.g. business jets) that do not have the fuel capacity or airworthiness approvals for long haul flights would need to make multiple stops enroute to non-EEA MRO facilities and back to the EEA/UK. The impacts for larger aircraft would also be significant. For example, flying from Western Europe to Turkey or Morocco adds approximately 3,000 km each way and for a Boeing 737 this would take slightly less than four hours. For an airline which has 50 aircraft requiring an annual "D check" (heavy maintenance inspection of the majority of components, carried out every 6-10 years), this would involve 400 hours of flight time (return trip) or 20 days of foregone revenue, equivalent to €1.4 million. Scaling this up to the EU passenger aircraft fleet, which stands at approximately 6,700, suggests lost revenues in the tens of millions per annum just due to the need to have around 700 aircraft which require a "D check" each year. Using the above estimate for a fleet of 50 aircraft, this would amount to €20 million in revenue lost by European airlines for "D checks" alone. This figure excludes the costs of fuel and personnel, as well as the fact that additional flights bring forward maintenance interval requirements and impact on the total lifespan of an aircraft.

In addition, based on a leasing cost for a large passenger jet of around $500,000/month in 2021 (€421,500, £362,250)[74], 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[75] 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** below. Similar growth is expected in air freight transport. If this growth path were to be achieved, by 2036 the air transport industry would contribute 15.5 million in direct jobs and $1.5 trillion of GDP to the world economy. Once the impacts of global tourism are taken into account, these numbers could rise to 97.8 million jobs and $5.7 trillion in GDP.

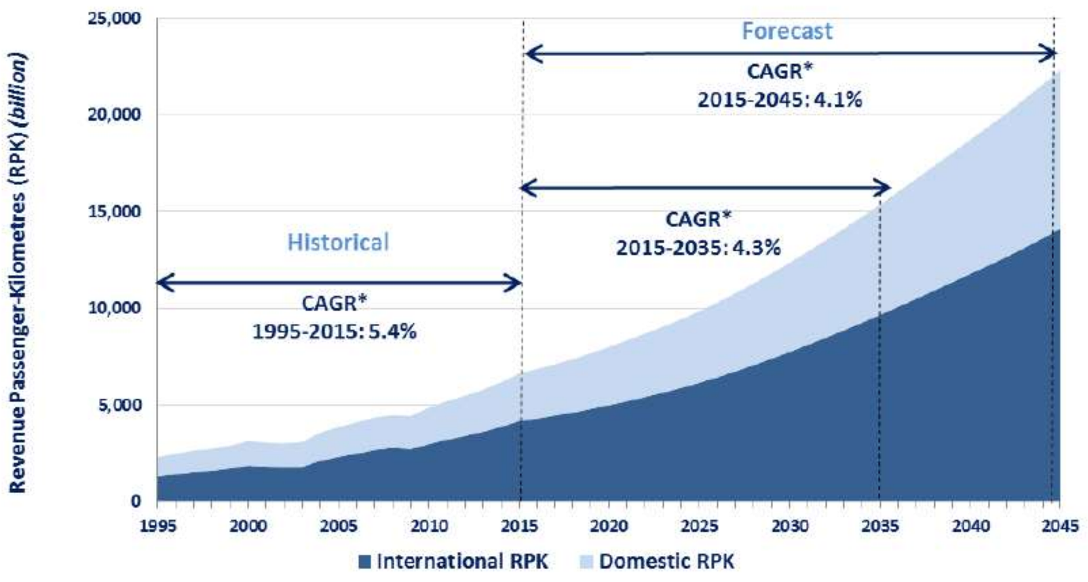

Figure 5-2: Forecast compound annual growth rates – Revenue Passenger-kilometres

Post Covid-19, projections are for a lower rate of increase in air traffic, with Airbus suggesting a growth rate between 2019 and 2040 of around 3.9% CAGR.[76] The impact of COVID has resulted in an expected

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

[75] https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf

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

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[77] (covering inter-regional and intra-regional/domestic) for the period between 2018 to 2038.

This level of growth in EU air traffic, together with the jobs and contributions to GDP that it would bring, could be impacted under the NUS. In particular, impacts on the ability of MROs to undertake repairs and carry out maintenance where this would require the use of chromium trioxide-based anodising to ensure the continued airworthiness of aircraft could impact on the realisation of such growth. No quantitative estimate of the level of impact can be provided, but it is clear that the closure of EU-based MRO operations in particular could impact on the availability of aircraft and hence passenger and freight transport until substitution has taken place as expected over the requested review period (unless airlines responded by buying more planes 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 those military forces; and impacts on companies acting as suppliers to military forces.

Three national Ministries of Defence (MoDs – two in the EEA and the UK MoD) have provided direct support to the ADCR out of the concern that the non-Authorisation of CAA could have a negative impact on their activities. In addition, MROs providing services to a further two MODs located in the EEA have supported the ADCR so as to ensure that they are able to continue to maintain and repair military aircraft, ships, and ground-based systems into the future. The implications of having to cease these activities are significant. Military equipment which could not be maintained to appropriate safety requirements would have to be removed from service, with this also impacting on internal security services and emergency services. Not only would this impact on the availability of key equipment in the case of a military emergency, but it would also affect the size of potential operational forces.

It is also worth noting that Governments are likely to be reluctant to send military aircraft to MRO facilities located in non-EU countries, although 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.

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).[78] 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

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

[78] https://ec.europa.eu/commission/presscorner/detail/en/IP_22_4595

start-ups. Some of these gains may not be realised if the main EU defence OEMs have to divert resources into shifting part of their manufacturing base outside of the EEA.

Companies in the European defence sector represent a turnover of nearly EUR 100 billion and which 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, and investments in the defence sector have a significant economic multiplier effect in terms of creation of spin-offs and technology transfers to other sectors, as well as the creation of jobs. For example, according to an external evaluation of the European Union's Seventh Framework Programme, through short-term leverage effect and long-term multiplier effects each euro spent by the Seventh Framework Programme (FP7) generated approximately an additional €11 billion of estimated direct and indirect economic effects through innovations, new technologies and products.[79] If the manufacture and servicing of military aircraft and other derivative defence products were to move out of the EEA/UK under the NUS, as indicated by OEMs and Design to Build companies as the most likely response, then these multiplier effects would be lost to the EEA economy. In addition, the ability if 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 extend to new products.

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 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 5-7 provides a summary of the economic impacts under the non-use scenario.

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[79] https://www.evropskyvyzkum.cz/cs/storage/bf5134fec407f6e005288c0e2631ad232c38c013?uid=bf5134fec407f6e005288c0e2631ad232c38c013

Table 5-7: Summary of economic impacts under the non-use scenario over the requested Review Period (12 years, @ 4%)

Economic operator	Quantitative	Qualitative
Applicants	• See formulation SEA	Not assessed
A&D companies	• Annualised lost profits: ○ EEA: €837 – 870 million ○ UK: €131 – 330 million • 12-year lost profits: ○ EEA: €7,852 – 8,162 million ○ UK: €1,231 – 3,100 million	Relocation costs, impacts on R&D, impacts on supply chain coherence, impacts on future growth in the sector
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 • Impacts on military forces' operational 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

The most plausible non-use scenario in the event of a non-renewal of the Authorisation to use chromates inside the EEA - even if it may not be practical and would involve huge levels of investment - would be to shift the activity involving use of the chromates to another country (outside the EEA or UK).

Under this scenario, as noted above, the environmental impacts would be real and the effects enormous. If manufacturing activities using chromates and not using chromates are separated on both sides of the European border, huge logistics and transport related requirements would have to be introduced with dramatic impacts on the A&D sectors' environmental footprint.

For MRO activities, each time an aircraft would need a minor repair requiring a component be treated by CAA, it would force the manufacturer to go to a non-European site. In the case of a major repair, would become stranded or, less likely, would have to be dis-assembled for transport to a non-European site. Some stranded final products would become obsolete prematurely, due to the lack of the parts needed for their maintenance and repair. This would go against the principles underlying the Circular Economy and the sustainable use of raw materials, by limiting the ability of the sector to repair and re-use components and assemblies.

Today, the civil aviation industry strives to develop new technologies to reduce the amount of CO_2 emissions by 15 - 20% on each generation of in-service aircraft (make aircraft movements emission-free), since it is well aware that aviation continues to grow significantly.

Even despite the COVID-19 pandemic that represents an unprecedented crisis and has severely affected air traffic and had high negative impacts on the whole civil aviation industry, aviation is expected to double in the next 20 years. Consequently, a refused authorisation renewal would lead to aircraft manufacturing and MRO activities involving chromate uses to move outside the EEA. In addition to the socio-economic consequences this would have, the drastic increase in CO_2 emissions, would outweigh all the benefits achieved by aviation efforts to reduce fuel consumption and CO_2 emissions of in-service aircrafts.

The non-use scenario would also result in some existing aircraft and equipment becoming redundant prematurely; due to the lack of the components needed for their maintenance and repair. This outcome would work against the Circular Economy and the sustainable use of raw materials, by limiting the ability of the sector to repair and re-use components and products.

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 64 sites in total.

Direct job losses will impact on workers at the site involved in CAA and linked pre-treatment and post-treatment processes, as well those involved in subsequent production 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 due to the magnitude of the impacts across the A&D sector, it may be difficult for workers to find another job (especially as there may be a skill mismatch if there are large scale levels of redundancies).

Estimates of the direct job losses that would arise at downstream users' sites under the NUS were presented above. For ease of reference, the totals are repeated in **Table 5-8** below. The size of these figures reflects the importance of chromic acid anodising to the production of aluminium and other parts, as well as to maintenance and repairs of such parts at a subset of MRO facilities. No consideration is given to job losses at sub-contractors providing services such as cleaning, site maintenance, etc. to the BtPs, DtBs, MROs and OEMs.

As context, the civil aeronautics industry alone employees around 405,000 people in the EU, with the defence sector employing more than 500,000 and supporting a further 1.2 million[80]. The figures in Table 5-8 indicate that approximately 32,900 of these aerospace and defence company jobs could be in jeopardy under the NUS. Similarly, around 14,100 jobs could be lost in the UK.

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[80] https://www.eudsp.eu/event_images/Downloads/Defence%20Careers%20brochure_1.pdf

Table 5-8: Predicted job losses in aerospace companies under the NUS		
Role	Total direct job losses due to cessation of manufacturing activities or relocation under the NUS	
	EEA	UK
Build to print (143 sites)	7,903	2,115
Design to build (27 sites)	4,980	6,851
MROs (15 sites)	4,948	2,474
OEM/Tier 1 (25sites)	15,081	2,633
Total sites (210)	32,911	14,072
Notes: Totals may not exactly match sums of column entries due to rounding		

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[81]). 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 that varies according to the mean duration of unemployment. These vary by country, with the mean duration of unemployment weighted by the number of employees for each country relevant to aerospace and defence sector productions sites varying from 7 months to 1.6 years.

These figures are combined with the ratio of social costs per job loss provided in Dubourg (2016) and annual wages to calculate the social costs per lost job. Data were collected in the SEA questionnaire on the average salary for workers involved in the use of the chromates. The typical range given is from €30k to 50k, rising to an average maximum of around €76k, across all 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 will underestimate the average salary given that A&D jobs in the prime OEMs and DtB companies are higher paid than those in other industries.

The resulting estimates of the social costs of unemployment are given in **Table 5-9** based on consideration of the geographic distribution Article 66 notifications and the location of suppliers to the ADCR's OEMs and DtB companies, as well as MROs. The social costs are estimated at €3.86 billion or the EEA countries and around €1.2 billion for the UK.

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[81] 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

Table 5-9: 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 (€)
France	8,228	1,113,050,400
Poland	3,291	330,052,800
Italy	2,962	383,001,696
Germany	5,496	609,825,216
Spain	2,962	353,928,960
Czech Republic	1,827	213,579,274
Netherlands	889	89,114,256
Sweden	1,827	173,825,467
Romania	329	33,567,072
Ireland	329	34,409,760
Hungary	329	38,623,200
Malta	329	28,510,944
Norway	329	38,201,856
Belgium	905	117,028,296
Finland	905	83,039,880
Portugal	329	39,746,784
Slovakia	329	49,297,248
Austria	329	33,847,968
Bulgaria	329	36,937,824
Denmark	329	24,578,400
Lithuania	329	38,623,200
Total EEA	**32,911**	**3,862,790,501**
United Kingdom	14,072	1,176,419,200
Total	**46,983**	**5,039,209,701**
Notes: Totals may not exactly match sums of column entries due to rounding		

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.

Under the NUS, there could be significant wider impacts on jobs given the likelihood that some of the largest players in the EEA/UK aerospace and defence sector would relocate their activities elsewhere with a partial or full cessation of manufacturing in the EEA/UK.

A UK Country Report on the "Economic Benefits from Air Transport in the UK" produced by Oxford Economics (2014) indicates the following with respect to the aerospace sector's contribution to UK employment in 2012:

- Indirect employment effects: 139,000 jobs implying a multiplier effect of 1.36 indirect jobs for every direct job;

- Induced employment effects: 86,000 jobs implying an additional multiplier effect of 0.84 induced jobs for every direct job.

Indirect employment effects will to a degree be captured by the estimates of lost jobs presented in Table 5-9 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[82] quotes an employment multiplier of between 2.2 to 2.4, with this covering both indirect and induced employment effects. The sector is identified as bringing a major contribution to the wider economy.

These combined multiplier effects may be regionally significant. The European Aerospace Cluster Partnership[83] has members located in over 44 aerospace clusters across 18 countries. **Figure 5-3**Error! Reference source not found. below is a "snip" taken from their website highlighting the location of these different hubs across the EU and UK, to provide an indication of where effects may be experienced at the regional level. As will be appreciated from this figure, the relocation of the industry outside the EEA/UK could have severe social impacts including higher levels of unemployment resulting in long term impacts on mental health and other social factors.

Under the non-use scenario, the economic impact on each region could have severe consequences. For example, Aerospace Wales consists of over 180 members which employ 23,000 employees with a turnover of over £6.5 billion in Wales, while the Andalucía Aerospace Cluster has over 37 members, 16,000 employees with over €2.5 billion turnover (See Annex 2). Both of these clusters are an essential part of the local economy.

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[82] 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

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

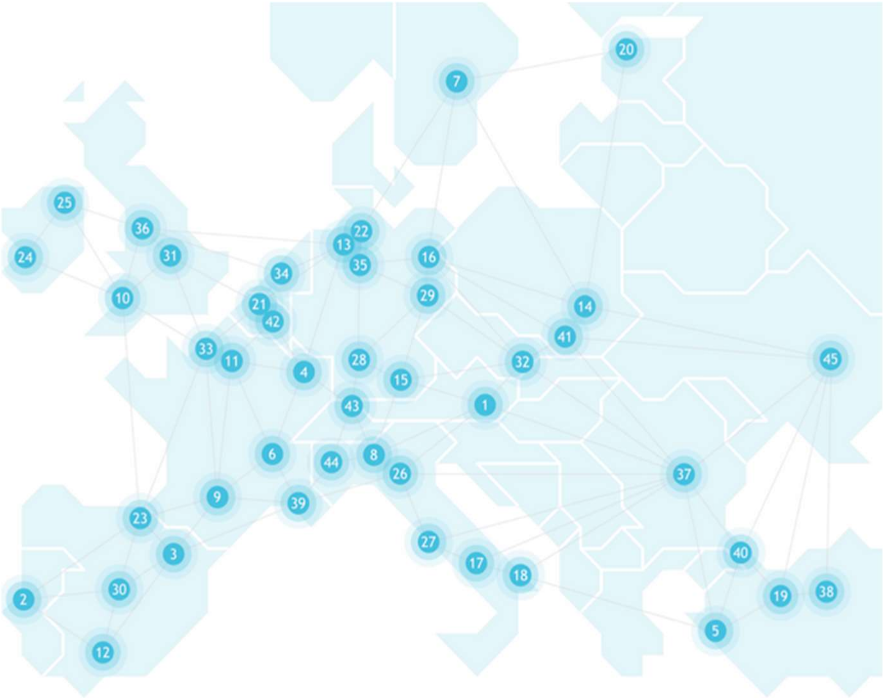

Figure 5-3 Aerospace clusters across Europe
Source: https://www.eacp-aero.eu/about-eacp/member-chart.html

5.4.2.2 Air transport multiplier effects

A 2019 "Aviation Benefits Report"[84] produced by a high-level group formed by the International Civil Aviation Organisation (ICAO) provides an assessment of the economic impacts of the aviation sector. These are linked to its direct impact as well as indirect, induced and catalytic effects. At a regional level, it is estimated that air transport supports 12.2 million jobs in Europe. 2.6 million of these jobs are direct within the aviation sector, with the remaining 9.6 million stemming indirectly from the aviation sector or relating to induced or catalytic effects.

Clearly not all these jobs would be impacted under the NUS, although some impact would be expected should there be reductions in the number of flights, increased delays and other effects from the loss of EEA/UK based MRO activities in particular.

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

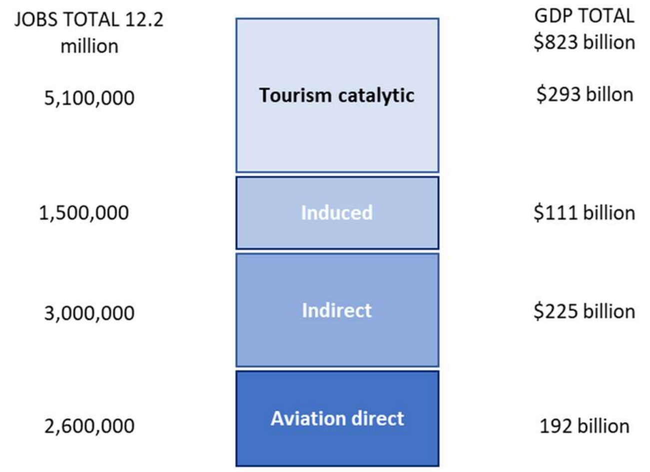

Figure 5-4: Aviation related multiplier effects

Based on: **https://www.icao.int/sustainability/Documents/AVIATION-BENEFITS-2019-web.pdf**

The potential employment losses associated with a decline in European aviation can be seen by reference to the impacts of COVID-19[85]. A "COVID-19 Analysis Fact Sheet" produced by Aviation Benefits Beyond Borders reports the following:

- A reduction from 2.7 direct aviation jobs in Europe supported pre-COVID to 2.1 million jobs post-COVID (i.e. at the end of 2021); and

- 13.5 million jobs in supported employment pre-COVID in Europe to 8.1 million at the end of 2021.

Although one would not expect the losses in supported employment (i.e. indirect, induced and catalytic effects) to be as great, it is clear that a disruption to civil aviation could have significant employment impacts.

5.4.3 Summary of social impacts

In summary, the social impacts that would arise under the NUS include the following:

- Direct job losses:
    - Around 32,900 jobs in the EEA due to the loss of CAA, linked treatment process and assembly or manufacturing activities, and
    - Over 14,070 jobs in the UK due to the loss of CAA, linked treatment process and assembly or manufacturing activities;

- Social costs of unemployment:
    - €3.86 billion for the EEA, and
    - €1.2 billion for the UK;

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

- Indirect and induced unemployment at the regional and potentially 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 5-10 sets out a summary of the societal costs associated with the non-use scenario. Figures are provided as annualised values and as present values 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 25-30% for the full 12-year period as design owners work continues towards development, testing, qualification, validation, certification, and industrialisation of alternatives.

Table 5-10: 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**
Producer surplus loss due to ceasing the use applied for: Impacts on applicants - Lost profits EEA - Lost profits UK Impacts on A&D companies: - Lost profits EEA - Lost profits UK	Applicants: Not estimated here, see formulation SEA A&D companies EEA: €1,578 – 1,640 million UK: €247 – 623 million	Applicants: Not estimated here, see formulation SEA A&D companies EEA: €837 – 870 million UK: €131 – 330 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[1]	EEA: €3,863 million UK: €1,176 million	EEA: €1,931 million UK: €588 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	EEA: €5,441 – 5,503 million UK: €1,423 – 1,799 million	EEA: €2,768 – 2,801 million UK: €719 – 918 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 EU	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 CAA, such as the energy sector (e.g. use on turbines including wind turbines) Impacts on emergency services and their ability to respond to incidents Impacts on cargo transport	

1) Estimated using the approach set out by Dubourg
2) Totals have been rounded

6 Conclusion

6.1 Steps taken to identify potential alternatives

Potential alternatives to Cr(VI) for anodising should be “generally available”[86].

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 anodising are shown in **Figure 6-1:**

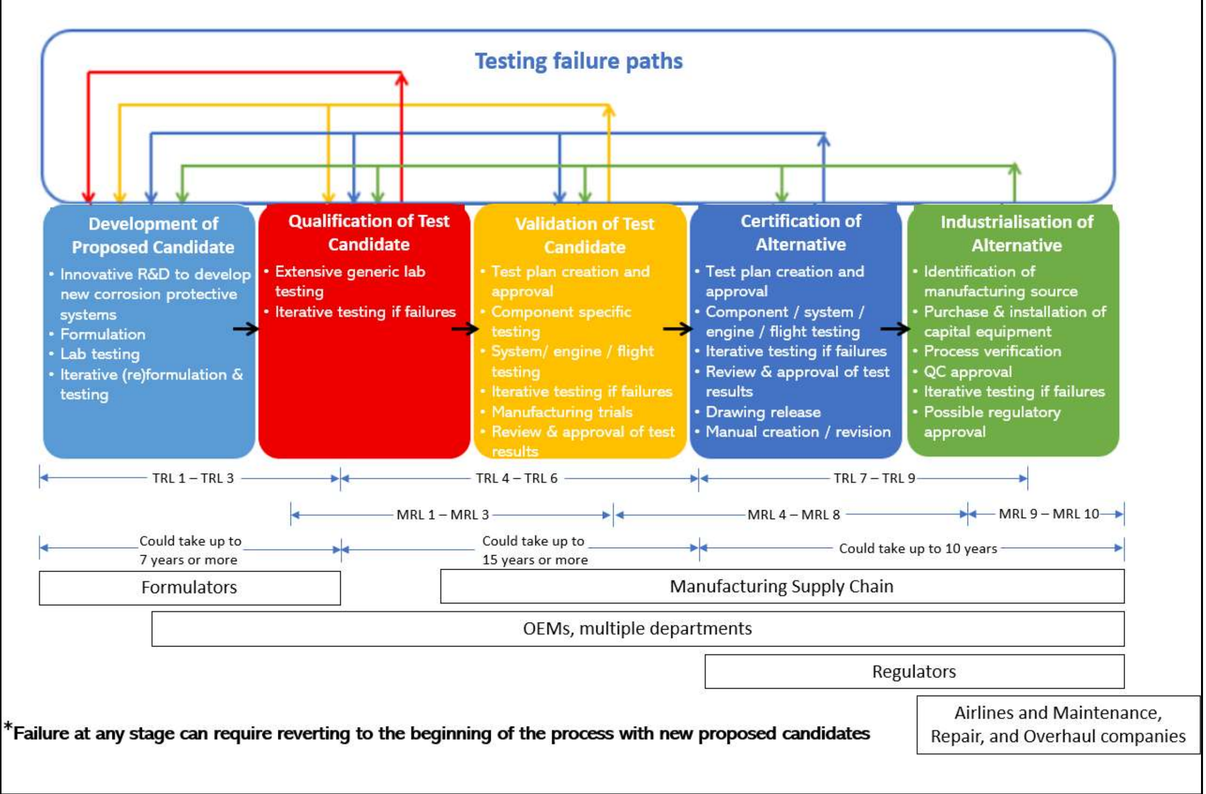

Figure 6-1: Schematic showing the key phases of the substitution process
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note that failures may not become apparent until a late stage in the process.
Source: Adapted from “Use of strontium chromate in primers applied by aerospace and defence companies and their associated supply chains, Application for Authorisation 0117-01, GCCA (2017)

Activities undertaken include:

- Development of test alternatives in laboratory environments up to TRL 6;
- Qualification of test alternatives and suppliers including:

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[86] 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)]

  - Modification of drawings;
  - Updating specifications;
  - Introduction of new processes to suppliers; and
  - 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 anodising. Individual members often have multiple substitution plans within anodising, reflecting the complexity of different components to be treated, the various substrates, and the different performance resulting from test candidates in these different situations. While there have been successes, with some members having been able to implement alternatives to Cr(VI) in certain limited situations and for certain substrates, thereby reducing their Cr(VI) usage, many technical challenges remain.

As discussed in Section 3.7.2 and shown in **Figure 6-2** of the 47 distinct substitution plans for anodising assessed in this combined AoA-SEA , 15% of them are expected to have achieved MRL 10 by September 2024. MRL 10 is the stage at which it is expected production will be in operation and there will be a significant reduction in Cr(VI) use for the components covered in that substitution plan.

The proportion of substitution plans that are expected to achieve MRL 10 is then expected to progressively increase to 51% in 2028, 68% in 2031, and 94% in 2036.

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 significant proportion are not expected to have achieved MRL 10 and are expected to be predominantly at the certification or industrialisation stages, with some substitution plans at earlier stages. For these substitution plans (which are from several member companies), there is still expected to be a need for the use of Cr(VI).

As a result of the individual members' substitution plans summarised above, **the ADCR requests a Review Period of 12 years for the use of Cr(VI) in anodising**.

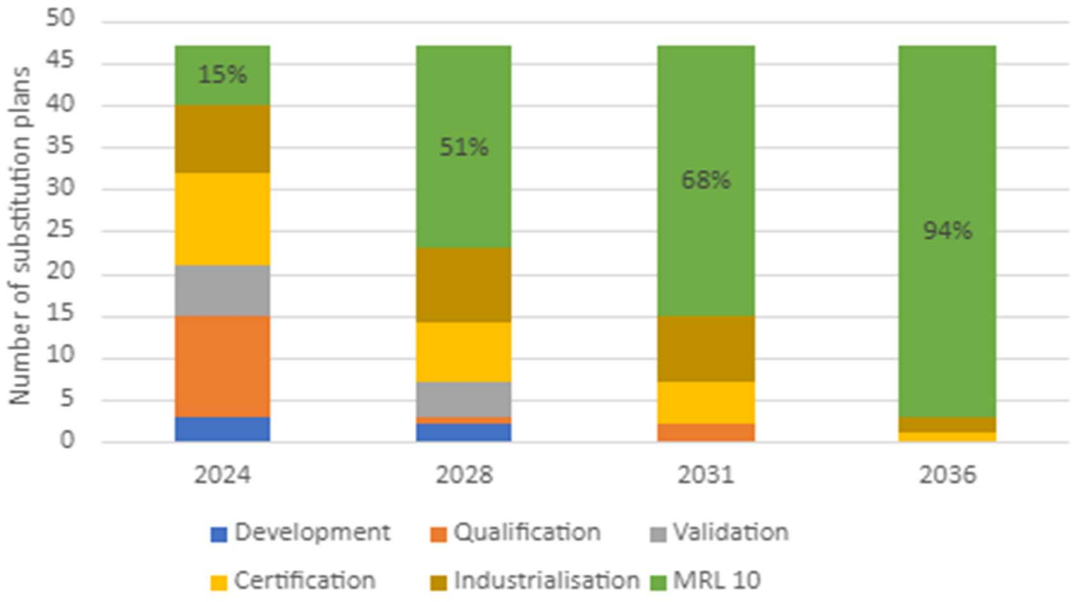

Figure 6-2: Expected progression of substitution plans for the use of Cr(VI) in anodising, by year. The vertical axis refers to number of substitution plans (some members have multiple substitution plans for anodising). The percentage value shown on each of the green bars indicates the proportion of substitution plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which there is expected to be a significant reduction in Cr(VI) usage.

Source: RPA analysis, ADCR members

6.3 Comparison of the benefits and risk

Table 6-1 summarises the socio-economic benefits of the continued use of Chromium trioxide for anodising by companies in the aerospace and defence sector. Overall, net benefits of between ca. €5.40 - 5.50 billion for the EEA and €1.42 - 1.80 billion for the UK (Net Present Value social costs over 2 years/risks over 12 years, 4% discount) can be estimated for the continued use scenario. These figures capture continued profits to A&D companies and the social costs of unemployment. They also include the monetised value of the residual risks to workers and the public via the environment (estimated at €1.83 million and €0.47 million for the EEA and UK respectively over 12 years).

As can be seen from **Table 6-1**, the ratio of societal costs to the monetised value of the residual health risks is greater than 2,975 to 1 under lower bound assumptions on profit losses.

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 – CT substance sales	Losses in profits from reduced sales of the chromate substances and associated formulations. Losses quantified in the Formulation SEA	Substance imported/risks of formulation covered in formulation SEA	
Monetised profit losses to A&D companies	EEA: €1,578 – 1,640 million UK: €247 - 623 million	Monetised excess risks to directly and indirectly exposed workers, taking	EEA: €1.31 million UK: €0.22 million

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	
		into account reductions in risk due to conditions placed on continued use	
Social costs of unemployment	EEA: €3,863 million UK: €1,176 million	Monetised excess risks to the general population, taking into account reductions in risk due to conditions placed on continued use	EEA: €0.52 UK: €0.25
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: €5,439 – 5,501 million ○ UK: €1,423 – 1,799 million - Ratio of societal costs to risks: ○ EEA: 2,975 : 1 to 3,009 : 1 ○ UK: 3,042 : 1 to 3,844 : 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, the critical corrosion protection, chemical resistance, layer adhesion, layer thickness and wear resistance benefits associated with CAA would be lost to aerospace and defence downstream users in the EEA/UK

↓

Due to certification and airworthiness requirements, downstream users in the A&D value chain would be forced to undertake CAA activities outside the EEA/UK or shift to suppliers outside of the EEA/UK

↓

OEMs would shift production and assembly activities outside the EEA/UK as it would be too inefficient and costly to transport parts and assemblies for CAA only

↓

DtB suppliers may have more flexibility and be able to shift only part of their production activities outside the EEA/UK resulting in the loss of profits and jobs

↓

BtP suppliers in the EEA/UK would be forced to cease CAA and linked treatments, leading to loss of contracts and jobs due to relocation of customers outside the EEA/UK

↓

MROs would have to shift some of their activities outside the EEA/UK, where CAA is an essential part of maintenance, repairs and overhaul activities

↓

Relocation of MRO activities outside the EEA/UK would cause significant disruption to the A&D sector itself

↓

Ministries of Defence would face logistical difficulties in maintaining aircraft and other equipment, severely impacting on mission readiness. Service agreements would need to be reached with non-EEA countries

↓

Civil aviation, passengers, freight shippers and emergency services would face reduced flight availability and routes, as well as increased costs

Overall, it is clear that the benefits of the continued use of CT in anodising activities significantly outweigh the residual risks from continued use.

Three further points are relevant. **Firstly, the use of the chromium trioxide in anodising is required (and may be required beyond 12 years) to ensure the operational capabilities of the military and the ability to comply with international obligations as partner nations at the EU level and in a wider field, e.g. with NATO.**

Secondly, the requirements of the ADCR members – as downstream users - have been carefully identified and analysed, taking as the starting point the parent authorisations and the substance-use combinations covered by these. Over the lifetime of the ADCR consortium, the number of uses identified as requiring authorisation and the number of OEMs and downstream users supporting each use has decreased (including the continued need for use of the different chromate substances), to ensure that authorisation is only sought for those cases where there is no substitute that is fully qualified and certified as per stringent airworthiness requirements and industrialised by all members and within their supply chains. The continual re-visiting of supply chain requirements fed into the narrowing of the substance-use combinations requiring re-authorisation compared to the original applications for authorisation.

Finally, the non-use scenario would involve the relocation of economically and strategically important manufacturing processes. This would be in contradiction to the EU policy on "Strategic dependencies and capacities", which highlights the need to minimise such dependencies where they could have a significant impact on the EU's core interests, including the access to goods, services and technologies.[87] 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.[88]

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

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

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)[89].

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 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*

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[89] https://echa.europa.eu/documents/10162/13580/seac_rac_review_period_authorisation_en.pdf/c9010a99-0baf-4975-ba41-48c85ae64861

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 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[90]. They are a key driver underlying the difficulties facing the sector in substituting CAA across all components within final products. The long service life of aircraft and other products makes it difficult to undertake all of the tests required to qualify and certify a component with the substitute, due to the level of investment and costs that would be involved in such an activity for out of production A&D products; it would require testing at multiple levels (components, sub-assemblies, assemblies, final aircraft/defence equipment).

The ADCR would like to emphasise the crucial role every single component within an A&D product plays with respect to its safety. An aircraft is a complex system involving not only design of the aircraft itself, but also its use and maintenance history in varied climates and service. An aircraft is exposed to massive forces and extremely high stress levels due to high velocities and environmental impacts. Therefore, every single component needs to be designed and manufactured with serious attention and care.

In a complex system, change introduces new forms of failure. Any change will bring failures that can be anticipated – and some that are unanticipated. The components in an A&D product need to be adjusted to each other very precisely on the design as well as on the manufacturing level. When in the early design phase for completely new engines, for example, there is an opportunity to consider

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[90] 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.

introducing a material change. Mostly such a material change will be a step improvement on a previous design, in line with the principle of proven engineering. Very rarely is a substantial design change introduced into an existing product, as this would involve substantial cost and risk.

Even where such a small change is considered feasible in principle, the implications are significant and highly complex; time consuming, systematic TRL-style implementation is required to minimise the impact of unanticipated failures and the serious repercussions they might cause. Even when an OEM has been able to undertake the required testing and is in the process of gaining qualifications and certifications of components with a substitute, it may take up to seven years to implement the use of a substitute across the value chain due to the scale of investment required and the need for OEMs to undertake their own qualification of different suppliers.

In addition, MoDs rarely revise specifications for older equipment, which must nevertheless be maintained and repaired. MROs servicing military equipment therefore must undertake any maintenance or repairs in line with the OEMs' original requirements. Similarly, MROs in the civil aviation field are only legally allowed to carry out maintenance and repairs in line with OEMs' requirements as set out in Maintenance Manuals. Long service lives therefore translate to on-going requirements for the use of the chromates in the production of spare parts and in the maintenance of those spare components and the final products they are used in.

As such, a review period of at least 12 years is warranted and requested for the highly complex substitution issues the ADCR is addressing in this combined AoA-SEA. A 12-year review period of itself may not be sufficient for the A&D industry to fully replace CAA across all uses (and in particular defence related applications) even though 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 and DtB manufacturers.

6.4.3 Criterion 2: Cost of moving to substitutes

Over the past 30 years, there has been significant levels of expenditure on R&D into alternatives as part of large-scale collaborative projects (including those partially funded by the European Commission), as well R&D carried out by the major OEMs and DtB companies. The level of expenditure is in the tens of millions of Euros into alternatives to CAA, as discussed in Sections 3 and 4.

Where possible, and for specific components and final products, some new designs have been able to utilise newly developed alloys that do not require chromium trioxide-based anodising. However, even in some new designs, there may be a need for the use of CAA due to safety considerations.

As illustrated in Section 4.2.3.4, companies have already invested significantly into the adoption of alternatives, where these have been qualified and certified. Examples of the level of investments necessary include €500k - 750k by BtP and DtB companies into creating new a chromate-free anodising line alongside existing CAA lines. Such investment by small and medium sized companies requires the ability to draw on capital reserves built up over time, as well as to obtain loans to finance the investments. In a period characterised by significant negative impacts on A&D manufacturing activity (2020 to 2021), incurring such expenditure has not been feasible for large numbers of companies.

For the larger DtBs and OEMs, the levels of investment required are far higher once an alternative has been certified. Industrialisation may mean investment into large numbers of anodising lines, as well as assisting (potentially including financial assistance) suppliers and ensuring quality control and performance of those suppliers to the certification requirements. The associated costs can be tens of millions per component and/or per "use" (i.e., anodising, pre-treatment, post-treatment, etc.). The result is a need to stage implementation over a period of up to five to six years to undertake the implementation work required and to build up the funding required.

In this respect, it should be recognized that modern commercial aircraft in their entirety consist of between 500,000 to 6 million components, depending on the model. Depending on the materials of construction, 15-70% of the entire structure of an aircraft may require 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 into newer models wherever it is safe to do so.

These technical hurdles are a fundamental reason why the aerospace 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

Cr(VI) coatings were validated/certified in the 1950s and 60s and extensive in-service performance has validated the performance of chromated materials. This includes modifications to design practice and material selection based upon resolution of issues noted in service. Chromic acid anodising, due to its extensive performance history, represents the baseline that alternatives must match to demonstrate equivalence.

Although use of CT in anodising continues, it should be recognised that significant achievements have been made in its substitution. Indeed, some OEMs and DtBs have already found substitutes to CAA for their components and final products. Others, however, still face difficulties due to differences in performance requirements, substrates and geometries. This combined AoA/SEA is only concerned with this second set that are still working towards substitution.

However, the progression that has been made by towards substitution is illustrated by the achievements of one of the ADCR members in reducing their level of dependency on use of the chromates in CAA and other applications (see **Figure 6-3**).

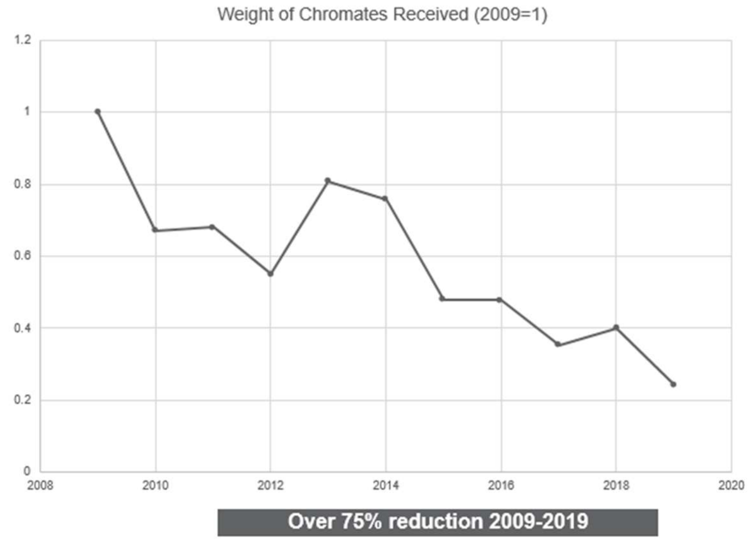

Figure 6-3: Reductions in chromate dependency over the period 2009 -2019

This 75% reduction in the use of the chromates by weight reflects the massive efforts and investment in R&D aimed specifically at substitution of chromium trioxide. Although these efforts have enabled substitution across a large range of components, effective substitutes will not be available across all components and products for at least 12 years (and perhaps longer for those parts and products which have to meet military requirements, including those pertaining to UK, EEA and US equipment).

Testing corrosion protection systems in environmentally relevant conditions to assure performance necessarily requires long R&D cycles for alternative corrosion prevention processes. A key factor driving long timeframes for implementation of fully qualified components using alternatives by the aerospace and defence industry is the almost unique challenge of obtaining relevant long-term corrosion performance information. This includes testing changes in the process of corrosion protection, including changes in the pre-treatment and post-treatment steps.

As a result, there are very long lead times before technologies developed from a research project can be implemented into real products. Technologies which are available on the market today are the result of extensive research, including research funded by grants and conducted over the last 25 plus years. In 2020, the European A&D industries spent an estimated €18 billion in Research and Development (with an approximate 40:60 split between civil and military activities, and investment in R&D in the US roughly four times higher)[91].

A PricewaterhouseCoopers (PwC) study[92] 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”.

As stated many times already, A&D companies cannot simply apply a less effective corrosion protection process as aviation and defence substantiation procedures demand component performance using alternatives to be equal or better. If such performance is not achieved, then the alternatives cannot be used. The implications for repair, replacement and overhaul must also be understood before moving to an alternative. 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) alternative. There is a complex relationship between each part/component and its performance requirements within its own unique design parameters, which requires component certification for each individual substitution.

6.4.5 Criterion 4: Legislative measures for alternatives

As discussed in detail in section 3.1.2, the identification of a test candidate Cr(VI)-free alternative 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

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

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

production can commence. Each stage must be undertaken to acquire the necessary certification to comply with airworthiness and other safety-driven requirements.

From start to finish, significantly more than 12 years is required to move from Phase 1 to Phase 5 (i.e. to identify, qualify, validate, certify and industrialise alternatives) for all critical A&D applications. The ADCR OEMs and DtBs as design owners are currently working through this process with the aim of implementing chromate-free anodising by 2036; their current substitution plans are designed to ensure they achieve TRL9 and MRL10 within the next 12 years or sooner. This includes gaining airworthiness certification or military safety approvals, both of which can take up to several years to ensure safety. It may take more than 12 years to gain final approvals for some defence uses, particularly with respect to repairs, although the design owners are working to resolve current difficulties by 2036.

Several of the ADCR members also note that military procurement agencies prefer key components of defence equipment to be produced in the EEA, although there are also international agreements enabling manufacture in partner countries. In contrast to other industry sectors, shifting production to a non-EU territory and import of finished surface treated parts or products into the EU is more complex, as it could create a dependence on a non-EU supplier in a conflict situation.

Furthermore, the provision of defence exemptions, as allowed for in Article 2 (3) of the REACH regulation, is **not** a suitable instrument to ensure the continued availability of chromium trioxide for anodising 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 chromium trioxide by several actors in several EU member states (i.e. it often relies on a transnational supply chain). In contrast, defence exemptions are valid at a national level and only for the issuing member state. Furthermore, the defence exemption process cannot be used as an alternative to the normal authorisation process unless this is necessary for confidentiality reasons and in the interest of defence. Thus, defence applications also need to be covered by the normal authorisation process.

Finally, the EU defence sector requires only minor quantities of CT for chromic acid anodising. On the basis of a defence exemption alone, the quantities demanded would not be sufficient for chromate-suppliers and surface treatment companies to continue to offer their services and products. As a result, CAA for military aircraft and equipment would not continue in the EEA or UK if other civilian applications were not also possible. This can only be ensured by the granting of an authorisation.

6.4.6 Criterion 5 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 by the SEA questionnaire, A&D companies have invested in monitoring and the installation of additional risk management measures in response to the conditions placed on the continued use of chromium trioxide under the initial (parent) authorisations. This has resulted in reduced exposures for both workers and reduced emissions to the environment. As substitution progresses across components and assemblies and the associated value chains, consumption of chromium trioxide 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[93].

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 2021[94]) and Europe's trade balance (55% of products developed and built in the EU 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. Airbus' Global Market Forecast for 2021-2040 indicates that there will be a need for over 39,000 new passenger and dedicated freighter aircraft delivered over the next 20 years, with 15,250 of these replacing older less fuel-efficient models.[95] The value of this future demand is estimated in the US$ trillions. Airbus also has released results from its "Global Services Forecast" which shows a Maintenance Repair and Overhaul (MRO) business totalling US$1.8 trillion and the need for in excess of 500,000 new pilots over the next 20 years."

Boeing's market outlook 2016-2035 supports these estimations: "Over the next 20 years, Boeing is forecasting a need for over 39,600 airplanes valued at more than $5.9 trillion. Aviation is becoming more diverse, with approximately 38 percent of all new airplanes being delivered to airlines based in the Asia region. An additional 40 percent will be delivered to airlines in Europe and North America, with the remaining 22 percent to be delivered to the Middle East, Latin America, the Commonwealth of Independent States, and Africa."

The socio-economic benefits of retaining companies in this sector in the EEA/UK are clearly significant. As demonstrated in the socio-economic analysis presented here, these benefits clearly outweigh the associated risks to human health.

6.5 Substitution effort taken by the applicant if an authorisation is granted

As the AoA shows, where alternatives have been proven as technically feasible – on a component-by-component basis – they have been, or are in the process of, being implemented. However, there are still many applications that do not have technically feasible alternatives available which need to be authorised.

This work will continue over the requested review period with the aim of phasing out all uses of CAA. All illustrated in Section 3.7 on-going substitution is expected to result in significant decreases in the volumes of the four chromates used in CAA within seven years from the end of the review period, with

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[93] 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

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

[95] https://www.airbus.com/en/products-services/commercial-aircraft/market/global-market-forecast

a phase out complete by the end of 12 years. However, technically feasible alternatives are still at the development phase (Phase 1 out of the 5 phases) for some components and final products, where alternatives have not been found to meet performance requirements.

6.6 Links to other Authorisation activities under REACH

This combined AoA-SEA is one of a series of applications for the re-authorisation of the use of chromium trioxide in surface treatments carried out by the A&D industry. This series of combined AoA/SEAs has adopted a narrower definition of uses original Authorised under the CTAC, CCST and GCCA parent applications for authorisation.

In total, the ADCR will be submitting 11 combined AoA/SEAs covering the following uses and the continued use of chromium trioxide, sodium dichromate, potassium dichromate, sodium chromate and 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-Al metallic coatings
9) Inorganic finish stripping
10) Chromate rinsing after phosphating
11) Slurry coatings

Combined AoA/SEAs will also be submitted for strontium chromate, pentazinc chromate octahydroxide and potassium hydroxyoctaoxodizincatedichromate, that may be used in combination with the above chromates, and which have review periods ending in January 2026.

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8 Annex 1 Standards Applicable to Anodising

Table 8-1 lists examples of standards reported by ADCR members applicable to anodising.

Table 8-1: Examples of standards applicable to anodising key functions

Standard Reference	Standard Description	Key function(s)/Parameters of use
ASTM B117-19[(a)]	Standard Practice for Operating Salt Spray (Fog) Apparatus	Corrosion resistance. Apparatus, procedure, and conditions required to create and maintain the salt spray (fog) test environment
ISO 2409 [(b)]	Paints and varnishes – Cross-cut test	Adhesion promotion (adhesion to subsequent coating or paint) : Method for assessing the resistance of paint coatings and varnishes (including wood stains) to separation from substrates when a right-angle lattice pattern is cut into the coating, penetrating through to the substrate
ISO 9227 [(c)]	Corrosion tests in artificial atmospheres — Salt spray tests	Procedure to be used in conducting the neutral salt spray (NSS), acetic acid salt spray (AASS) and copper-accelerated acetic acid salt spray (CASS) tests for assessment of the corrosion resistance of metallic materials, with or without permanent or temporary corrosion protection.
ASTM B244 [(d)]	Standard Test Method for Measurement of Thickness of Anodic Coatings on Aluminum and of Other Nonconductive Coatings on Nonmagnetic Basis Metals with Eddy-Current Instruments	Coating thickness

(a) Standard Practice for Operating Salt Spray (Fog) Apparatus (astm.org)

(b) ISO - ISO 2409:2020 - Paints and varnishes — Cross-cut test

(c) ISO - ISO 9227:2017 - Corrosion tests in artificial atmospheres — Salt spray tests

(d) ASTM B244-09(2021)

9 Annex 2: European Aerospace Cluster Partnerships

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	Italy	Campania	159	12000	1.6 billion Euros

Cluster Name	Country	City	Number of Companies	Employees	Sales/turnover
Campania Aerospace District					
DTA Distretto Tecnologico Aerospaziale s.c.a.r.l	Italy	Apulia	13	6000	78 million Euros
Estonian Aviation Cluster (EAC)	Estonia	Tallinn	19	25000	3% of GDP
Flemish Aerospace Group	Belgium	Flanders	67	3300	1.2 billion Euros
Hamburg Aviation e.V	Germany	Hamburg	300	40000	5.18 billion Euros
HEGAN Basque Aerospace Cluster	Spain	Basque Country	56	4819	954 million Euros
Innovation & Research for Industry	Italy	Emilia Romagna	30	2000	500 million Euros
International Aviation Services Centre (IASC)Ireland	Ireland	Shannon	60	46000	3.6bn GVA
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	

Cluster Name	Country	City	Number of Companies	Employees	Sales/turnover
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 plus member companies (including over 1,000 SMEs), supporting around 1,000,000 jobs (direct and indirect) across the country.

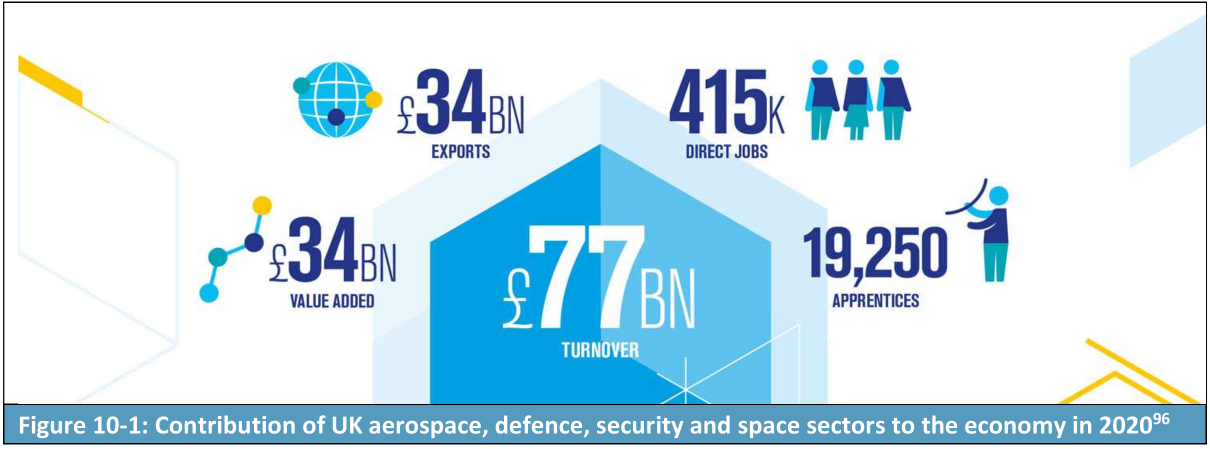

Figure 10-1: Contribution of UK aerospace, defence, security and space sectors to the economy in 2020[96]

The UK aerospace sector is considered by the government to be "hugely important to the UK economy"[97], 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 southeast – see **Figure 10-2**.

Given the economic importance of the sector, it has been the focus of an Aerospace Sector Deal launched on 6 December 2018) under the UK Industrial Strategy. The deal is aimed at helping industry move towards greater electrification, accelerating progress towards reduced environmental impacts, and has involved significant levels of co-funding by the government (e.g. a co-funded £3.9 billion for strategic research and development activities over the period up to 2026)[98]. To date, this co-funded programme has invested £2.6 billion, across all parts of the UK.

It is anticipated that the UK aerospace sector will continue to grow into the future, due to the global demand for large passenger aircraft, as discussed further below.

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

[97] BEIS, Aerospace Sector Report, undated.

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

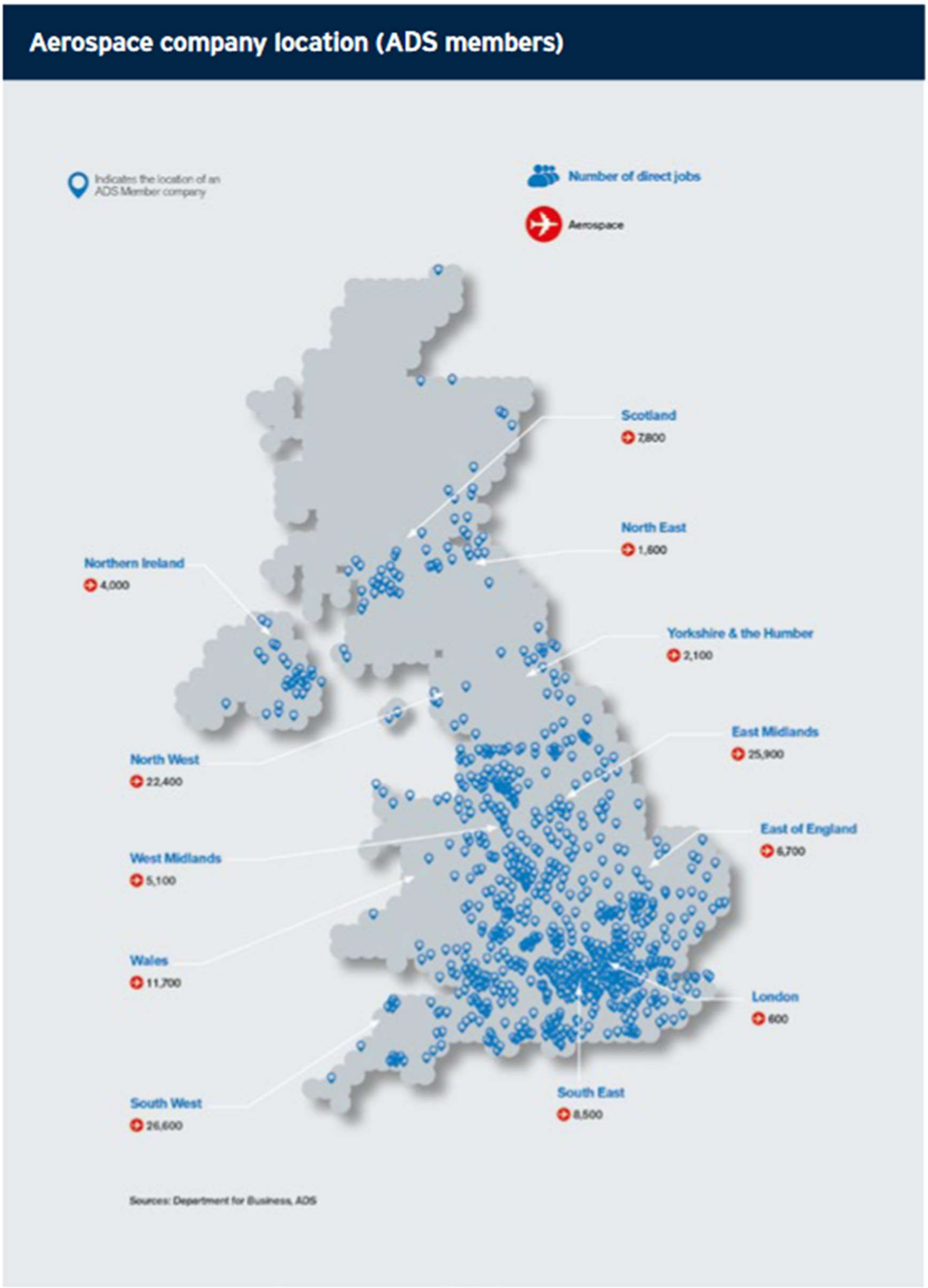

Figure 10-2: Location of aerospace manufacturing sites and associated jobs in the UK[99]

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[99] 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 2013-2026.

This will help in maintaining the current expected market development in the UK, which would see a 2.3% per year growth in real terms, leading to direct added value of just over £14 billion in 2035 (compared to £9 billion in 2016). In 2016, the UK aerospace sector employed around 112,500 people, with each direct job in the aerospace industry creating at least one additional job within the aerospace supply chain. This gives around 225,000 people directly and indirectly employed by the aerospace sector in high-value design and high value manufacturing jobs. By maintaining its current direction of growth, the sector is expected to create up to a further 45,000 positions by 2035.

The value of the sectors is also significant in wider economic terms. Investment in aerospace research and technology leads to wider impacts beyond the sector. Every £100 million spent on R&T by the government crowds-in around £300 million of additional private sector investment. Furthermore, every £100 million invested benefits not only UK aerospace GVA by £20 million per year, but also the wider economy by £60 million per year through technology spillovers. These include automotive, marine, oil and gas, nuclear, electronics, composites, metals and other UK industrial sectors. In total, the return on government investment in the sector is estimated as delivering an additional £57 billion of gross value added for the UK aerospace sector and a further £57 billion to the wider UK economy between 2015 and 2035.

10.2 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**[100]. Again the importance of the sector to UK exports and value added, as well as employment is clear from Figure 9-3.

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

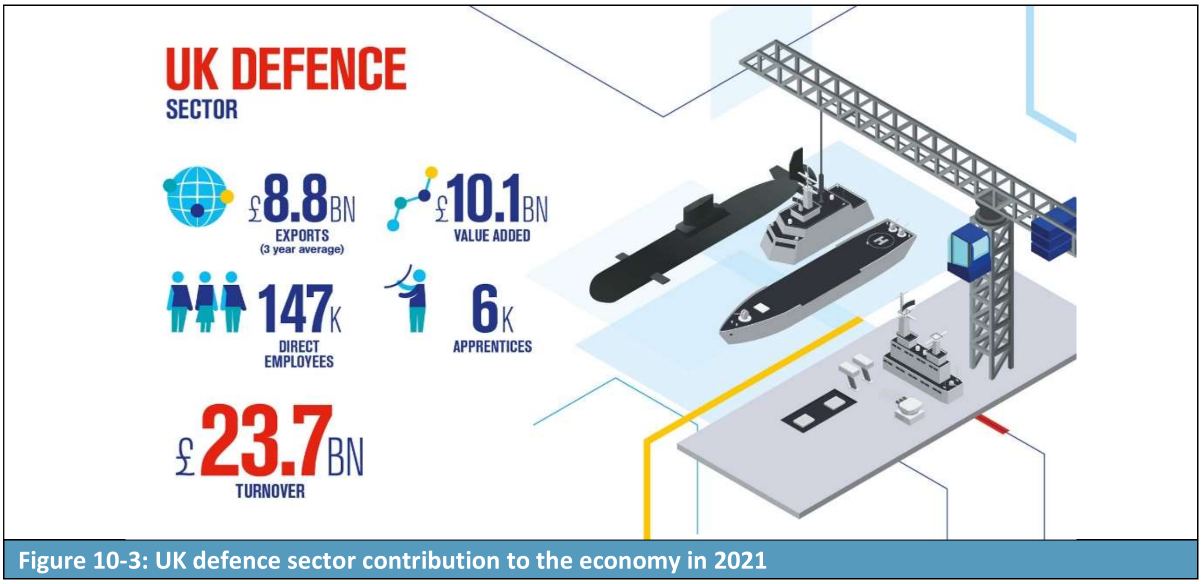

Figure 10-3: UK defence sector contribution to the economy in 2021