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
Date:	February 2023
Substance:	Chromium trioxide (includes "Acids generated from chromium trioxide and their oligomers", when used in aqueous solutions)
Use title:	Pre-treatments: Deoxidising, pickling, etching and/or desmutting 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 to Cost Ratio

BtP – Build-to-Print manufacturer

CAGR – Compound Annual Growth Rate

CCC – Chemical Conversion Coating

CCST – Chromium VI Compounds for Surface Treatment

CMR – Carcinogen, Mutagen or toxic for Reproduction

Cr(VI) – Hexavalent chromium

CSR – Chemical Safety Report

CT – Chromium trioxide

CTAC – Chromium Trioxide Authorisation Consortium

DtB – Design-to-Build manufacturer

DtC – Dichromium tris(chromate)

EASA – European Aviation Safety Agency

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

ECHA – European Chemicals Agency

EEA – European Economic Area

ESA – European Space Agency

HvE – Humans via the Environment

GCCA – Global Chromates Consortium for Authorisation

GDP – Gross domestic product

GOS – Gross operating surplus

GVA – Gross value added

ICAO – International Civil Aviation Organisation

MoD – Ministry of Defence

MRL – Manufacturing readiness level

MRO – Maintenance, Repair and Overhaul

NADCAP – National Aerospace and Defence Contractors Accreditation Program

NATO – North Atlantic Treaty Organisation

NUS – Non-use scenario

OELV – Occupational Exposure Limit Value

OEM – Original Equipment Manufacturer

RAC – Risk Assessment Committee

REACH – Registration, Evaluation, Authorisation and restriction of Chemicals

RR – Review Report

SC – Sodium chromate

SD – Sodium dichromate

SEA – Socio Economic Analysis

SEAC – Socio Economic Analysis Committee

SME – Small and medium-sized enterprises

SVHC – Substance of Very High Concern

T&E – Testing and Evaluation

TRL – Technology Readiness Level

UK – United Kingdom

WCS – Worker contributing scenario

Glossary

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

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

Term	Description
Heat resilience	The ability of a coating or substrate to withstand repeated cycles of heating and cooling and exposure to corrosive conditions. Also known as cyclic heat-corrosion resistance.
Hot corrosion resistance	The ability of a coating or substrate to withstand attack by molten salts at temperatures in excess of 400°C.
Industrialisation	The final step of the substitution process, following Certification. After having passed qualification, validation and certification, the next step is to industrialise the qualified material or process in all relevant activities and operations of production, maintenance, and the supply chain. Industrialisation may also be referred to as implementation.
Layer thickness	The thickness of a layer or coatings on a substrate.
Legacy parts	Any part that is already designed, validated, and certified by Airworthiness Authorities or for defence and space, or any part with an approved design in accordance with a defence or space development contract. This includes any part in service.
Material	The lowest level in the system hierarchy. Includes such items as metals, chemicals, and formulations (e.g., paints).
Maintenance, Repair and Overhaul (MRO)	The service of civilian and/or military in-service products. Term may be used to describe both the activities themselves and the organisation that performs them.
NACE	The Statistical Classification of Economic Activities in the European Community. It is part of the international integrated system of economic classifications, based on classifications of the UN Statistical Commission (UNSTAT), Eurostat as well as national classifications.
NADCAP	National Aerospace and Defence Contractors Accreditation Program which qualifies suppliers and undertakes ISO audits of their processes.
Net Present Value	Valuation method to value stocks of natural resources. It is obtained by discounting future flows of economic benefits to the present period.
Original Equipment Manufacturer (OEM)	Generally large companies which design, manufacture, assemble and sell engines, aircraft, space, and defence equipment (including spare parts) to the final customer. In addition, an OEM may perform MRO activities.
Part	Any article or complex object.
Pickling	The removal of surface oxides and small amounts of substrate surface by chemical or electrochemical action.
Present Value	The discounted sum of all future debt service at a given rate of interest. If the rate of interest is the contractual rate of the debt, by construction, the present value equals the nominal value, whereas if the rate of interest is the market interest rate, then the present value equals the market value of the debt.
Pre-treatment	Pre-treatment processes are used, prior to a subsequent finishing treatment (e.g., chemical conversion coating, anodising), to remove contaminants (e.g., oil, grease, dust), oxides, scale, and previously applied coatings. The pre-treatment process must also provide chemically active surfaces for the subsequent treatment. Pre-treatment of metallic substrates typically consists of cleaning and/or surface preparation processes.
Producer surplus	Represents the gain to trade a producer receives from the supply of goods or services less the cost of producing the output (i.e., the margin on additional sales).
Proposed candidate	A formulation in development or developed by a formulator as a part of the substitution process for which testing by the design owner is yet to be determined. In the parent applications for authorisation, this was referred to as a 'potential alternative'.
Qualification	1. Part of the substitution process following Development and preceding Validation to perform screening tests of test candidate(s) before determining if further validation testing is warranted

Term	Description
	2. The term qualification is also used during the industrialisation phase to describe the approval of suppliers to carry out suitable processes.
Requirement	A property that materials, components, equipment, or processes must fulfil, or actions that suppliers must undertake.
Resistivity	Property that quantifies how a given material opposes the flow of electric current. Resistivity is the inverse of conductivity.
Social Cost	All relevant impacts which may affect workers, consumers and the general public and are not covered under health, environmental or economic impacts (e.g., employment, working conditions, job satisfaction, education of workers and social security).
Specification	Document stating formal set of requirements for activities (e.g., procedure document, process specification and test specification), components, or products (e.g. product specification, performance specification and drawing).
Standard	A document issued by an organisation or professional body that sets out norms for technical methods, processes, materials, components, and practices.
Sub-system	The second highest level in the system hierarchy. Includes such items as fuselage, wings, actuators, landing gears, rocket motors, transmissions, and blades.
Surface morphology	The defined surface texture of the substrate.
System	The highest level in the system hierarchy. Includes such items as the airframe, gearboxes, rotor, propulsion system, electrical system, avionic system, and hydraulic system.
System hierarchy	The grouping/categorisation of the physical elements that comprise a final product (such as an aircraft), according to their complexity and degree of interconnectedness. Comprises materials, parts/components, assemblies, sub-systems, and systems.
Temperature resistance	The ability to withstand temperature changes and extremes of temperature.
Test candidate	Materials which have been accepted for testing or are currently undergoing testing by a design owner, as a part of the substitution process. In the parent applications for authorisation, this was referred to as a 'candidate alternative'.
Type certificate	Document issued by an Airworthiness Authority certifying that an Aerospace product of a specific design and construction meets the appropriate airworthiness requirements.
Validation	Part of the substitution process following Qualification and preceding Certification, to verify that all materials, components, equipment, or processes meet or exceed the defined performance requirements.
Value of statistical life	Values the impact of risks to the length of life.
Verification	The process of establishing and confirming compliance with relevant procedures and requirements.
Wear resistance	The ability of a surface to withstand degradation or loss due to frictional movement against other surfaces.
Sources: GCCA and ADCR consortia	

DECLARATION

We, the Applicants, are aware of the fact that further evidence might be requested by HSE to support information provided in this document.

Also, we request that the information blanked out in the "public version" of the Analysis of Alternatives and Socio-economic analysis is not disclosed. We hereby declare that, to the best of our knowledge as of today 27 February 2023 the information is not publicly available and, in accordance with the due measures of protection that we have implemented, a member of the public should not be able to obtain access to this information without our consent or that of the third party whose commercial interests are at stake.

Signature: Date: 27 February 2023

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1 Summary

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

1.1 Introduction

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

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

The parent authorisations to this combined AoA/SEA covered multiple surface treatments and different individual chromates. This combined AoA-SEA covers only one of the currently authorised types of surface treatment – pre-treatment processes – and therefore adopts a narrower definition of "use" compared to the original Chromium Trioxide Authorisation Consortium (CTAC) and Chromium VI Compounds for Surface Treatment (CCST) applications. A pre-treatment should ensure that a substrate is adequately prepared or enhanced to optimise or activate the surface ready to receive and to compliment the function of the subsequent treatment, or treatments.

The pre-treatment process is tailored to the nature of the surface preparation required. These are described as deoxidation, desmutting and pickling/etching (scale conditioner). All processes are used for the same purpose to prepare the surface for the subsequent treatment process. Preparation of the surface may require the removal of contaminants, such as oxides or residues from other processes, for example machining, and/or the activation of the surface to enhance the functionality of the subsequent treatment/coating, for example adhesion.

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

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

The other surface treatments that are still being supported by the ADCR are covered by separate, complementary submissions for each "use."

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

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

1) Pre-treatments: Deoxidising, pickling, etching and/or desmutting using chromium trioxide, and/or sodium dichromate in aerospace and defence industry and its supply chain.

The "applied for use" involves the continued use of chromium trioxide (CT), and sodium dichromate (SD), across the EEA and the UK in pre-treatment processes for a further 12-year review period. These two chromates were included in Annex XIV of Regulation (EC) No 1907/2006 due to their intrinsic properties (mutagenic, carcinogenic, toxic for reproduction; depending on the chromate). According to Article 62 (4)(d) of this Regulation, the chemical safety report (CSR) supporting an Application for Authorisation (AfA) needs to cover only those risks arising from the intrinsic properties specified in Annex XIV. The carcinogenicity, mutagenicity and reproductive toxicities of CT, its acids, and SD are driven by the chromium VI (Cr(VI)) ion released when the substances solubilise and dissociate.

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

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

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

With respect to the SEA, the grouping approach ensures that there is no double-counting of economic impacts and the social costs of unemployment. This would occur if the assessment was carried out separately for each chromate's use in pre-treatment due to the fact that different chromates may be used within the same facility.

The potential for double counting is significant given that approximately 80 sites in the EEA and 20 sites in Great Britain are anticipated as undertaking pre-treatment. This includes sites in involved in the production of components and end products, as well as maintenance, repair and overhaul services for both civil aviation and military bodies, as well as aeroderivative uses.

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

Table 1-1: Maximum tonnages used in pre-treatment (substances and formulations)

	Chromium trioxide	Sodium dichromate
EEA	Up to 25 t/y	Up to 45 t/y
UK	Up to 10 t/y	Up to 5 t/y

1.2 Availability and suitability of alternatives

For the past several decades, ADCR members who are "design owners" (including Original Equipment Manufacturers (OEMs) and Design-to-Build 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 the chromates in pre-treatments as a specific use. At the current time, the remaining uses form a part of an overall system. The purpose of the pre-treatments is to prepare the surface prior to the application of the subsequent treatment(s). Key functions from pre-treatments are:

- Corrosion resistance;
- Adhesion of subsequent coatings (including structural bonding);
- Surface preparation prior to further processing;
- Removal of contaminants/complexes after etching processes;
- Surface roughness modification: Removal of mechanically deformed layers/oxides/other compounds from the substrate; and
- Selective removal of material to reveal the surface or to improve surface properties.

Performance requirements are also considered when assessing the technical feasibility of proposed candidates. These include:

- Shall neither cause end grain pitting nor intergranular attack in excess of certain depth;
- Metal removal of the substrate, which shall not exceed certain limits;
- Adequate etch rate;
- Minimum fatigue – no degradation due to processing;
- Mechanical strength – no degradation due to processing;
- Water-break free surface without streaks or discolorations. No pitting or selective attack to the substrate. No non-rinseable residuals or contamination from the deoxidising solutions observed on the surface;
- Must not induce de-gassing from surface under vacuum;
- Does not incur pits, corrosion products, discolouration, uneven etching, increased surface roughness or other defects that would prohibit further chemical processing; and
- Does not impact compressive stress intentionally created by shot-peening or other processes.

Pre-treatment processes are an important step employed prior to the main process principally to ensure the full functionality of the main process is realised and preserved.

The OEMs and DtB manufacturers (as design owners) 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, considering progress of R&D, testing, qualification, validation and certification and industrialisation activities.

The companies are at different stages in the implementation of alternatives, with some indicating that they expect to be able to substitute the above chromates in pre-treatment processes across some of their current components, final products and MRO (maintenance, repair and overhaul) processes within the next four to seven years; 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 a further 12 years or more to gain certifications and to then implement current test candidates; a further set are constrained by military and/or MRO requirements which may mean that it will take at least 12 years to implement technically feasible substitutes.

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

Companies engaged in maintenance, repair, and overhaul (MRO) activities face particular substitution difficulties, as they are mandated to continue use of chromium trioxide and sodium dichromate in pre-treatment processes if this is specified in the Maintenance Manuals provided to them by the OEMs. MROs (military and civilian) are legally obliged to carry out their activities in line with the requirements set out in Maintenance Manuals, given the importance of these to ensuring airworthiness and the safety and reliability of final products. As a result, they rely on the completion of the R&D, testing and certification activities of the OEMs and the update of the Maintenance Manuals before they are able to adopt alternative substances or processes. This applies not only to MROs involved in servicing civilian aircraft but also military MROs servicing military equipment.

As a result of the different requirements outlined above, at the sectoral level, there will be an on-going progression of substitution over the requested 12-year review period, refer to Figure 1-1. The potential need for more than 12 years has been identified by multiple OEMs due to their failure to identify any technically feasible alternatives to date, or due to the need by MROs and MoDs for continued use in the maintenance and repair of in-service (legacy) final A&D products.

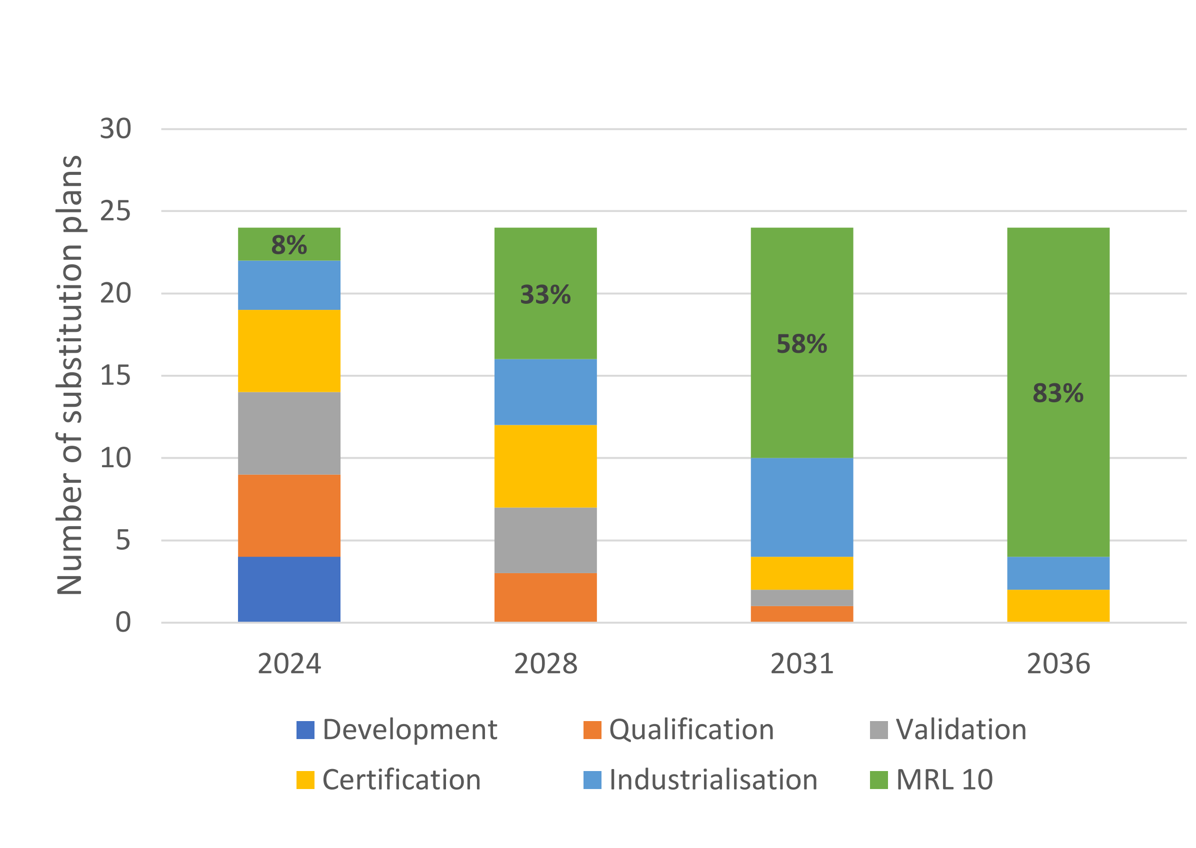

Figure 1-1: Expected progression of substitution plans for the use of Cr(VI) in pre-treatment, by year. The vertical axis refers to number of substitution plans (some members have multiple substitution plans for pre-treatments). The percentage value shown on each of the green bars indicates the proportion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

1.3 Socio-economic benefits from continued use

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

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

- Importers of the substances and formulators of the mixture used in pre-treatment will continue to earn profits from sales to the A&D sector. These are not quantified in this SEA but are detailed in the linked Formulation AoA/SEA;

- OEMs will be able to rely on the use of chromates by their EEA and UK suppliers and in their own production activities. The profit losses[3] to these companies under the non-use scenario would equate to between €1.5 – 2.8 billion for the EEA and €0.14 – 0.56 billion for the UK, over a 2-year period (starting in 2025, PV discounted at 4%). These figures exclude the potential profits that could be gained under the continued use scenario from the global increase in demand for air transport;

- Build-to-Print (BtP) and Design-to-Build (DtB) suppliers would be able to continue their production activities in the EEA/UK and meet the performance requirements of the OEMs. The associated profit losses that would be avoided under the continued use scenario for these companies are calculated at between €410 – 460 million for the EEA and €140 – 450 million for the UK over a 2-year period (starting in 2025, PV discounted at 4%);

- MRO companies which provide maintenance and repair services to both civil aviation and/or military forces, would be forced to move some operations outside the EEA/UK, with the consequent profit losses equating to between at €100 – 2,800 million for the EEA and €180 – 560 million for the UK over a 2-year period (starting in 2025, PV discounted at 4%). Such relocation of strategically important activities would run contrary to the EU's New Industrial Strategy;

- Continued high levels of employment in the sector, with these ensuring the retention of highly skilled workers paid at above average wage levels. From a social perspective, the benefits from avoiding the unemployment of workers involved in pre-treatment and linked treatment, manufacturing and assembly activities are estimated at €3.45 billion in the EEA and €610 million in the UK These benefits are associated with the protection of around 30,000 jobs in the EEA and around 6,100 jobs in the UK;

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

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

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

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

1.4 Residual risk to human health from continued use

The parent authorisations placed conditions on the continued use of the chromates in surface treatments, including in pre-treatment. The A&D sector has made huge efforts to be compliant with

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

these conditions, investing in risk management measures but also improved worker and environmental monitoring. Significant technical advances have been made in developing and qualifying alternatives for use on some components/final products, although there remain technical challenges for other components and final products. As a result, it is projected that from 2024, based on current company-specific substitution plans, where technically and economically feasible, consumption of the chromates by ADCR members and their suppliers will decline significantly over the requested 12-year review period.

For the purposes of the human health risk assessment, however, it has been assumed that the quantities used and the number of sites using the chromates remains constant over the 12-year period. This will lead to an overestimate of the residual risks to both workers and humans via the environment.

Risks to workers have been estimated based on the use of exposure monitoring data, supplemented by modelling data as appropriate. Across the 80 EEA sites where chromate-based pre-treatment processes are anticipated as taking place, an estimated total of 1,760 workers may be exposed to Cr(VI); and for the 20 UK sites where pre-treatment takes place the figure is 440 .

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 pre-treatment is considered to take place, an estimated 37,000 people in the EEA and around 27,000 people in the UK[4] are calculated as potentially being exposed to Cr(VI) due to chromate-based pre-treatment activities.

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

- EEA: 0.51 statistical fatal cancers and 0.12 non-fatal cancers over the 12-year review period, at a total social cost of €750,000

- UK: 0.21 fatal cancers and 0.06 non-fatal cancers over the 12-year review period at a total social cost of €310,000.

1.5 Comparison of socio-economic benefits and residual risks

The ratios of the total costs on non-Authorisation (i.e., benefits of continued use) to the total residual risks to human health are as follows for the EEA and UK respectively (based on two years for economic losses and 12 years for health risks @ 4%):

- EEA: 9,005 to 1 for the lower bound of profit losses and unemployment costs or 10,763 to 1 for the upper bound profit losses and unemployment costs, where economic impacts are assessed over two years and residual risks over 12 years;

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

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

- UK: 4,254 to 1 for the lower bound of profit losses and unemployment costs or 4,444 to 1 for the upper bound profit losses and unemployment costs, where economic impacts are assessed over two years and residual risks over 12 years.

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

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

- The avoided impacts on air transport – both passenger and cargo – across the EEA and the UK due to stranded aircraft on the ground (AoG), reductions in available aircraft, increased cost of flights for passengers, or cargo shippers, etc.;

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

- The avoided negative environmental impact associated with prematurely obsoleted final products which creates excess waste in the disposal of components and increased scrappage in the manufacture of the replacements. Scrap is material that is wasted during the production process; 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 pre-treatment, and the quantities used in this surface treatment are expected to start significantly reducing year on year until the majority use is phased-out in 2036.

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

- A Binding Occupational Exposure Limit Value (OELV) has been introduced under EU Directive 2004/37/EC that will become more stringent after January 17th, 2025; this Binding OELV was recommended by the Tripartite Advisory Committee on Safety and Health based on consensus and will provide an additional level of protection for workers undertaking pre-treatment.

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

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

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

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

- **The strict regulatory requirements that must be met generate additional, complex requalification, recertification, industrialisation activities**, to ensure the continued airworthiness of aircraft and the safety and reliability of defence equipment (including air, naval and land-based systems). These requirements mean that there is no simple or single drop-in replacement for the chromates in pre-treatment, which can be considered to be "generally available" following the European Commission's definition[6].

- **The A&D industry has been undertaking R&D into alternatives for the past 30 years**. This includes participation in research initiatives partially funded by the European Commission and national governments. Considerable technical progress has been made in developing, validating qualifying and certifying components for the use of alternatives, however, it is not technically nor economically feasible for the sector as a whole to have achieved full substitution within a seven year period. Although some companies have been able to qualify and certify alternatives for some of their components, others are still in the early phases of testing and development work due to alternatives not providing the same level of performance to the chromates. They will not be able to qualify and certify a proposed or test candidate for some components within a seven year time frame. It is also of note that pre-treatment is used throughout the supply chain and by large numbers of smaller suppliers. As a result, sufficient time will be required to fully implement alternatives through the value chain once they have been certified.

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

- **It is important to note that the use of the chromates is required to ensure the operational capabilities of the military and the ability to comply with international obligations as partner nations at the EEA level and in a wider field, e.g., with NATO**.

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

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

[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)

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

2 Aims and Scope of the Analysis

2.1 Introduction

2.1.1 The A&D Chromates Reauthorisation Consortium

This combined AoA/SEA is based on a grouping approach and covers all the soluble chromates relevant for the specific use of pre-treatment processes (deoxidising, pickling/ etching (scale conditioner) and desmutting) by the ADCR consortium members and companies in their supply chain. The ADCR has adopted a narrower scope for the use definition, to provide a more meaningful and specific description of use than the initial "parent" applications (see Section 2.2), which covered a wide range of surface treatments and substrates.

The use of the chromium trioxide and sodium dichromate in pre-treatments is limited to those situations where it plays a critical (and currently irreplaceable) role in ensuring the protection of substrates to meet product performance, reliability, and safety standards, particularly those relating to airworthiness set by European Aviation Safety Agency (EASA). This is also true with respect to their use in defence, space and in aerospace derivative products, which include non-aircraft defence systems, such as ground-based installations or naval systems. Such products and systems also have to comply with numerous other requirements including those of the European Space Agency (ESA) and of national MoD.

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

As a result, the analysis presented here is based on an extensive programme of work funded and carried out by the main OEMs and DtBs, and key suppliers where this includes small, medium, and other large actors within the sector. It is based on sector-specific data and detailed information obtained from the ADCR members (which includes OEMs, DtBs, BtPs, MROs and MoDs) and collected from their A&D suppliers throughout the supply chain. In total, data were collected from companies covering over 260 A&D sites in the EEA and UK, with data for 53 of those sites used in developing this combined AoA/SEA.

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

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

2.1.2 Aims of the combined AoA and SEA document

The downstream users supporting the ADCR consortium have no qualified (from a technical perspective) and economically feasible alternatives for use on all of their components and final products which can be fully implemented across all products, components and MRO processes before the expiry of the original authorisations; they must continue to use the chromates in pre-treatment activities carried out within the EEA and UK, as it is fundamental to the functionality of associated subsequent treatments, for example preventing corrosion of critical A&D parts and components. Pre-treatment processes form part of an overall anti-corrosion process, which may also include post-treatments in addition to pre- and main treatments. This overall treatment system is aimed at ensuring the compulsory airworthiness requirements of aircraft and safety of military equipment.

Although the A&D sector has been successful in implementing alternatives for some components with less demanding requirements, the aim of this application is therefore to enable the continued use of the chromates in pre-treatments beyond the end of the existing review period which expires in September 2024, for the processes where alternative implementation has not yet been successful. It demonstrates the following:

- The technical and economic feasibility, availability, and airworthiness (i.e., safety) challenges in identifying an acceptable alternative to the use of the chromates, which does not compromise the functionality and reliability of the components treated by pre-treatments 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 chromates in pre-treatments. 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 of out-of-production civilian and military aircraft and other defence systems;

- The socio-economic impacts that would arise for ADCR downstream users and their suppliers, downstream supply chains and, crucially, for the EEA and UK more generally, if the applicants were not granted re-authorisations for the continued use of the chromates over an appropriately long review period; and

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

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

2.2 The Parent Applications for Authorisation

This combined AoA and SEA covers the use of the following chromates in pre-treatment.

• Chromium trioxide (includes "Acids generated from chromium trioxide and their oligomers", when used in aqueous solutions)	EC 215-607-8	CAS 1333-82-0
• Sodium dichromate	EC 234-190-3	CAS 10588-01-9

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

Chromium trioxide (CT) has been included in Annex XIV of REACH (Entry No. 16) due to its carcinogenic and mutagenic properties as it is classified as carcinogenic (Cat. 1A) and mutagenic (Cat. 1B). As CT mainly used as aqueous solution in the pre-treatment, this combined AoA/SEA also covers the acids generated from CT and their oligomers (Entry No. 17). In the remainder of this document, references to CT always include the acids generated from CT and their oligomers.

Sodium dichromate (SD; Entry No. 18) has been included in Annex XIV of REACH due to its CMR properties as it is classified as carcinogenic (Cat. 1B), mutagenic (Cat. 1B) and reproductive toxicants (Cat. 1B).These chromates were granted authorisations for use in pre-treatment across a range of applicants and substances. Table 2-1 summarises the initial applications which are the parent authorisations for this combined AoA/SEA.

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

Table 2-1: Overview of Initial parent Applications for Authorisation					
Application ID/ authorisation number	**Substance**	**CAS #**	**EC #**	**Applicants**	**Parent Authorisation – Authorised Use**
0032-02 REACH/20/18/7, REACH/20/18/9, REACH/20/18/11	Chromium trioxide	1333-82-0	215-607-8	Various applicants (CTAC consortium)	Functional chrome plating where any of the following key functionalities is necessary for the intended use: wear resistance, hardness, layer thickness, corrosion resistance, coefficient of friction, or effect on surface morphology
0032-04 REACH/20/18/14, REACH/20/18/16, REACH/20/18/18	Chromium trioxide	1333-82-0	215-607-8	Various applicants (CTAC consortium)	Surface treatment for applications in the aeronautics and aerospace industries, unrelated to functional chrome plating or functional chrome plating with decorative character, where any of the following key functionalities is necessary for the intended use: corrosion resistance/active corrosion inhibition, chemical resistance, hardness, adhesion promotion (adhesion to subsequent coating or paint), temperature resistance, resistance to embrittlement, wear resistance, surface properties impeding deposition of organisms, layer thickness, flexibility, and resistivity
0032-05 REACH/20/18/21, REACH/20/18/23, REACH/20/18/25	Chromium trioxide	1333-82-0	215-607-8	Various applicants (CTAC consortium)	Surface treatment (except passivation of tin-plated steel (ETP)) for applications in various industry sectors namely architectural, automotive, metal manufacturing and finishing, and general engineering (unrelated to functional chrome plating or functional chrome plating with decorative character) 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
0043-02 REACH/20/5/3,	Sodium dichromate	10588-01-9	234-190-3	Various applicants (CCST consortium)	Use for surface treatment of metals (such as aluminium, steel, zinc, magnesium, titanium, alloys), composites and sealings of anodic films for the aerospace sector in surface treatment processes.

REACH/20/5/4, REACH/20/5/5 24UKREACH/20/5/3					

2.3 Scope of the analysis

2.3.1 Brief overview of uses

2.3.1.1 Process description

Pre-treatment by the aerospace and defence industry and its supply chain in the EEA and the UK involves the use of CT and SD.

Pre-treatments in the aerospace and defence supply chains is carried out exclusively in industrial settings. Before undergoing subsequent treatment, the surface of the component to be treated must be absolutely free of contaminants, corrosion, and other foreign matter. A pre-treatment step is then essential to the successful outcome of associated subsequent treatments. It is usually not a stand-alone process but part of a process chain that involves main treatments performed with or without Cr(VI) compounds. Pre-treatment processes can be deoxidising, pickling/etching (scale conditioner)[8] and/or desmutting. These different processes have the same general mode of action and the same purpose; decontamination and preparation of the surface and removal of surface irregularities to facilitate the functionality of the subsequent treatment.

Pre-treatments can be either non-electrolytic, or electrolytic processes using a solution containing Cr(VI) together with acid compounds. Application is typically by immersion; however, a variety of methods are available. These include:

- Dip/immersion
- Brush
- Sponge
- Spray

Pre-treatment processes can be targeted depending on the nature of the surface preparation required. Regarding deoxidising a chemical reaction occurs between the oxide layer on the surface of the component and the pre-treatment, removing the oxide film present on the substrate. Very little substrate material is removed with this process.

Pre-treatment processes differ in the surface contamination targeted, and amount of substrate removed. This may be dependent on contact time, concentration of active constituents, temperature, and other parameters such as pH. It is important to monitor and control non-targeted chemical reactions as they may be detrimental to the quality or safety of the component or assembly. Deoxidising removes surface oxides thereby preparing the surface. Pickling/etching removes surface oxides and limited underlying metal substrate. During etching, the substrate is affected in a more aggressive manner (up to 15µm of the substrate may be removed depending upon operating parameters). Desmutting is usually considered as an additional pre-treatment used to remove residues or complexes that are often left after etching for example.

There is considerable overlap between these terms in the Aerospace and Defence industry. Indeed, depending on the company, the site and the country, different terminology may be used to describe the same treatment either designated as deoxidising, pickling, etching and/or desmutting. It can be noted that a variant of pickling/etching within the scope of pre-treatments

[8] Referred to as pickling/etching

is “electropolishing” used to describe an electrolytic pickling or etching treatment with specific parameters of use and performance requirements.

It is not uncommon for the same or similar operational conditions to be applied for all pre-treatment processes (concentration, temperature; varying in contact duration to achieve the required surface finish). At some sites, the same baths are used to perform different pre-treatment processes, only the immersion duration differs.

Cr(VI) is reduced to Cr(III) during this process and no Cr(VI) is incorporated into or onto the surface layer. As a consequence, subsequent machining activities on treated parts are not further included in this assessment.

The key functionalities of Cr(VI) for deoxidising, pickling, etching and/or desmutting are detailed in Section 3.2.1.

Deoxidising, pickling, etching and/or desmutting are in most cases carried out by immersion of parts in treatment baths. Typically, the treatment baths for deoxidising, pickling, etching and/or desmutting are positioned in a large hall where baths for other immersion processes are also present; some of these baths might also involve the use of Cr(VI) although they may be unrelated to the present use. The immersion tanks can be placed individually or within a line of several immersion tanks. Usually, at least one rinsing tank with water is positioned after an immersion tank, for rinsing off the pre-treatment solution from the part(s).

A variety of substrates are cleaned with a pre-treatment: Mainly aluminium, but also magnesium, stainless steel, nickel, steel, copper, or brass.

Figure 2-1: Pre-treatment immersion baths
Source: ADCR member

2.3.1.2 Choice of chromate

Deoxidising, pickling, etching and/or desmutting in the Aerospace and Defence industry and its supply chains are mainly performed with chromium trioxide but also with sodium dichromate. The two chromates do not differ in terms of functionality for this use. The reason why either one or the other is used is, in most cases, due to that particular chromate being defined in the specifications of the customer for a particular component and/or application; such a specification by the customer often has a historical or empirical background.

When no specification is given by a client, the choice of the chromate by the site is often based on practical reasons, e.g., because a site prefers to use one of the two chromates for other processes as well, and/or the handling of one of the substances is preferred.

2.3.1.3 Relationship to other uses

As shown in Figure 2-2, some main treatments (anodising, chemical conversion coating, electroplating or passivation of stainless steel) require one or more pre-treatment steps. These pre-treatment processes involving chromates can be deoxidising, pickling, etching and/or desmutting.

For the combination with each main treatment, all details on the main treatment are described in the dedicated CSR (see ADCR dossiers “Anodising”, “Electroplating”, “Chemical Conversion Coating”, or “Passivation of stainless steel”).

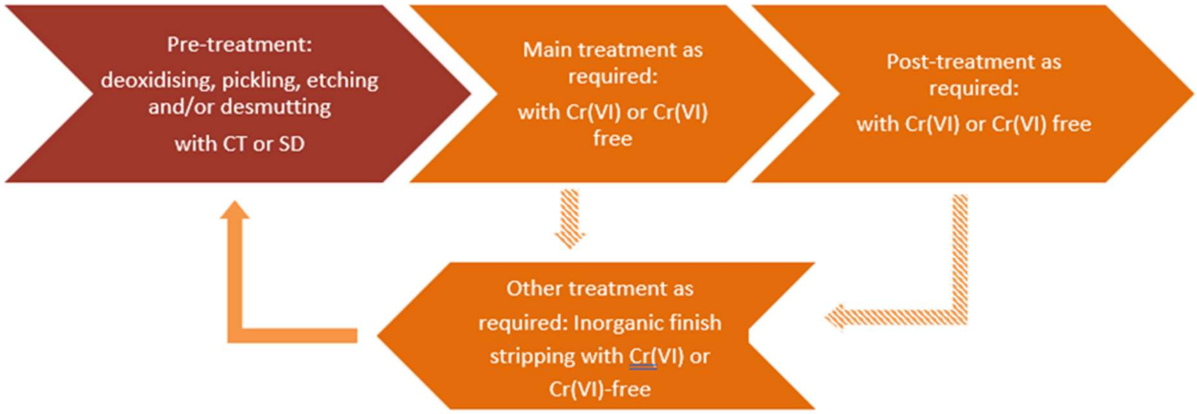

Figure 2-2: Schematic presentation of treatment steps

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

Cr(VI) pickling/etching, deoxidizing, or desmutting solutions may be required as individual pre-treatment processes prior to certain (non-coating) processes such as chemical milling or welding, that are sensitive to surface contamination.

It is also reported that in some old applications, like in the case of paint application, Cr(VI) and Cr(VI)-free coatings are applied directly to pre-treated substrates without the need for a subsequent underlying intermediate treatment.

It is important to note, however, that these pre-treatment processes form part of a process flow and the benefits from the continued use of chromate-based pre-treatment may also rely on the ability to continue using the hexavalent chromates in other processes where these are required by OEMs. For example, use of Cr(VI) conversion coatings can form part of a corrosion protection process (see Figure 2-2), and it may not be possible to substitute a chromate-based pre-treatment if it is not compliant with a technically feasible alternative for the chemical conversion coating. Combined AoA/SEAs for the main treatments that work together with pre-treatment processes to form a corrosion protection system, are the focus of other ADCR dossiers.

2.3.2 Temporal scope

Due to the lack of qualified and viable alternatives for the use of the chromates in pre-treatment processes for A&D components, it is anticipated that it will take a further 12 years or more to develop, qualify, certify, and industrialise alternatives for all substrate and component/design combinations across the sector as a whole. Over this 12-year period, the temporal boundaries adopted in this assessment take into account:

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

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

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

2.3.3 The supply chain and its geographic scope

2.3.3.1 The ADCR Consortium

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

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

Most of the larger ADCR members (15 of 24) support the use of chromates in pre-treatment; this may be either for their own use or for use in the supply chain. The larger members in particular may be supporting the use of one or more of the chromates in pre-treatment to ensure it is available to their suppliers as well as their own use. Both CT and SD are evenly supported in the EEA.

A third of the larger ADCR members (8 of 24) support the use of chromates in the UK with most member supporting chromium trioxide and sodium dichromate. As for EU REACH, the larger members are supporting both their use and use by their UK suppliers.

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

	Use	Chromium trioxide	Sodium dichromate
EEA	Deoxidising	8	8
EEA	Desmutting	4	4
EEA	Pickling/Etching (scale conditioner)	9	7
UK	Deoxidising	6	4
UK	Desmutting	2	2
UK	Pickling/Etching (scale conditioner)	5	3

2.3.3.2 Suppliers of chromate substances and mixtures

The types of Cr(VI) products used in pre-treatment are listed in the table below. For pre-treatment, four generic chromate products have been identified. In broad terms, the two chromates (chromium trioxide and sodium dichromate) may be sold in solid form (including as a pure substance) and in aqueous solutions of various strengths. Four generic chromate products have been identified as being used in pre-treatment; these are listed in Table 2-4.

Table 2-4: Products used in pre-treatment

Product A	Solid chromium trioxide (flakes or powder), pure substance or mixture (100%)
Product B	Aqueous solution of chromium trioxide as purchased (up to 60% w/w)
Product C	Solid sodium dichromate (flakes or powder), pure substance or mixture (up to 100%)
Product D	Aqueous solution of Sodium dichromate as purchased (up to 99% (w/w)

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

2.3.3.3 Downstream users of the chromates for pre-treatment

Pre-treatment 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[9] (DtB) – companies which design and build components;
- Build-to-Print (BtP) – companies that undertake specific processes, dictated by their customers, involving chromates on components; and
- Maintenance, Repairs and Overhaul (MRO) – companies that service aircraft, space and defence equipment.

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

It is important to note that companies may fit into more than one of the above categories, acting as an OEM, DtB, and MRO[10], where they service components they designed and manufactured which are already in use. Similarly, a company may fall into different categories depending on the customer and the component/final product.

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

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

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

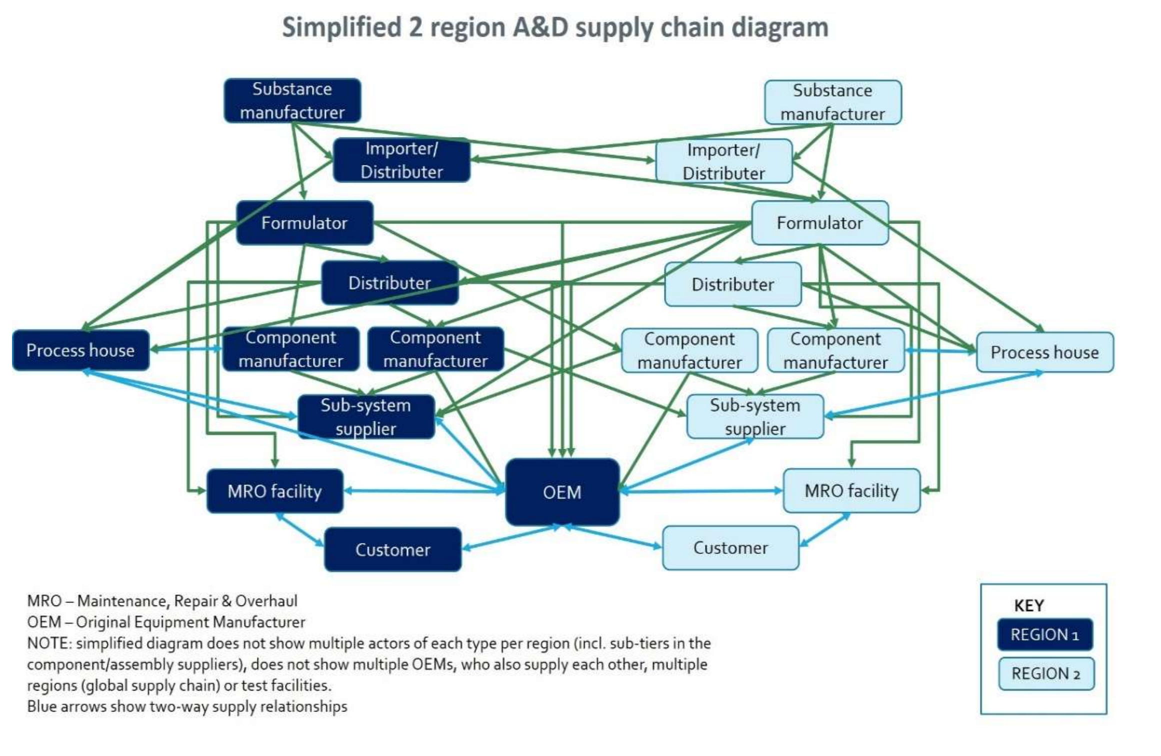

Figure 2-3: Complexity of supply chain roles and relationships within the A&D sector Two-way supply relationship are indicated by the double headed arrows

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

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

Table 2-5: Distribution by role of SEA questionnaire respondents providing information on pre-treatment

Role	**Number of companies EEA & UK**	**Number of sites** EEA & UK
OEMs	6	17
Design and build	7	7
Build-to-Print	18	22
MRO mainly (civilian and/or military)	6	7
Total	37	53

2.3.3.4 OEMs, DtB and BtP Manufacturers

This surface treatment is carried out by companies across all roles within the supply chain. In the case of EEA/UK-based OEMs, these suppliers are often located in the same country (if not the same region) as their main OEM customer.

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

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

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

Both DtBs and BtPs tend to be located relatively close to their customers, which sometimes results in the development of clusters across the EU and within the UK.

2.3.3.5 Maintenance, Repair and Overhaul

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

A representative life cycle of a typical aerospace product – a commercial aircraft - is illustrated in Figure 2-4. This highlights that: the development of a new aerospace system can take up to 15 years; the production of one type of aerospace system may span more than 50 years; and the lifespan of any individual aircraft is typically 20-30 years. Figure 2-4 provides an overview of the life cycle of weapon systems, which are usually used much longer than the originally projected lifetime. Such life cycles can be significantly longer than 50 years. For such systems, it is extremely costly to identify and replace legacy applications of chromates without impacting performance, where performance has been assured for many decades.

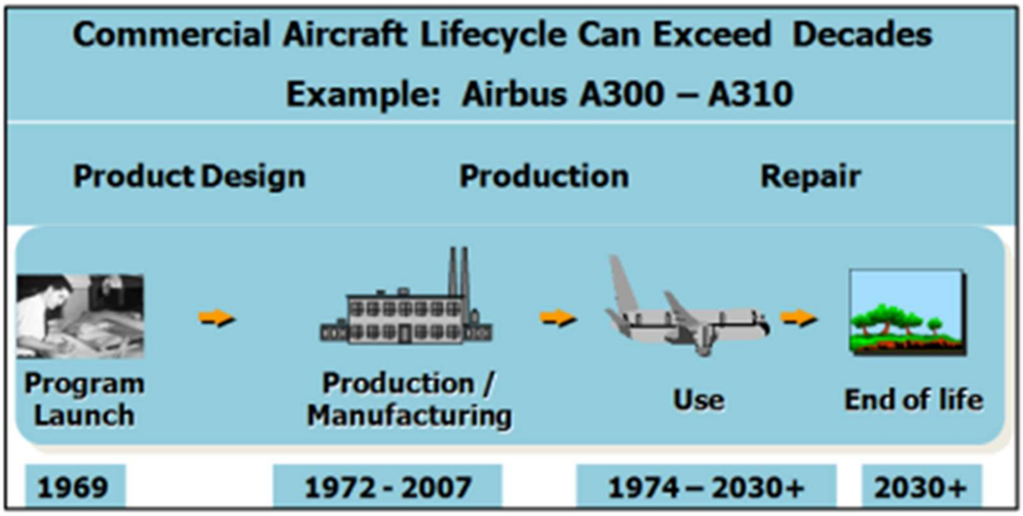

Figure 2-4: Commercial Aircraft Service Life, from ECHA & EASA (2014)[11]

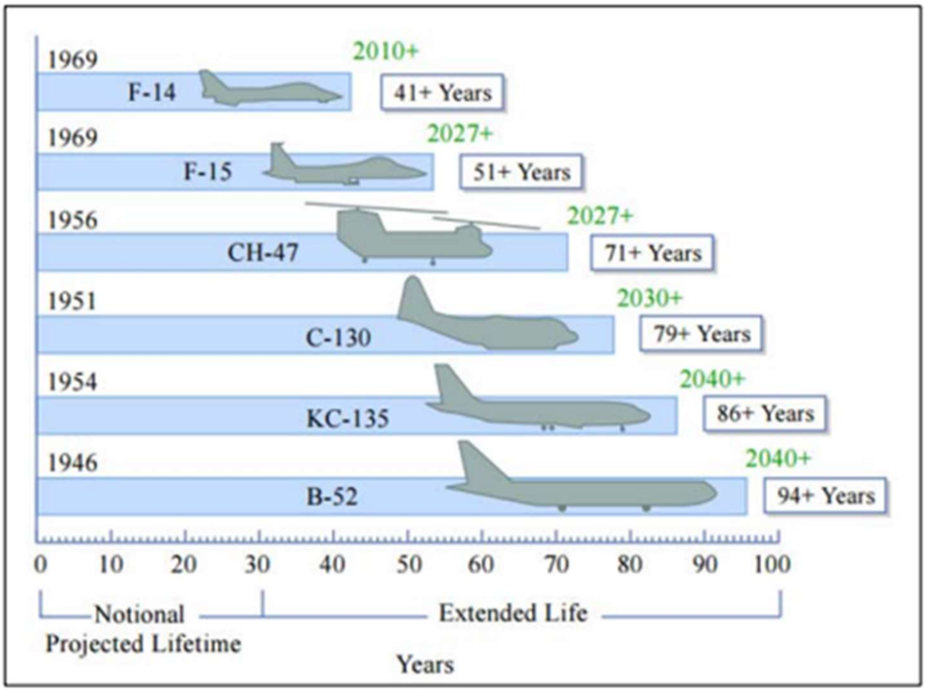

Figure 2-5: Life cycles of defence aircraft, from A Haggerty (2004)[12]

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

12 https://studylib.net/doc/13484803/lifecycle-considerations-aircraft-systems-engineeering-al...

Even if new designs/components – coming onto the market in the short to medium term – might succeed in dispensing with the need for pre-treated components, products already placed on the market still need to be maintained and repaired using chromate-based pre-treatment until suitable alternatives are validated for use in MRO for those existing products. Maintenance manuals for such existing products (which the user is legally obliged to comply with) detail, amongst other information, the processes, and materials initially qualified (sometimes decades ago) and required to be used, which form a substantial portion of the type certification.

As a result, MROs (and MoDs) face on-going requirements to undertake pre-treatment in strict adherence to the requirements of qualified repair and maintenance schemes to ensure continued safe operation of the final A&D products.

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

2.3.3.6 Estimated number of downstream user sites

Based on the information provided by the companies, it would appear that work involving pre-treatment for ADCR members is undertaken at numerous sites across the EEA with an average of 10 sites per OEM/DtB company – although some of the larger companies have over 20 active sites (either their own or their suppliers)

Furthermore, there are countries – France, Germany, Italy and Poland - where several OEMs and DtB companies have major facilities. As such, there is likely to be some overlap since some BtP and DtB companies will carry out pre-treatment on components supplied to more than one OEM or DtB company in their area. Taking this into account, the estimated number of sites in the EEA has been taken as 80.

For the UK, based on the information provided by the OEMs and DtB companies, as well as considering relevant data, it would appear that pre-treatment for ADCR members is undertaken at around 20 sites across the UK.

Under Article 66 of REACH downstream users covered by an authorisation up their supply chain must notify ECHA of their use. As of 31 December 2021, ECHA had received 908 notifications relating to the various REACH Authorisations listed above covering 1127 sites across the EU-27 (and Norway). The distribution of notifications by substance and authorisation is summarised below. It is important to note that some sites may draw on more than one Authorisation for use of the same substance. 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.

There are more sites than notifications, reflecting the fact that some notifications cover more than one site[13]. However, several of the authorisations cover 'surface treatment' which covers more treatments than just pre-treatment processes. As such, the number of sites undertaking pre-treatment will be far fewer than the indicated 1127. Furthermore, some sites will be using more than one of the chromates for pre-treatment processes lowering the figure even further. Indeed, some ADCR members may use multiple chromates at an individual site for pre-treatment.

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

With these points in mind, the estimated 80 EEA sites to be covered by this combined AoA-SEA and by the ADCR applicants is believed to be consistent with the ECHA data on Article 66 downstream user notifications.

Table 2-6: Number of downstream users using chromium trioxide and sodium dichromate notified to ECHA as of 31 December 2021

Substance	Authorisation	Authorised Use	Notifications	Sites
Chromium trioxide	20/18/7-13	Surface treatment of metals	526	619
	20/18/14-20	Surface treatment of metals	263	357
Sodium dichromate	20/5/3-5	Surface Treatment for aerospace	61	84
	20/4/1	Surface treatment of metals	58	67
Totals			**908**	**1127**

Source: Number of downstream uses covered by granted authorisations as notified to ECHA by 31 December 2021, data available from https://echa.europa.eu/du-66-notifications

2.3.3.7 Geographic distribution

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

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

Table 2-7: Number of authorised sites using chromium trioxide or sodium dichromate notified to ECHA as of 31 December 2021	
Country	**# Sites**
France	34%
Germany	14%
Italy	12%
Poland	9%
Spain	8%
Czech Republic	4%
Sweden	3%
Other EU-27 countries and Norway	16%
EU-27 plus Norway	100%

2.3.3.8 Customers

The final actors within this supply chain are the customers of A&D final products treated via pre-treatment processes.

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 12 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[14]. More specifically to Europe, in 2019 over one million passengers travelled by air in the European Union, with net profits of over US$ 6.5 billion (€5.8 billion, £5.1 billion)[15]. 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[16]. 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 pre-treatments.

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

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

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

[16] *Source:* Eurostat (gov_10a_exp)

extend the service life of aging aircraft given the costs of new military aircraft. Maintenance of aircraft and products is already reported to face difficulties due to material obsolescence issues over the extremely long service lives of such hardware. A major issue is obtaining readily available components for the vast number of aircraft flying beyond their originally expected lifecycles.

2.4 Consultation

2.4.1 Overview

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

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

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

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

Further details of each are provided below.

2.4.2 Consultation with applicants

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

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

2.4.3 Consultation with downstream users

2.4.3.1 ADCR Consortium members

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

1) Phase 1 involved collection of information on surface treatment activities that each member undertook. This included:
    a. Supply chains

b. Substances used in each activity and associated volumes
c. Key functions provided by the substance
d. Locations for each activity
e. Likelihood of substitution before 2024

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

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

3) Phase 4 collected information for the SEA component of this document, with this including:
    a. Base data on the economic characteristics of different companies
    b. Additional information on volumes used of the chromates and for what processes, and trends in this usage over the past seven years and as anticipated into the future
    c. The importance of chromate-using processes to the turnover of individual companies
    d. Past investments in R&D into alternatives
    e. Past investments into capital equipment related to on-going use of the chromates as well as to their substitution; this included investment in new facilities outside the EEA
    f. Numbers of employees directly involved in use of the chromates as well as the total number of employees at sites that would also be directly impacted under the Non-Use scenario
    g. Economic and social impacts under the Non-use scenario.

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 must move to alternatives certified for the manufacture of their components and products as part of their own design activities.

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

As a final count, data for 53 sites operated by the ADCR OEMs and their DtB and BtP suppliers provided responses to these questionnaires. The information provided by the companies forms the basis for the SEA component of this document.

2.4.3.3 MROs

For consistency purposes, MROs were asked to also complete the BtP or DtB questionnaires. Again, these were supplied directly to MROs or were distributed by ADCR members to key suppliers.

MoDs were also asked to participate in the work and a number of military MROs provided data on their activities to ensure that these would also be covered by a renewed Authorisation. Their data is included in the SEA as appropriate to their activities.

3 Analysis of Alternatives

3.1 SVHC use applied for

3.1.1 Substance ID and Overview of the key functions and usage

The definition of pre-treatment processes , as agreed by ADCR members, is:

> *"Deoxidising: Required to prepare and activate the surface prior to further processing i.e., to remove surface oxides. Very little metal is removed during deoxidising; Desmutting: Removal of residue that is often left over from etching processes; Pickling/etching (scale conditioner): Removal of oxides or other compounds from a metal surface by chemical or electrochemical action; etching is a process that changes the metal surface as well as removing material".*

As indicated in Section 2, the chromates that are of relevance to the Applied for Use are:

Chromium trioxide (includes "Acids generated from chromium trioxide and their oligomers", when used in aqueous solutions)	EC 215-607-8	CAS 1333-82-0
Sodium dichromate	EC 234-190-3	CAS 10588-01-9

Pre-treatment processes are reported to be applied by a variety of methods, typically by immersion. Other reported application methods include brush and sponge. Examples of immersion baths are given in **Figure 3-1.** Pre-treatment tanks may be placed individually or in series with a rinsing tank to wash off the pre-treatment solution.

Figure 3-1: Pre-treatment immersion baths
Source: ADCR member

3.1.1.1 Process steps and overview of key functions

As described in section 2.3.1.3, there are various steps in the surface treatment process; pre-treatments, main treatments, and post-treatments.

The use of chromates (Cr(VI)) for pre-treatments to prepare the surface is crucial to the treatment system as a whole. A variety of pre-treatment processes including deoxidising, pickling/etching, and desmutting are available for the preparation of surfaces prior to subsequent treatments. Other cleaning steps may also be applied in a suite of preparatory steps, for example degreasing. However, degreasing, and alkaline cleaning are not covered in this combined AoA-SEA.

Surface preparation with pre-treatments must not adversely impact the functionality of subsequent treatments. Consequently pre-treatment, although a discrete process which can be assessed separately, is not considered a standalone process when evaluating candidate alternatives but as part of a whole treatment system process chain (GCCA, 2016b) . Further Cr(VI) compounds might also be used within the whole process chain (i.e., including the main and post-treatment process steps) that are not subject to this AoA.

Pre-treatment processes are used to prepare the substrate surface. This is dictated by the performance requirements and functionality criteria for a given combination of substrate, component/design, and service environment. The substrate surface must be completely free of contamination, either corrosion products or other foreign matter from whatever source. Surface preparation is key to the success of subsequent processes. The pre-treatment must not impact the subsequent main-treatment key functions and performance requirements. It is essential that the pre-treatment works in harmony or synergy with the main-treatment to ensure a successful outcome from the treatment system as a whole.

Pre-treatment processes are routinely used prior to a host of main-treatments including; anodising, electroplating, chemical conversion coating, and passivation of stainless steel. Each main treatment process is subject to its own technical feasibility criteria. These often require bespoke testing to evaluate key functions and performance requirements of the main treatment and related service environment of the component. The main treatment often works in synergy with the pre-treatment, inextricably linking each process in the delivery of the treatment system. Therefore, pre-treatment substitution plans must often be introduced and approved in unison with the main-treatment alternative.. This ensures delivery of a stable Cr(VI)-free treatment system where each part of the process is in harmony with the other. Main treatment down-stream uses deliver a selection of targeted functions and performance aspects to the design/component. Where multiple downstream processes share a common pre-treatment, the diversity of performance requirements expected from a single common pre-treatment process proliferate. This adds complexity to the qualification and certification steps within the substitution process for any single Cr(VI)-free pre-treatment. If a pre-treatment alternative cannot meet all key function and performance requirements for all down-stream processes, multiple pre-treatment alternatives may need to be approved in parallel to replace the universal incumbent Cr(VI) pre-treatment. Consequently certification of Cr(VI)-free pre-treatments can be wide ranging, complex, and time intensive when used in combination with multiple main treatment downstream uses.

The processes used for these different methods of surface preparation are referred to in this combined AoA-SEA as deoxidising, desmutting and pickling/etching; collectively referred to as pre-treatments and introduced in section 2.3.1.1.

The role of deoxidising can vary depending upon the nature of any other preparatory steps that may immediately precede it (such as degreasing), and the purpose of the subsequent main treatment process that follows. If an alkaline degreasing process is used, then deoxidising acts as an intermediate step to neutralise the resulting alkaline environment, and to remove any remaining contaminating oxides which may interfere with the subsequent treatment step(s). Deoxidising is reported to remove typically up to 1µm of material from the substrate, including surface oxide and intermetallic particles, leaving a surface containing chromium oxide (CCST, 2015)

Desmutting describes the removal of certain contaminants from surfaces. These may include metal sulphides and other complexes, or insoluble intermetallic particles incorporated into the metal matrix and released after etching. Desmutting solutions dissolve these particles without significant additional etching of the substrate. Desmutting may be used for example in the preparation of stainless steel before bonding or photochemical machining, a process using masking and acid to produce burr-free thin sheet metal components (*Photochemical Machining | Resonetics*, 2023) The desmutting pre-treatment process is used after an electrolytic preparation step to remove contaminants and achieve adequate adhesion of the subsequent bonded layer (CTAC, 2015b).

Pickling/etching has a variety of functions, for example to improve adhesion of the subsequent layer. The main treatment of electroplating for example is dependent upon adhesion of the plated coating to the underlying bulk substrate, which in turn is dependent upon force of attraction at the molecular level between the bulk substrate and electroplated coating. Any contamination such as oxides, corrosion products or other residues of the bulk substrate interfere with this bonding mechanism, thereby weakening adhesion. Pickling/etching removes these contaminants.

Pickling/etching may be distinguished from other pre-treatments by the amount of substrate material removed including oxides formed as a result of exposure to the atmosphere. Pickling typically removes up to 0.6µm during a five minute pickling step. Etching is more aggressive, typically removing 2 – 4µm over the same duration. Cr(VI) is used in pickling/etching to moderate the etch rate to prevent over-etching. This is important where strict dimensional tolerances must be adhered to. Another benefit of Cr(VI) for pickling/etching is for example its minimal impact on fatigue properties, which is required for fatigue sensitive components or assemblies(CTAC, 2015b). Etching is also used to remove small amounts of metallic substrate for inspection processes such as dye penetrant inspection (CTAC, 2015a).

A variant of pickling/etching is an electrolytic process often referred to as electropolishing, used to modify surface topography; reduce micro-roughness. This variant of the pickling etching process is used for specialised applications which can typically remove up to 15µm of material. Process parameters; current applied, exposure time and electrolyte, can be optimised to control the amount of metal removed, maintaining dimensional tolerances if required. The process does not impose any mechanical or thermal impact, so is suitable for small or delicate components of a wide variety of shapes and sizes Cr(VI) is used for buffering to assist rinsing off solutions after this process and for removing flaws and debris. Benefits of electropolishing include reducing surface roughness to aid corrosion resistance and to provide a surface for enhanced adhesion for subsequent bonding processes. Specific other benefits include the treatment of martensitic stainless steel by electropolishing with Cr(VI) to improve fatigue behaviour of structural parts (CTAC, 2015b).

Corrosion performance of subsequent treatments benefit from pre-treatment processes. For example, passivation treatments are negatively influenced by an inhomogeneous substrate which results in unpredictable corrosion resistance performance. Pre-treatments can be used to provide a homogenous surface more receptive to the passivation treatment, improving its performance (GCCA, 2016a).

Key functions of the chromates (Cr(VI)) in pre-treatment processes are:

- Corrosion resistance;
- Adhesion of subsequent coatings (including structural bonding);
- Surface preparation prior to further processing;
- Removal of contaminants/complexes after etching processes;
- Surface roughness modification: Removal of mechanically deformed layers/oxides/other compounds from the substrate; and
- Selective removal of material to reveal the surface or to improve surface properties.

In addition to the above key functions, when testing candidate alternatives to Cr(VI) in pre-treatments, a series of performance requirements need to be assessed dependent upon the service environment of the substrate or component to be treated. A non-exhaustive list of performance requirements is provided below:

- Shall neither cause end grain pitting nor intergranular attack in certain excess and depth;
- Metal removal of the substrate shall not exceed certain limits;
- Adequate etch rate;
- Minimum impact on fatigue performance – no degradation;
- Tensile strength testing – no degradation;
- Water-break free surface[17] without streaks or discolorations;
- No pitting or selective attack to the substrate;
- No non-rinseable residuals or contamination from the deoxidising solutions observed on the surface;
- Must not induce de-gassing from surface under vacuum;
- Does not induce pits, corrosion products, discolouration, uneven etching, increased surface roughness, or other defects that would prohibit further chemical processing; and
- Does not impact shot-peen compressive layer[18]

End grain pitting is a form of corrosion emanating from exposed end grain of the metallic substrate. Intergranular attack describes corrosion where the boundaries of crystallites of the substrate material corrode in preference to their interiors (Aerofin Laboratories, 2023)

3.1.1.2 Components that may be treated with the Annex XIV substance

As detailed above, pre-treatment processes like all surface treatments, modify the surface of the substrate to improve the substrate properties and adapt it to its specific use conditions. There are

[17] A water break free test uses immersion of a substrate in water. If the water does not break into droplets on the surface, then the surface is free from hydrophobic contaminants.

[18] Cold process used to produce a compressive residual stress layer and modify the mechanical properties of metals and composites. It entails striking a surface with shot (round metallic, glass, or ceramic particles) with force sufficient to create plastic deformation. Available at Shot peening - Wikipedia, accessed 12 December 2022

many corrosion and wear prone areas on A&D products which require the application of surface treatments. Examples of these are included in Table 3-1 below:

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

Structural/flight	Propeller/rotor	Engine/power plant	Additional Space- and Defence-specific
Aileron and flap track area	Blade tulip and hub	Auxiliary Power Units (APUs)	Air-transportable structures
Centre wing box	Gearbox	Carburettor	Fins
Cockpit frames	High bypass fan components	Data recorders	Gun barrels and ancillaries
Differential	Main and tail rotor head assemblies	Engine Booster and Compressors including Fan Containment	Interstage Skirts
Emergency valve landing gear	Propeller speed controller	Engine control unit	Launchers (rocket, satellite, etc.)
Environmental control systems	Propellers	Engine External components	Missile and gun blast control equipment
External fuel tanks	Transmission housing	Fuel pump	Missile launchers
Flight control systems		Gearbox	Pyrotechnic Equipment
Fuselage		Hydraulic intensifier	Radomes (Radar Domes)
Hydraulic damper		Ram air turbine	Rocket motors
Hydraulic intensifier		Starter	Safe and arm devices
Landing equipment		Vane pump	Sonar
Nacelles			
Pylons			
Rudder and elevator shroud areas			
Transall (lightning tape)			
Undercarriage (main, nose)			
Valve braking circuit			
Window frames			
Wing fold areas			
Source: (GCCA, 2017)			

It is important to note that even with the highly developed Cr(VI)-containing pre-treatment and 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 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 parts and assemblies

Wherever possible, A&D hardware is repaired rather than replaced. In addition to both time and cost considerations, this is a much more environmentally friendly approach from a lifecycle perspective, resulting in reduction of hazardous chemical usage, energy usage, carbon footprint, waste generation, etc. 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 & 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**[19]**,** 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

[19] 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

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.

The civil aviation industry must comply with the airworthiness requirements derived from Regulation(EC)No 2018/1139[20] in the European Economic Area (EAA). Similar airworthiness requirements exist in all countries where aeronautical products are sold. These regulations require a systematic and rigorous framework to be in place to qualify all materials and processes to meet stringent safety requirements that are subject to independent certification and approval through the European Aviation Safety Authority (EASA), and other agencies requirements. Safety critical defence aviation and space systems are subject to similar rigorous performance requirements as seen in the civil aviation sector, while ground and sea-based defence systems are managed more adaptively based on specific system requirements.

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

The A&D companies that design and integrate the final product (e.g., aircraft, engines, radar, and other defence systems), are each responsible for their own product qualification, validation, and certification, according to airworthiness regulations or defence/space customer requirements. Even superficially similar components, when used in different systems or under different environmental conditions, may have unique design parameters and performance requirements, driven by the requirements of the final product. Consequently, an alternative that has successfully been implemented for one component in a given subsystem will not necessarily be suitable for use in a different subsystem. Implementation of an alternative in varying scenarios of use must be individually assessed, validated, and certified across the components, subsystems and systems that make up the final product, for example an engine, aeroplane, helicopter, missile, or tank (as illustrated in **Figure 3-2**).

Military/defence OEMs have additional challenges because individual defence customers usually assume full design/change authority upon accepting the military/defence hardware designs. This means that any intent to change the hardware configuration, including coatings and surface treatments, must be approved by the military/defence agency, who are more 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 defence customers, it is often required to obtain permission from each customer prior to hardware

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

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/defence OEM effort to make hardware changes to existing designs to meet legislated goals such as chrome 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.

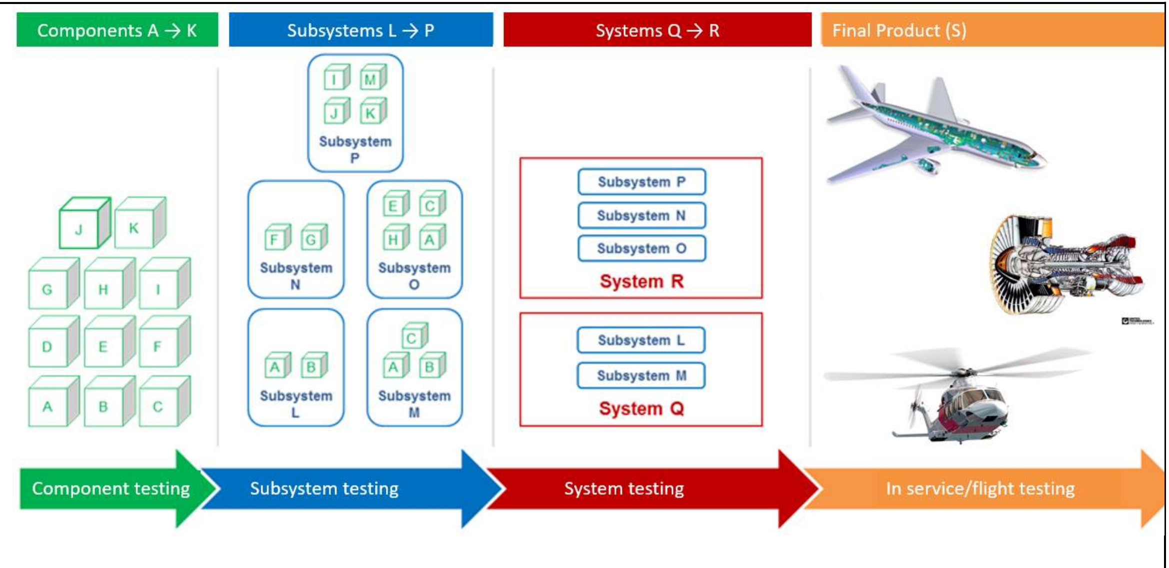

Figure 3-2: Assessment requirements in the implementation of alternatives
Source: Adapted from GCCA white paper

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

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

TRL	Definition	Description
1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.
2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3	Analytical and experimental critical function and/or characteristic proof-of-concept	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.

Table 3-2: Technology Readiness Levels as defined by US Department of Defence		
TRL	**Definition**	**Description**
4	Component and/or breadboard[a] validation in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively “low fidelity” compared with the eventual system. Examples include integration of “ad hoc” hardware in the laboratory.
5	Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include “high-fidelity” laboratory integration of components.
6	System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology’s demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7	System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space).
8	Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to determine if it meets design specifications.
9	Actual system through successful mission[b] operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.

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

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

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

Table 3-3: Manufacturing Readiness Levels as defined by US Department of Defence		
MRL	**Definition**	**Description**
1	Basic Manufacturing Implications Identified	Basic research expands scientific principles that may have manufacturing implications. The focus is on a high-level

Table 3-3: Manufacturing Readiness Levels as defined by US Department of Defence		
MRL	**Definition**	**Description**
		assessment of manufacturing opportunities. The research is unfettered.
2	Manufacturing Concepts Identified	This level is characterized by describing the application of new manufacturing concepts. Applied research translates basic research into solutions for broadly defined military needs.
3	Manufacturing Proof of Concept Developed	This level begins the validation of the manufacturing concepts through analytical or laboratory experiments. Experimental hardware models have been developed in a laboratory environment that may possess limited functionality.
4	Capability to produce the technology in a laboratory environment	This level of readiness acts as an exit criterion for the MSA Phase approaching a Milestone A decision. Technologies should have matured to at least TRL 4. This level indicates that the technologies are ready for the Technology Development Phase of acquisition. Producibility assessments of design concepts have been completed. Key design performance parameters have been identified as well as any special tooling, facilities, material handling and skills required.
5	Capability to produce prototype components in a production relevant environment	Mfg. strategy refined and integrated with Risk Management Plan. Identification of enabling/critical technologies and components is complete. Prototype materials, tooling, and test equipment, as well as personnel skills have been demonstrated on components in a production-relevant environment, but many manufacturing processes and procedures are still in development.
6	Capability to produce a prototype system or subsystem in a production relevant environment	This MRL is associated with readiness for a Milestone B decision to initiate an acquisition program by entering into the EMD Phase of acquisition. Technologies should have matured to at least TRL 6. The majority of manufacturing processes have been defined and characterized, but there are still significant engineering and/or design changes in the system itself.
7	Capability to produce systems, subsystems, or components in a production representative environment	System detailed design activity is nearing completion. Material specifications have been approved and materials are available to meet the planned pilot line build schedule. Manufacturing processes and procedures have been demonstrated in a production representative environment. Detailed producibility trade studies are completed and producibility enhancements and risk assessments are underway. Technologies should be on a path to achieve TRL 7.
8	Pilot line capability demonstrated; Ready to begin Low Rate Initial Production	The system, component or item has been previously produced, is in production, or has successfully achieved low rate initial production. Technologies should have matured to TRL 9. This level of readiness is normally associated with readiness for entry into Full Rate Production (FRP). All systems engineering/design requirements should have been met such that there are minimal system changes. Major system design features are stable and have been proven in test and evaluation.
9	Low rate production demonstrated; Capability 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.

Table 3-3: Manufacturing Readiness Levels as defined by US Department of Defence		
MRL	**Definition**	**Description**
10	Full Rate Production demonstrated and lean production practices in place	Technologies should have matured to TRL 9. This level of manufacturing is normally associated with the Production or Sustainment phases of the acquisition life cycle. Engineering/design changes are few and generally limited to quality and cost improvements. System, components or items are in full-rate production and meet all engineering, performance, quality and reliability requirements. Manufacturing process capability is at the appropriate quality level.
Source: Manufacturing Readiness Level (MRL) - AcqNotes		

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

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

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

3.1.2.2 Process, requirements, and timeframe

Identification & Assessment of need for substitution

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

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

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

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

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

Definition of requirements

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

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

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

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

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

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

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

Key phases of the substitution process

Once initial technical requirements are defined, test candidates can then be identified and tested by the design owner. **Figure 3-3** 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.

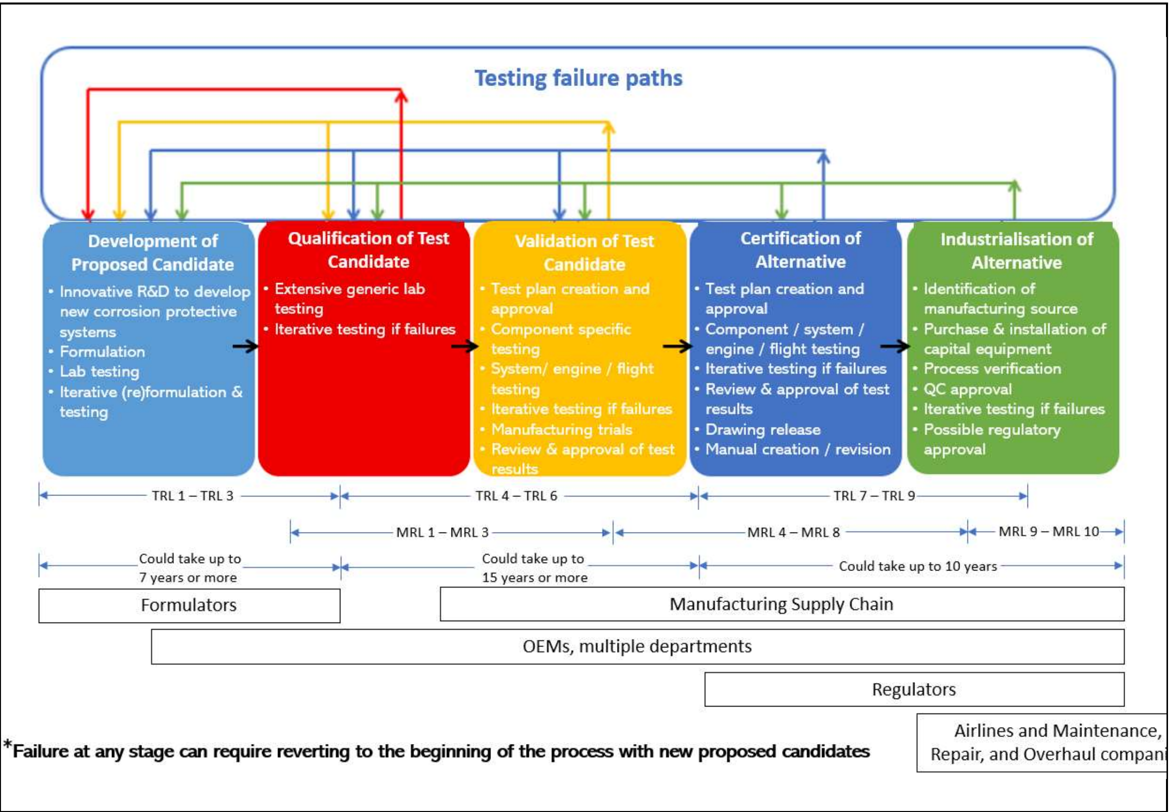

Figure 3-3: Schematic showing the key phases of the substitution process
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note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

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

Development of proposed candidates

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

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

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

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

Development typically involves an iterative process of re-formulation and re-testing to identify one or more proposed candidate. It is important to note that many iterations of these formulas are rejected in the formulator's laboratory and do not proceed to evaluation by the design owner. Formulators estimate that it typically takes two to five years of testing potential formulations before a proposed candidate is identified for submittal to the design owner[21].

Qualification of test candidate

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

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

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

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

[21] GCCA

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

Validation of test candidate

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

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

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

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

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

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

Certification of alternative

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

Steps in the Certification stage include:

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

For the civil aviation industry, the output of the original certification process is a Type Certificate, issued by the airworthiness authority (e.g., EASA) and granted to the engine, propeller, and airframe OEM. This is issued for the original design of the final product, rather than for each individual component, however every component of the final product must be designed, developed, and validated as meeting the requirements of the overall product and system design. The overall compliance demonstration for a new Type Certificate therefore may cover several thousand individual test plans, of which some will require several years to complete. This interconnection is illustrated using the example of an aircraft in **Figure 3-4** below.

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

Removing a material or process reliant upon Cr(VI) and implementing an alternative is particularly challenging as it will involve in service or in production components. Re-certification of all components incorporating the new processes and materials is therefore required. As discussed in the description of the certification process in the GCCA AfA for strontium chromate[22], each of these components will need to be approved individually:

> "*Importantly, even if an alternative is in use in one component in aerospace[23] 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*

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

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

the different design parameters. Extensive experience shows that an alternative that is successfully certified in one component in one model cannot necessarily be successfully certified in another. In other words, the circumstances for each component in each model are unique and extrapolation is impossible without validation and certification."

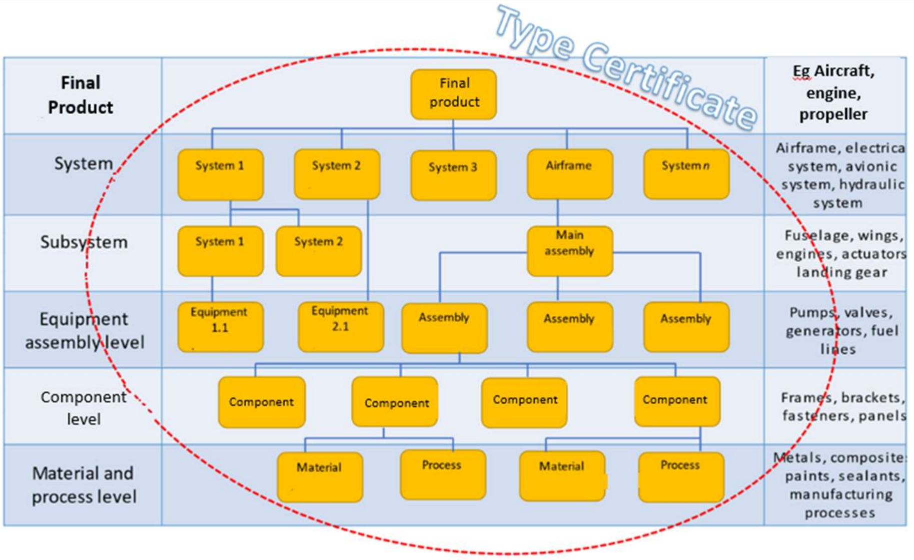

Figure 3-4: System hierarchy of a final product shows the interconnection of each level in the system hierarchy, and how changes at a lower level have impacts on the higher levels.
Source: ADCR member

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

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

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

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

Industrialisation of alternative

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

Elements of the Industrialisation of alternative process include:

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

A&D products consist of up to a million components provided by thousands of suppliers or manufactured internally by OEMs, making communication between OEMs and their supply chain regarding what is permissible for use on A&D products key. Suppliers must be vetted through a supplier qualification process prior to being issued a contract. This process typically involves internal approval, contract negotiation, running a specific qualification test 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 3-5** below.

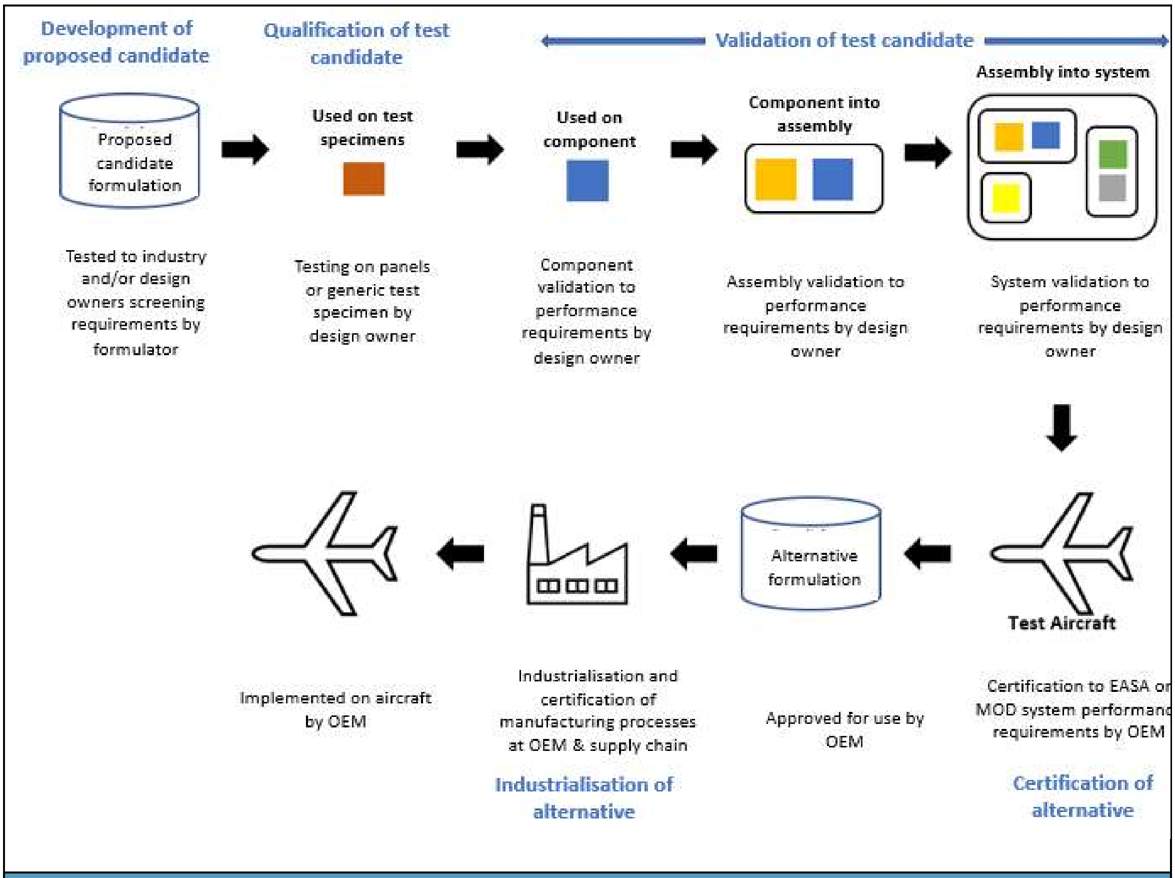

Figure 3-5: Process to Certify a Formulation for use on Aircraft. Formulations used in production have completed this process. New or reformulations must follow same process for use in production.
Source: ADCR member

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 pre-treatments

3.2.1.1 Introduction

The development of technical feasibility criteria for proposed candidates to replace the use of the Cr(VI) substances in pre-treatments 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 impart in this use, and that any test candidates (substances and technologies) would also need to impart in order to deliver the functions attributed to pre-treatments.

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

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

- Corrosion resistance;
- Adhesion of subsequent coatings (including structural bonding);;
- Surface preparation prior to further processing;
- Removal of contaminants/complexes after etching processes;
- Surface roughness modification: Removal of mechanically deformed layers/oxides/other compounds from the substrate; and
- Selective removal of material to reveal the surface or to improve surface properties.

The impact of test candidates on performance requirements must also be evaluated. As described in section 3.1.1.1 a variety of additional performance requirements may be assessed depending on the pre-treatment process, and service environment(s) that the substrate, component or assembly will operate in. Design owners may also assess against other bespoke performance requirements on a case by case basis as appropriate.

Examples of performance requirements for the pre-treatment processes of deoxidising, pickling/etching and desmutting are given below:

- Shall neither cause end grain pitting nor intergranular attack in excess of certain depth;
- Metal removal of the substrate shall not exceed certain limits;
- Adequate etch rate;
- Minimum impact on fatigue performance – no degradation;
- Tensile strength testing – no degradation;
- Water-break free surface without streaks or discolorations;

- No pitting or selective attack to the substrate;
- No non-rinseable residuals or contamination from the deoxidising solutions observed on the surface;
- Must not induce de-gassing from surface under vacuum;
- Does not induce pits, corrosion products, discolouration, uneven etching, increased surface roughness, or other defects that would prohibit further chemical processing; and
- Does not impact shot-peen compressive layer.

As noted above, this combined AoA/SP and SEA covers the use of two chromates for pre-treatment; chromium trioxide (includes “acids generated from chromium trioxide and their oligomers"), and sodium dichromate.

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 of pre-treatments. By extension, the donor chromate substance containing Cr(VI) delivers the functions attributed to Cr(VI) within the over-arching use.

Mode of action is important to consider when analysing test candidates as there may be something unique about the chemistry of Cr(VI) in contributing to a particular function that cannot easily or sufficiently be replicated by another substance; any impact on the functionality and performance requirements of the intended use must be assessed.

The discussion below explains the relevance of each technical feasibility criteria, capturing key functionality and performance requirements in the context of the overall use whilst considering the role of standards and specifications in the assessment of proposed candidates.

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 in section 3.1.2, proposed candidates are at an early stage of evaluation, represented by TRL 1 to 3. This low level of maturity is not recognised as representative of credible test candidates. Proposed candidates are screened against the key functions and performance requirements as appropriate, required by the pre-treatment use. These functions are measured against performance thresholds using standardised methodologies. 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 the 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 the proposed candidate exhibits 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 to 6 and above. Testing regimes to meet the requirements of TRL 4 to 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 3-6**. 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 3-6: Multi-climate chamber for simulated environment testing
(Airbus SAS, 2022)

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

Interrelationship of pre-treatments with main treatments and their impact on the surface treatment functions and system as a whole.

When considering the surface treatment system, pre-treatment processes strongly influence the successful delivery of subsequent uses.

The removal of surface oxides via deoxidising prepares a surface for passivation and hence deoxidising is pivotal in the successful application of passivation and the delivery of corrosion resistance. Where desmutting is used to treat for example stainless steel contaminated with residual complexes such as metal sulphides and insoluble intermetallic particles, the desmutting effectively prepares the surface to support subsequent adhesion and bonding processes.

Pickling/etching, including electropolishing, removes surface contaminants that could impair corrosion resistance or adhesion of subsequent layers. These contaminants embedded on the substrate surface can result from various processes including machining, welding, fabrication and grinding, or from exposure to atmospheric oxidation. Removal of heavy contamination resulting from industrial fabrication processes can require more aggressive etching processes which could impact the underlying substrate, for example its fatigue strength. Pickling/etching processes containing Cr(VI) benefit from minimal impact on fatigue properties. This is an important performance requirement for fatigue sensitive components or assemblies which may be subject to main treatments that need to be carefully controlled to minimise fatigue debit (knock-down) , for example anodising. Therefore, collectively the pre-treatment and main treatment must not impact fatigue strength beyond specified limits.

Electropolishing may also be used to modify the roughness (surface topography) of the substrate to facilitate adhesion to subsequent coatings. It is reported that surface roughness can reduce capacity for surface deformation required for unimpeded contact between two surfaces. Even a relatively small degree of roughness can weaken this interaction between surfaces reducing adhesion delivered by subsequent processes, such as bonding application and electroplating for example. Excessive surface roughness can also decrease initial corrosion resistance as a result of increased surface area. In addition electropolishing is used to reduce surface roughness to improve corrosion resistance (Chaghazardi and Wüthrich, 2022) . As a consequence of these inter-relationships, it is not possible to effectively deliver the treatment system without considering the impact of the pre-treatment process or processes when assessing proposed candidates for the main treatment or use.

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, including pre-treatment, at the same time to ensure a stable treatment system. Examples exist on the market of proprietary main treatment alternatives that use pre-treatment chemistries specified by the formulator of the Cr(VI) free main treatment. In these cases, both need to be evaluated and approved together. Time and complexity is added to the substitution process if the proprietary pre-treatment chemistry is new and not already certified for use. 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. It is often good practice to approve Cr(VI)-free test candidates for both pre-treatment and subsequent uses together to ensure both are compatible with one another, despite the added time and complexity that this may introduce.

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[24]:

- Hardware[25] base alloy(s);
- Contact or mating surfaces with other parts;
- Exposure to fluids;
- Structural stress and strain; and
- External environment.

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

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

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

- Exposure to chemicals e.g., de-icer, lubricants, salts, sea water/moisture;
- Temperature;
- Galvanic influences from different metals in contact with one another; and
- Mechanical effects; galling[26], 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 pre-treatment alternative may not provide a universal solution to delivery of all technical criteria in combination with subsequent uses under all scenarios.

3.2.1.3 Technical feasibility criterion 1: Corrosion resistance

The A&D industry have very demanding requirements for corrosion resistance. As discussed in section 3.1.1.1, pre-treatment processes provide a homogeneous uniform surface free from contamination that facilitates the delivery of subsequent uses and corrosion resistance functionality. Inhomogeneous surfaces exhibiting contamination sites can cause uneven deposition of the subsequent treatment or block access to the substrate thereby impeding corrosion resistance from the main use and treatment system as a whole. The pre-treatment must not contribute to corrosion in the form of corrosion pits or other defects for example intergranular attack or end grain pitting greater than limits specified by the design owner. Excessive surface roughness of the substrate decreases initial corrosion resistance as a result of increased surface area. Reducing surface roughness improves corrosion resistance.

3.2.1.4 Technical feasibility criterion 2: Adhesion of subsequent treatments

Pre-treatment processes are critical to the functionality of the main use and adhesion of subsequent coatings as appropriate. Etching processes remove surface contaminants that would otherwise impede adhesion of subsequent layers or affect the uniform application of a subsequent treatment, promoting adhesion of a coating to the substrate (including structural bonding). Contaminants present on, or embedded in, the substrate are likely to interfere with adhesion of subsequent layers or successful application of a main treatment. Electropolishing may also be used to modify the roughness (surface topography) of the substrate to facilitate adhesion to subsequent coatings For some components, an extremely smooth surface is required. For others, a controlled level of surface roughness is beneficial for adhesion of subsequent coatings. Excessive roughness can serve to decrease the adhesion and cohesive strength, reducing adhesion for subsequent processes such as bonding applications and electroplating.

3.2.1.5 Technical feasibility criterion 3: Surface preparation prior to further processing

The role of Cr(VI) in deoxidising is to improve the uniformity of substrate removal and activate the surface for subsequent processing. Deoxidising serves to renew and activate the substrate surface by removing surface oxide and the majority of intermetallic particles and readies it to receive the next treatment in the production process. Typically, no more than 1µm of the surface is removed, subject to operating conditions (CTAC, 2015b). Deoxidation removes uncontrolled or excess oxide layers that interfere with downstream processes. A predictable oxide layer forms immediately after deoxidising

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

which is tolerable if downstream processes are conducted immediately. Therefore deoxidation may be required between manufacturing processes where the component is fabricated at one site and followed by a downstream process at another, for example if there is a significant time between manufacture of the component and electroplating. If the component to be electroplated is exposed to the atmosphere, oxidation of the surface will start immediately leading to excess build up over time. Without a deoxidation step to prepare the surface of the component, it is likely that adhesion will be compromised or fail altogether if excess build-up of oxide has developed.

3.2.1.6 Technical feasibility criterion 4: Removal of contaminants/complexes after etching processes

Etching processes produce residues as a by-product. These include metal sulphides, complexes as well as insoluble intermetallic particles incorporated in the metal matrix. The pre-treatment process of desmutting dissolves these particles and removes other contaminants without significant additional etching of the substrate. Applications of desmutting include the preparation of stainless steel before bonding or photochemical machining. Another use of desmutting is the removal of insoluble surface material and oxides prior to anodising.

3.2.1.7 Technical feasibility criterion 5: Surface roughness: Removal of mechanically deformed layers/oxides or other compounds from the substrate

Surface roughness influences the adhesion of subsequent coatings. As discussed above electropolishing modifies the surface topography of the substrate, improving adhesion to subsequent coatings. For some components, an extremely smooth surface is required. For others, a controlled level of surface roughness is beneficial for adhesion of subsequent coatings, while excessive roughness can serve to decrease the adhesion and cohesive strength of subsequent layers . In addition, excessive surface roughness can also decrease initial corrosion resistance as a result of increased surface area. Pickling/etching processes remove mechanically deformed layers including oxides and other compounds from the substrate that contribute to surface roughness. Etching is used in support of quality control processes to prepare surfaces for example by removing metal smear from machining processes. Once prepared, these surfaces are monitored for the presence of defects such as cracks or other imperfections, by visual dye penetrant inspection tests. Dye penetrant inspection (e.g., ASTM E 1417) is used to check for defects including pits, corrosion products, discolouration, uneven etching, increased surface roughness etc., that could impact subsequent treatment processes. A reported benefit of using Cr(VI)-based etchants is their very low impact on fatigue strength for sensitive components (CCST, 2015) (GCCA, 2016a)

3.2.1.8 Technical feasibility criterion 6: Selective removal of material to reveal the surface or surface properties

The selective removal of controlled amounts of substrate material to remove defects and activate the surface is dependent on a controlled etch rate. The quality of the subsequent coating is influenced by control of the etch rate. The etch rate must be matched to the substrate to avoid under or over etching. Either outcome could compromise the performance of the subsequent treatment, for example optimum adhesion for bonding processes. The etching process should not incur detrimental intergranular attack or end grain pitting outside of specified limits (CTAC, 2015b).

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 Research and Development Collaborations

To further highlight the significant efforts being made by the aerospace and defence sector to substitute Cr(VI) from pre-treatments, ongoing and past R&D collaborations are identified below. Collaborations are mentioned within the parent AfAs associated with the ADCR consortium combined AoA-SEA reports, e.g. the Global Chromates Consortium for Aerospace (GCCA), chromium trioxide Authorisation Consortium (CTAC) and chromium VI Compounds for Surface Treatment (CCST). This review focuses on collaborations which include research into the development of alternatives for pre-treatment. 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 collaboration/projects include:

- **HITEA 3:** HITEA3 (Highly Innovative Technology Enablers for Aerospace) part of series of programmes linked to the REACh Compliant Hexavalent Chrome Replacement for Corrosion Protection funded a selection of aerospace research projects., namely the Advanced Hex Chrome-free Surface Technologies for Corrosion Protection consortium, between May 2016 and July 2019. This project considered alternatives to pickling/etching, including proprietary mixtures. This was the final project under the HITEA consortium. Participants in the programme moved to separate in-house projects to conduct further development.

- **OptiComp:** A follow on project from HITEA 3. Proprietary mixtures were identified for pickling/etching applications. Proposed candidates include proprietary mixtures based on sulfonitroferric acid with co-formulants. A focus of the project was to develop a better understanding of Cr(VI) free deoxidisers and to assess as pre-treatment candidates to REACH compliant conversion coatings and anodising processes.

- **FANTASTIC:** (Future Advance Nacelle Technologies and Structural Integration Concepts) considers alternatives for sodium dichromate for pickling and etching and deoxidising for aircraft structures. A nacelle is a streamline housing used on aircraft, the streamline casing of an aircraft engine. Alternatives considered for pickling and etching, and deoxidising include nitric acid, sulphuric acid-ferric sulphate and proprietary mixtures containing these and other active co-formulants. Multiple Cr(VI) free deoxidisers and etch solutions for pre-treatment prior to Cr(VI) free bond primer.

Within the period since the parent authorisations were granted, further development has been conducted by members on selected proposed candidates shown in Table 3-4 above. The commentary in Section 3.5 below provides an overview of each proposed candidate reported within the parent AoAs together with any relevant advancements reported within the ADCR consortium.

3.4.1.2 Past Research

Regarding the replacement of chromates, despite the fact that the aerospace sector is widely seen as the instigator of technology change in multiple essential engineering disciplines (including the use of new metals, composites, and plastics) (Royal Academy of Engineering, 2014), this should be set against the diversity of applications 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 3-7. 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 3-7: Examples of finished products in A&D sector
Rheinmetall – Systems & Products, n.d.; Royal Navy , 2021

As highlighted throughout, the substitution of chromates in the aerospace and defence sector is met by particularly strong challenges. (Rowbotham and Fielding, 2016) highlight the nature of such challenges, noting that there are an estimated three million components in each of the 20,000-plus aircraft in service. Due to the demanding nature of service environments in the aerospace and defence sector, and potential for serious consequences if only one component should fail, dictate that very stringent measures are adopted and enforced when developing and qualifying Cr(VI)-free test candidates.

Various R&D activities were reported within applications for authorisation relating to this combined AoA/SEA for the use pre-treatment. Proposed candidates for the replacement of Cr(VI) in pre-treatment processes are shown in Table 3-4, categorised under the relevant pre-treatment process or processes as appropriate. This list comprises all the alternatives that were reported in the parent AfAs. Note that not all proposed candidates reported in the parent AfAs have been the focus of research and progression by the members.

Table 3-4: Cr(VI)-free proposed candidates for pre-treatments reported in parent AfAs[27]

Proposed candidate	Pre-treatment process	TRL Status reported/inferred in parent AfAs	AfA ID
Nitric/sulphuric acid	Deoxidising	6	0032-02
Phosphoric/fluoride solutions[(a)]	Deoxidising	3-5	0032-05
Sulfonitroferric acid	Deoxidising	3 - 6	0032-04 0032-05 0043-02
Nitric/sulphuric acid	Pickling/etching[(b)]	6	0032-02
Sulfonitroferric acid	Pickling/etching	3 - 6	0032-02 0032-04 0032-05 0043-02
Sulphuric acid with sodium or ammonium peroxydisulphate[(c)]	Pickling/etching	3 - 5	0032-02
Nitric/hydrofluoric acid solution (Nitric acid containing fluoride from HF or ammonium bifluoride)	Pickling/etching[(d)]	3 - 5	0032-05
Sulphuric (electrolytic pickling)	Pickling/etching	1 - 3	0032-04 0032-05
Proprietary mixtures; sulphuric acid plus Cr(III), NaF, ammonium bifluoride[(e)]	Desmutting	1	0032-05
Hydrogen peroxide plus ammonium bifluoride[(f)]	Pickling/desmutting	1-3	0032-05
Sulphuric acid with peroxymonosulphate/peroxydisulphate	Desmutting	3 - 5	0032-02
Mineral acids; sulphuric acid with hydrochloric acid[(g)]	Desmutting	Failed	0032-05
Sodium hydroxide containing additives[(h)]	Pickling/etching	3 - 5	0032-05

(a) Applied to copper or brass for the removal of heavy oxides.
(b) Pickling copper
(c) Etching copper. Major drawback; bath starts degrading after two weeks of use.
(d) Only suitable on some metal alloys or for some applications.
(e) Failed, smut could not be removed.
(f) Smut removal from molybdenum; close monitoring required to prevent over-etching.
(g) Unsatisfactory results concerning smut removal and reproducibility.
(h) Not suitable for removal of welding and brazing flux and localised repairs

Commentary is given below on the relative merits and/or development of the above candidate alternatives reported in the parent analysis of alternatives.

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

Nitric/sulphuric acid

Nitric/sulphuric acid was reported to be used for selective applications such as the etching of copper /removal of heavy red oxides. Due to its aggressive nature in comparison to Cr(VI), use was restricted to those applications that did not require careful control of the etch rate, which is mandatory for some applications. Copper etching performance, effect on intergranular attack, surface roughness characteristics, and etch rate, were all reported as acceptable for specific applications (CTAC, 2015a). Use of nitric/sulphuric acid to treat other substrates, such as aluminium, was not reported

ADCR members reported nitric/sulphuric acid mixtures as in use, at an advanced stage of development or under investigation for specified deoxidising processes albeit with the caveat that exclusions applied where not meeting design owner specification requirements or yet to be approved.

Phosphoric/fluoride solutions

Permitted for the removal of heavy oxides from copper and brass, technical feasibility was not reported for other substrates for in-line production activities. It is reported that phosphoric/fluoride mixtures were qualified for limited localised repair on stainless steel although typically not martensitic steels, as these grades can be affected by intergranular corrosion leading to ruptures (CTAC, 2015c, 2015a).

Phosphoric acid/sulphuric acid mixture

Other work reported by ADCR members focusing on phosphoric acid was in combination with sulphuric acid. This mixture of the two acids achieved good results for specific pickling uses, including electropolishing, for certain grades of stainless steel, although more specialised grades were reported to be incompatible with this acid mixture.

Sulfonitroferric acid

This test candidate has been developed over the broadest range of pre-treatment applications. It is available within proprietary mixtures with varying etch-rate characteristics influenced by co-formulants. For example, the presence of fluoride can increase the etch rate which may be too aggressive or difficult to control for some applications or where fatigue debit must be controlled. A reported advantage of using a proprietary formulation is increased stability in storage prior to preparation of the treatment bath. It was reported as used for pickling prior to chemical conversion coating and qualified for use prior to anodising main treatment.

Nitric/hydrofluoric acid mixture

Nitric/hydrofluoric acid was reported as a deoxidising solution prior to chemical conversion coating which is available and in use by some members. A pickling process is also reported with this test candidate; however, the preference is not to routinely use hydrofluoric acid for handling and health and safety reasons if possible. Proprietary mixtures are reported as available for deoxidising, other co-formulants may be present including iron sulphate. (CTAC, 2015c) report that nitric acid containing fluoride is only suitable for specific alloys and is not suitable for removing welding and brazing flux, localised repairs or for steel substrates.

Sulphuric acid (electrolytic pickling)

This technique had completed initial laboratory scale evaluation in past research activities with ongoing development for the pickling of stainless steels prior to bonding processes. The substrate's oxide layer is dissolved in the surface preparation pickling step. However, it is reported that further testing was ongoing as additional Cr(VI) pre-treatment process were still necessary to meet all required technical feasibility criteria prior to subsequent bonding processes. To conclude, although laboratory tests were positive, further R&D would be required before this pre-treatment could be implemented in place of Cr(VI) based pickling surface preparation processes.

Proprietary mixtures; sulphuric acid plus Cr(III), NaF, ammonium bifluoride

Identified as a proposed candidate evaluated for the purpose of pickling/desmutting molybdenum substrates. Development work was ceased at an early stage as results were poor with little to no removal of smut (CTAC, 2015c).

Hydrogen peroxide plus ammonium bifluoride

Initial laboratory testing conducted on desmutting molybdenum and also for desmutting stainless steels; 301, 302, and 304-type alloys. Results were reported to be positive. More testing was required however to develop the process further as it was reported to be difficult to control which could cause degradation of the metal substrate from over-etching (CTAC, 2015c).

Sodium hydroxide containing additives

This candidate is reported as in use as an alkaline pre-penetrant etch, or as a hot alkaline etch. (CTAC, 2015c) reported that as with nitric acid with fluorides, see above, sodium hydroxide-containing additives are preferred for etching aluminium alloys for specific applications, however it is not a suitable alternative for removal of welding and brazing flux, for localised repairs, or in combination with steel substrates.

Sulphuric acid with sodium or ammonium peroxydisulphate

Sulphuric acid with peroxydisulphate was identified as a candidate for etching copper. A major issue reported was the relatively short service life of the treatment bath, degrading after two weeks of use. This adds inefficiency to the process as continuous bath maintenance is required to maintain performance. The added maintenance incurs extra operational costs compared to Cr(VI) pre-treatment. Substituting with ammonium peroxydisulphate in place of sodium improved stability of the treatment bath. However additional operational complexity results from the need to segregate ammonium-containing wastewater from other effluent streams from the production process. For this reason, development with ammonium peroxydisulphate was not pursued (CTAC, 2015a).

Sulphuric acid with peroxymonosulphate.

The combination of sulphuric acid with the additive potassium peroxymonosulphate is reported to provide good initial results within the laboratory environment for removal of smut from stainless steel. This technique was at a relatively low level of maturity with only early exploratory laboratory tests completed. A caveat to the using of this combination is that it requires visual examination of the treated steel substrate to ensure that no end grain pitting results as a consequence of its use (CTAC, 2015a).

Mineral acids; sulphuric acid and hydrochloric acid

The mineral acids sulphuric and hydrofluoric acids have been evaluated for the desmutting of stainless steel grades (301, 302, and 304). These preliminary tests were unsuccessful. Reasons cited were unsatisfactory performance; smut removal, and reproducibility of the process (CTAC, 2015c) .

3.4.2 Consultations with customers and suppliers of alternatives

Details on consultation activities associated with the development of this combined 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 pre-treatment. The search was performed using Espacenet[28], 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 as well as Europe (EPO, 2020) .

Search terms were used to differentiate between the pre-treatment processes deoxidising, desmutting, and pickling/etching. Search terms used were:

- “Deoxidising” AND “metal” AND “no” AND “chromate”;
- “Desmutting” AND “metal” AND “no” AND “chromate”;
- “Etching” AND “non-ferrous” AND “metal” AND “chromate” AND “free”;
- “Etching” AND “ferrous” AND “metal” AND “chromate” AND “free”; and
- “Pickling” AND “metal” AND “without” AND “chromate”.

Searches were performed in November 2020 covering publication dates from 1 January 1995 to 31 December 2020.

Results were filtered via the main group classification filters C23, and C25 (descriptions below), patents were screened for links to pre-treatment processes. Those identified as potentially relevant to this combined AoA-SEA are presented in **Table 3-5** below. This is not presented as an exhaustive list, but representative of novel technologies that may merit evaluation versus established technical feasibility criteria assuming they are practical and/or potentially scalable to an industrial environment.

Espacenet classification filter title and descriptions:

- 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; and
- C25: Electrolytic or electrophoretic processes; apparatus therefore.

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

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

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. 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. Patents can also introduce limitations on the availability of a particular technology for example through the requirements for licencing. Where this is the case, a third party may obtain access to the technology if a licensing or some other commercial arrangement is available and meets the requirements of both parties.

Table 3-5: Patent search technology summary for pre-treatments

Treatment	Title	Patent reference	Summary of technology/alternative
Deoxidising/ Desmutting	Chromium-free conversion coating	US10550478B2	Deoxidiser/desmutting proprietary solution for aluminium alloy; active components include: •Ferric sulphate; •Nitric acid; •Sodium hydrogen difluoride; and •Sulphuric acid
Desmutting	Improved trivalent chromium-containing composition for aluminium and aluminium alloys	EP2971236A2	Trivalent chromium; •Fluorometallate anions; •Guanidinium ions; and •Organic anti-corrosion additive
Deoxidising	Systems for treating metal substrate	WO2020167758A1	Deoxidizing composition comprising a Group IVA metal and/or a Group IVB metal and free fluoride and having a pH of 1.0 to 3.0
Pickling	Metal material containing layered double hydroxide composite coating and preparation method of metal material	CN111471997A	Phosphorylation pickling process as a pre-treatment for polished aluminium alloy substrate prior to the main treatment process
Pickling	Magnesium alloy conversion film treatment method and conversion agent	CN110684970A	Pickling solution comprised of the following components; para. [0058]: • Tartaric acid; • Nitric acid; • Sulphuric acid; and • Sodium lauryl sulphate
Etching	Preparation method for aluminium alloy surface ATS composite film compatible to FEVE fluorocarbon powder coating.	CN110560344A	The invention provides a method for preparing an ATS composite film on the surface of the aluminium substrate that is compatible with a FEVE fluorocarbon coating system; does not require an etching step.

Table 3-5: Patent search technology summary for pre-treatments			
Treatment	Title	Patent reference	Summary of technology/alternative
	Aluminium alloy spraying pre-treatment method	CN110257840A	Multi-step treatment utilising a combination of an acid etching degreasant in an ultrasonic bath
	Treatment method for improving corrosion resistance of aluminium alloy products	CN108411292A	Multi-component etching solution; rare earth salt, fluorozirconic acid, titanic acid, sodium tungstate, ammonium fluoroborate, zinc dihydrogen phosphate, potassium fluorosilicate, and ammonium molybdate.
(EPO, 2020)			

Expanded review of selected patent applications

Title: Chromium-free conversion coating; US10550478B2

The field of the above invention relates to corrosion control of metals using a Cr(VI)- free conversion coating main treatment process. The patent includes an example of a non-Cr(VI) deoxidiser/desmutting proprietary product; Turco Smut Go NC, also known as Bonderite C-IC Smutgo NC Aero. This proprietary product is marketed for the deoxidation and desmutting of aluminium alloys by spray and immersion application. However, this proprietary product includes the classification 'may cause cancer'[29], therefore could be an example of regrettable substitution[30] and therefore not an appropriate alternative for Cr(VI) pre-treatment processes.

Title: Improved trivalent chromium-containing composition for aluminium and aluminium alloys; EP2971236A2

The applicant describes a pre-treatment deoxidising phase prior to the conversion coating, description paragraph [0123] reference Turco Deoxalume 2310, that utilises a chromium free acidic mixture containing sulphuric and hydrofluoric acids[31] marketed for the treatment of wrought aluminium alloys, in particular:

- Removal of surface oxides; and
- Desmutting following alkaline etching and chemical milling (Henkel, 2020).

It should be noted that although free of Cr(VI), the above pre-treatment is classified as 'toxic in contact with skin' which may require further careful consideration before implementation as an alternative to Cr(VI) pre-treatment processes.

Title: Systems for treating metal substrate; WO2020167758A1

A deoxidising composition bath within a multi-stage treatment for metal substrate. The deoxidiser is described as may comprise a Group IVA metal and/or a Group IVB metal, and free fluoride. Examples

[29] Henkel(2014), available at 1 (e-aircraftsupply.com), accessed 9 June 2021

[30] ECHA(2019), available at 93e9c055-483c-743a-52cb-1d1201478bc1 (europa.eu), accessed 16 December 2022

[31] Henkel(2021), available at $value (henkel.com), accessed 16 December 2022

of Group IVA metal compounds include: fluorosilicic acid, ammonium and alkali metal fluorosilicates. Substrates listed that may be treated are, steel, zinc coated steel, zinc, zinc alloys, galvanized steel, aluminium alloys, aluminium plated steel.

The deoxidizing composition may have a pH of 1.0 to 3.0 and may be applied alone, or as part of a system that can be deposited in a number of different ways onto a number of different substrates

The deoxidising solution can be administered as part of a system that deposits metal oxides onto the substrate surface promoting good adhesion to aluminium alloys. .

Title: Metal material containing layered double hydroxide composite coating and preparation method of metal material; CN111471997A

This invention describes a main treatment utilising a layered double hydroxide system to provide a protective a chromate free corrosion resistance surface for metal substrates. It comprises a two phase process the first phase being a surface preparation step. This may be in the form of mechanical grinding, degreasing, alkali washing or pickling.

The phosphorylation pickling process is described in paragraph [0083] as a pre-treatment for polished aluminium alloy substrate prior to the main treatment process.

Composition on the alkali solution paragraph [0065]:

- Sodium hydroxide 15 – 60g/l;
- Phosphate solution 5 – 20g/l; and
- Carbonate solution 20 – 40g/l.

Composition of the phosphorylation solution para. [0083]:

- Sodium monohydrogen phosphate 10-15g/l;
- Zinc nitrate 10-15g/l;
- Sodium nitrite 3-5glL; and
- Sodium fluoride 1-3g/l, pH=4.

The polished aluminium alloy parts are treated in acetone at room temperature and ultrasonic bath for 10-15 minutes. Then it is immersed for 10-15 minutes in the alkaline solution at 55-65°C prior to immersion in the phosphorylation solution, pickling at 50 - 60℃ for 15-30 minutes.

Other substrates including steel are not considered to be compatible with this process)..

Title: Magnesium alloy conversion film treatment method and conversion agent; CN110684970A

This invention is to provide a conversion coating system claimed to offer corrosion protection to magnesium alloys. It is free of chromium (Cr(VI)), phosphorous and fluorine.

Prior to the main treatment a surface conditioning agent is used, also referred to a pickling solution.

The pickling solution is comprised of the following components; para. [0058]:

- Tartaric acid;

- Nitric acid;
- Sulphuric acid; and
- Sodium lauryl sulphate (surfactant).

The purpose of the pickling solution is to remove oxide and other contaminants from the magnesium surface that could interfere with the adhesion of the conversion coating; paragraph [0059].

The pickling agent solution heated to 50 to 60°C, applied for one to three minutes to the treated substrate.

Magnesium substrates contribute in the reaction to form the conversion coating layer. Changing to treatment of another substrate such as steel or aluminium is anticipated to not be successful as the chemistry of the pre-treatment system is not likely to be compatible with or produce the surface characteristics required for slurry (diffusion) coating or anodising main treatments for example.

Title: Preparation method for aluminium alloy surface ATS (Al_2O_3-TiO_2-SiO_2) composite film compatible to FEVE (Fluoroethylene vinyl ether) fluorocarbon powder coating; CN110560344A

A premise of this invention is to remove the need for an acidic etch pre-treatment when processing aluminium alloys used in the fabrication of parts used in the aerospace sector, amongst others. The patent describes the protection process during the aluminium alloy pre-treatment step claiming there is no need for an alkali washing and acid etching step on the aluminium alloy surface, and that the natural oxide film on the aluminium alloy surface is retained. The invention provides a method for preparing an ATS composite film on the surface of the aluminium substrate that is compatible with a FEVE coating system. The system allows the use of a non-chromate degreasant pre-treatment, which preserves the natural protective aluminium oxide layer. This includes a metal complexing chelating agent ethylenediaminetetraacetic acid (EDTA). Complexing agents such as EDTA are generally avoided in surface finishing as they can to some extent inhibit the recovery of metal ions in standard wastewater treatment processes.

Title: Aluminium alloy spraying pre-treatment method; CN110257840A

The process is a multi-step treatment using a combination of an acid etching degreasant in an ultrasonic bath. The method is outlined as a sequential flow of activities in the patent claim 1. The preparation is a mixture of inorganic and organic components including a fluoride donor, ammonium hydrogen fluoride, iron sulphate, and sodium nitrate[32]. The process describes a 'matting' or sanding step which is optional. Sanding material is selected from one of the following: alumina, yttria, zirconia and one or more of chromium oxides. The method is claimed to decontaminate surfaces obtaining a required surface roughness, together with promoting bonding, adhesion and corrosion resistance. The application of ultrasonic vibration in the acid etchant accelerates the removal of contaminants and facilitates subsequent surface treatments

[32] Espacenet (2022): Available at Espacenet – search results

Title: Treatment method for improving corrosion resistance of aluminium alloy products; CN108411292A

Step five of the six stage process described in this patent is an etching step claimed to enhance corrosion resistance for aluminium alloys. The composition of the treatment includes rare earth salt, fluorozirconic acid and other fluorinated compounds and oxidising agents. Hydrogen peroxide, peroxyacetic acid or sodium peroxide are cited as the oxidising agent. Reported benefits of the multi-step process include corrosion resistance, abrasion resistance and improved hardness.

Should this technology be assessed with other substrates, members reported that this process would not be suitable for steel or stainless steel substrates.

3.4.3.2 High-level literature review

A representative non-exhaustive technical literature review was carried out using Science Direct (Journals and Books)[33] online service using a series of keyword search terms listed in **Table 3-6** below. The purpose of this search was to identify examples of alternatives to Cr(VI) for pre-treatment processes that have been investigated in the academic field or within other industry sectors. Although it is acknowledged that technical requirements for pre-treatment in another sector may not be relevant within A&D, this non-exhaustive review demonstrates any potential sources of cross-fertilisation from other industries or academic research. This exercise is an example of initial screening for proposed candidates from industry and academia. The high-level literature review compliments the parallel non-exhaustive patent search. The results returned from the literature search are summarised in Table 3-6**.**

Results are presented against the different search terms used to cover the various pre-treatment processes; deoxidising, desmutting, and pickling/etching. An expanded review is presented below for selected research articles**.**

Table 3-6: Literature search for chromate free in Science Direct[(a)]

Search term[(f)]	Time period	Results	Open access	Review articles
Chromate free corrosion resistant pre-treatments[(a)]	2010 - 2021	347	14	34
Chromate free desmutting[(b)]	2010 - 2021	62	6	1
Chromate free deoxidising [(c)]	2010 - 2021	5	0	0
Chromate free etching [(d)]	2010 - 2021	624	35	73
Chromate free pickling [(e)]	2010 - 2021	379	20	40

(a) Keywords(chromate free corrosion resistant pretreatments) Year(2010-2021) - Search | ScienceDirect.com
(b) Keywords(chromate free desmutting) Year(2010-2021) - Search | ScienceDirect.com
(c) Keywords(chromate free deoxidising) Year(2010-2021) - Search | ScienceDirect.com
(d) Keywords(chromate free etching) Year(2010-2021) - Search | ScienceDirect.com
(e) Keywords(chromate free pickling) Year(2010-2021) - Search | ScienceDirect.com
(f) Using Boolean search term “AND” for each key word. Search date 16 December 2022

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

Expanded review of selected articles

This section expands upon selected articles highlighted from the searches summarised in **Table 3-6.** For context, and where clearly defined, industry sectors, substrates, and main treatment technologies are also summarised.

Title: Advances in coatings on biodegradable magnesium alloys

(Yin *et al.*, 2020) describe alkali-heat treated conversion coatings. This process is described as removing oil and other impurities as a pre-treatment for improved corrosion resistance and also strengthening adhesion between the substrate and outer layer. The process consists of immersion of the component/substrate in a supersaturated $NaHCO_3$-$MgCO_3$ solution, pH 9.3, for 24 hours, followed by a heat treatment at 500°C for 10 hours.

Title: Fundamentals and advances in magnesium alloy corrosion

Acid pickling and alkaline cleaning with and without chelating agents used in combination with machining, grinding, and degreasing procedures selected to preserve the mechanical properties of the substrate (Esmaily *et al.*, 2017).

Title: Effect of an Fe(II)-modified trivalent chromium conversion process on Cr(VI) formation during coating of AA 2024 alloy

The paper describes a laboratory process to prepare specimens of AA2024-T351 aluminium alloy prior to Cr(III) conversion coating. The pre-treatment consisted of the following steps Qi et al., 2018).

- Polishing with 4000 grit finish;
- Etch in 10% sodium hydroxide solution; and
- Desmut in proprietary product; chromium free Oxidit D30.

Title: Flash-PEO as an alternative to chromate conversion coatings for corrosion protection of Mg alloy

Pre-treatments process steps summarised below for the preparation of magnesium alloy AZ31B prior to main treatment Plasma Electrolytic Oxidation (PEO) also referred to as micro-arc oxidation (MAO). An electrochemical surface treatment to produce an oxidation layer on the substrate with a porous surface layer that promotes good subsequent coating adhesion and paintability (Wierzbicka *et al.*, 2021).

- Bonderite C – AK 4181: Alkaline surfactant(Henkel Canada Corp, 2019); 15 minutes at 80 to 90°C, 90 g/l; and
- Sulphuric acid based etching solution, (Bonderite C-IC 3610, room temperature,10g/l, etch rate > 10g/m2.

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

3.4.4 Shortlist of alternatives

Focusing on the overriding need to deliver key functions and maintain performance requirements critical to airworthiness, safety, and reliability, proposed candidates must demonstrate performance as good as, or better than, the incumbent Cr(VI) surface treatment. If performance requirements do not meet or exceed initial generic quality control screening thresholds, the proposed candidate will not advance to test candidate status where it is subject to bespoke Breadboard[34] level testing

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

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

Based on an assessment of technical feasibility and potential to be suitable alternatives to Cr(VI), the proposed candidate to have achieved greatest maturity as a test candidate in the most applications of pre-treatment is **sulfonitroferric acid** with or without the addition of fluoride, as permitted by technical feasibility criteria and performance requirement boundaries.

This and other test candidates are discussed in more detail in Section 3.5.

34 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

3.4.5 Performance requirements and testing

As noted above in Section 3.2.1, the key functions and technical feasibility criteria for pre-treatments are:

- Corrosion resistance;
- Adhesion of subsequent coatings (including structural bonding);
- Surface preparation prior to further processing;
- Removal of contaminants/complexes after etching processes;
- Surface roughness: Removal of mechanically deformed layers/oxides or other compounds from the substrate; and
- Selective removal of material to reveal the surface or surface properties (surface activation).

In support of initial screening, tests (also referred to as critical to quality tests), are conducted to assess performance of proposed candidates in the laboratory environment for each of the criteria. Corrosion resistance may be measured according to confidential internal specifications or publicly available standards, for example (SAE) QQ-P-35, Type II and SAE AMS03-2C Cleaning and Preparation of Metal Surfaces. This requirement details processes for the cleaning of metal surfaces to remove contaminants or deposits at any stage of manufacture, storage, or service and for the preparation of these surfaces for further treatment. ISO 2409 measures adhesion, the resistance of paint coatings to separation from substrates when a right-angle lattice pattern is cut into the coating, penetrating through to the substrate. Other examples of standards used in the evaluation of technical feasibility criteria and performance are given in Annex 1. Test methods and requirements contained therein do not define success criteria for test candidate validation.

Performance requirements extend beyond the key functions. Essential attributes or performance requirements of the use must be considered in addition to key functions to ensure substitution with an alternative does not lead to unintended consequences which could impact safety and/or reliability of a component. For this reason, the delivery of the key functionalities cannot be considered in isolation; due regard must be paid to additional performance requirements associated with the successful delivery of the use. As listed in section 3.1.1.1 a non-exhaustive list of performance requirements is provided below:

- Shall neither cause end grain pitting nor intergranular attack in certain excess and depth;
- Metal removal of the substrate shall not exceed certain limits;
- Adequate etch rate;
- Minimum impact on fatigue performance – no degradation;
- Tensile strength testing – no degradation;
- Water-break free surface[35] without streaks or discolorations;
- No pitting or selective attack to the substrate;
- No non-rinseable residuals or contamination from the deoxidising solutions observed on the surface;
- Must not induce de-gassing from surface under vacuum;
- Does not induce pits, corrosion products, discolouration, uneven etching, increased surface roughness, or other defects that would prohibit further chemical processing; and

[35] A water break free test uses immersion of a substrate in water. If the water does not break into droplets on the surface, then the surface is free from hydrophobic contaminants.

- Does not impact shot-peen compressive layer

Proposed candidates for the replacement of Cr(VI) in pre-treatments identified in parent AfAs are shown in **Table 3-7** below. This list comprises all the alternatives that were reported in the parent AfAs. A summary of the status of the candidates listed in **Table 3-7** is provided in Section 3.4.1.2

Table 3-7: Cr(VI)-free proposed candidates for pre-treatments reported in parent AfA

Proposed candidate	Pre-treatment process	TRL Status in parent AfAs	AfA ID
Nitric/sulphuric acid	Deoxidising	6	0032-02
Phosphoric/fluoride solutions	Deoxidising	3-5	0032-05
Sulfonitroferric acid	Deoxidising	3-6	0032-04 0032-05 0043-02
Sulfonitroferric acid	Pickling/etching	3-6	0032-02
Nitric/sulphuric acid	Pickling/etching	6	0032-02
Sulphuric acid with sodium or ammonium peroxydisulphate	Pickling/etching	3-5	0032-02
Nitric/hydrofluoric acid solution (Nitric acid containing fluoride from HF or ammonium bifluoride)	Pickling/etching	3-5	0032-05
Sulphuric electrolytic pickling	Pickling/etching	1-3	0032-04 0032-05
Proprietary mixtures; sulphuric acid plus Cr(III), NaF, ammonium bifluoride	Desmutting	1	0032-05
Hydrogen peroxide plus ammonium bifluoride[f]	Pickling/desmutting	1-3	0032-05
Sulphuric acid with peroxymonosulphate (potassium peroxymonosulphate)	Desmutting	3-5	0032-02
Sulphuric acid with hydrochloric acid	Desmutting	Failed	0032-05
Sodium hydroxide containing additives	Pickling/etching	3-5	0032-05

Table 3-8: Cr(VI)-free proposed candidates for pre-treatments reported by ADCR

Proposed candidate	Pre-treatment process	TRL Status reported in parent AfA
Nitric/sulphuric acid mixture	Deoxidising	6
Sulfonitroferric acid [a]	Pickling/etching	3-6
Phosphoric acid with fluoride	Deoxidising	3-5
Nitric/hydrofluoric acid mixture	Deoxidising/Desmutting	6
Sulphuric acid	Pickling/etching	3-4
Shot peening	Deoxidising	N/A

Table 3-8: Cr(VI)-free proposed candidates for pre-treatments reported by ADCR		
Proposed candidate	**Pre-treatment process**	**TRL Status reported in parent AfA**
Cr(III)	Pickling (anodic)	N/A
Sulphuric/Hydrofluoric acid mixture	Etching (anodic)	Failed
Phosphoric/sulphuric acids	Electropolishing	N/A
Sub-layer before Cr(III) plating[b]	Surface preparation prior to electroplating	N/A
Mechanical cleaning/Abrasive blast (sand, grit, glass beads)	Deoxidising	N/A
(a) Including proprietary formulation based on this technology (b) Alternative process to replace pre-treatment processes		

Proposed candidates not listed in **Table 3-8** were not advanced beyond the TRL levels reported in **Table 3-7**.

3.5 Progression of shortlisted alternatives

3.5.1 Introduction

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

Approval of the test candidate must include a complete understanding of the influence not only of the pre-treatment process, but also its interaction with all adjacent uses (main treatments) which together comprise the treatment system as a whole. Main treatments routinely include, chemical conversion coating, anodising, passivation of stainless steel and electroplating. Each main treatment delivers key functionality that will differ to varying extents from the others. A pre-treatment process must support the key functions of these main treatment processes irrespective of the substrate/design combination and application method. Understanding the influence and/or interaction of all processes within the surface treatment system is a key aspect to determining the suitability of a pre-treatment test candidate in a Cr(VI)-free treatment system for a given component design and substrate combination. . Any change in these system variables may lead to irregular, non-reproducible, or unacceptable performance of the test candidate delivering the pre-treatment process, and consequently impact its scope of use. . This scenario is a principal reason for the graduated or restricted implementation of pre-treatment test candidates in combination with different component/design families. To reiterate, variations in substrate, and component design, , have the potential to interact with the treatment system differently and combined with variations in main-treatment effect the performance of the pre-treatment test candidate.

Progression of pre-treatment test candidates is assessed against the following criteria:

- Technical feasibility/Technical Readiness
- Economic feasibility
- Safety considerations
- Availability
- Suitability.

As discussed above, a variety of substrates may be used depending on the component/design. Substrates identified include the following:

- Aluminium and its alloys
- Magnesium and its alloys
- Steel, including stainless-steel
- Nickel
- Brass
- Copper.

The above list of substrates is not intended to be exhaustive. Other metallic substrates may be subject to pre-treatment processes. For example, pickling/etching of molybdenum is reported for molybdenum based conversion coating (CTAC, 2015c).

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[36] 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[37], 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

[36] 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

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

Regulation, such as (EU) 2018/1139[38]. To reinforce this point, a civil aircraft's Certificate of Airworthiness is not valid until the Type Certificate has been approved by the Regulator (EASA, 2012) Defence equipment is subject to standalone change protocols including approval by the relevant Member State Ministries of Defence. Therefore, a test candidate not deemed available from a regulatory standpoint would not meet all required criteria within the above definition of 'suitable'.

3.5.2 Test candidate 1: Sulfonitroferric acid and derived proprietary formulations

3.5.2.1 Introduction

The parent AfAs, report extensive R&D to evaluate the performance of sulfonitroferric acid either on its own or present as a principal constituent in proprietary formulations. Varying degrees of success are reported depending on the substrate or design treated, together with the specification requirements of the design owner. In some selective cases sulfonitroferric acid has been implemented as a pre-treatment alternative to Cr(VI).

Overall, sulfonitroferric acid exhibits performance that merits further development as a promising test candidate to expand its use across more applications and substrates. Sulfonitroferric acid is qualified and implemented for surface preparation prior to anodising and chemical conversion coating on aluminium alloys for some specific applications in the aerospace sector. It is also approved for surface preparation prior to fusion welding, brazing, and for removal of foreign metal contamination (CTAC, 2015c).

Continuous development to refine and optimise this test candidate has proliferated a series of proprietary formulations that are derived from sulfonitroferric acid. These have been developed to meet specific surface preparation requirements. For example, removal of heavy oxide deposits, which are difficult to remove from some alloys, prior to subsequent treatment. Examples of these proprietary formulations and the role that they fulfil are provided below in section 3.5.2.2.

3.5.2.2 Technical feasibility/Technical Readiness Level of sulfonitroferric acid

Multiple members report sulfonitroferric acid and proprietary formulations derived from it fulfil technical feasibility criteria requirements for pickling/etching and deoxidising processes. These have therefore progressed to test candidate status and matured to TRL 9 for some applications, whilst other members reported progression to successful completion of critical to quality tests for TRL 6. This test candidate is reported as in use and compatible with various substrate types, including castable alloys prior to main treatments including anodising and chemical conversion coating.

As discussed above, proprietary formulations derived from sulfonitroferric acid are available on the market. Proprietary Cr(VI) free pre-treatments and main treatments, formulated to complement one another, provide an overall treatment system and are marketed for main treatments, for example chemical conversion coating. A reported benefit of sulfonitroferric acid is its neutral impact on fatigue

[38] 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)

debit, reported to be comparable with chromic acid pickling. However, this is a limitation if the requirement is to decontaminate heavier, tougher to remove deposits of oxides. Additionally, in some circumstances the alloy surface must be prepared with a minimum degree of etch to ensure the surface is left uniform and adequately prepared to receive the main treatment. An example of an applicable alloy/treatment used in aerospace is chemical conversion coating of aluminium alloy 2024 T3. Standard sulfonitroferric acid is reported to not meet the technical demands of the above scenario for all substrate and contamination combinations. Therefore, optimised proprietary formulations derived from this chemistry are required. Proprietary formulations are available as two part pre-cursor solutions which can be mixed when required to yield the sulfonitroferric treatment solution. A benefit of the two part solution is reported to be increased storage stability of the acid and metallic constituents. There is also the option to add co-formulants to provide added performance for certain use scenarios.

To illustrate, some proprietary formulations are on the market that include fluoride which modifies the etch characteristics of sulfonitroferric acid. This prepares the substrate surface where heavier oxide deposits are present and the production process dictates that a minimum amount of surface material must be removed. However, careful control of the operating parameters is required to ensure fatigue debit is not exceeded beyond specified limits. Impact on fatigue sensitive designs and substrates vulnerable to corrosion pits, intergranular attack or end grain pitting for example, may prohibit the use of sulfonitroferric acid with fluorides if not compliant with conformance standards such as ASTM F2111,[39] required to aid qualification of chemical treatment processes. In addition, it is reported that fluorides can influence the characteristics of the chemical conversion coating layer build up. Therefore, this potential impact also needs to be considered in the assessment of the test candidate.

For the specific use of chromic etching for bonding, sulfonitroferric acid solution has not demonstrated a sufficient level of adhesion strength when applied alone. Therefore, Cr(VI) pre-treatment has to be replaced by a sulfonitroferric acid pre-treatment and followed by PSA (Phosphoric Sulfuric acid Anodising) main treatment.

The sulfonitroferric acid pre-treatment does not meet all performance requirements for use with chemical conversion coating utilising Cr (III) resulting in regression compared to the Cr(VI) treatment. It is reported that using sulfonitroferric acid pre-treatment before Cr(III) chemical conversion coating of sheet and machined 2xxx series aluminium alloys, typically decreases corrosion resistance compared to Cr(VI) based pre-treatments. The impact and consequence of the reported reduction in corrosion resistance for the above test candidate/substrate combination must be assessed and approved by design owners and airworthiness authorities before sulfonitroferric acid can be considered for this specific substrate/main-treatment combination.

3.5.2.3 Economic feasibility of sulfonitroferric acid

The direct challenge for the substitution of the current Cr(VI) based pre-treatment by Sulfonitroferric acid is the higher costs. Although detailed analysis is not available at this stage, the prices could be up to one and a half times higher. Only a qualitative assessment of economic feasibility can be provided here due to the varying nature of impacts across the range of components on which pre-treatments are carried out, which makes extracting quantitative data even for general indicators difficult.

The operational costs will increase due to the following impacts:

[39] Standard Practice for Measuring Intergranular Attack or End Grain Pitting on Metals Caused by Aircraft Chemical Processes

- **Infrastructural costs:** Costs resulting from the construction of new lines to accommodate additional baths (the direct costs of new equipment have been estimated at 12,000 EUR);

- **Longer process times:** Moving to sulfonitroferric acid will require the introduction of a two-step industrial process (particularly so for the proprietary formulations) which will lead to an increase in production times and hence reductions in production rates (potentially with consequent impacts on turnover);

- **Raw material prices:** In general, the price of raw materials for the potential candidate is higher than the price of the Cr(VI)-based formulations currently in use. The bath life of the alternatives is shorter, so a higher quantity of the potential candidate per annum (and hence per unit of production) would be needed;

- **Waste disposal cost:** Potential increases in the volume of waste and therefore disposal costs are higher than current levels. Indirect costs from modifications to waste disposal streams have also been stated.

In many cases, it is difficult to accurately predict the indirect costs occurring from substituting in a Cr(VI) free pre-treatment, in some cases the processes are outsourced which could lead to additional complications. Some outsource suppliers may not be able to handle the alternative substance, depending on the size of the supplier there may be issues with financing any new equipment required or problems if more space is needed. Finding new suppliers may be difficult and will most likely come at a cost, time would be spent finding alternatives and qualifying any new suppliers and new contracts would need to be negotiated

3.5.2.4 Health and safety considerations related to the use of sulfonitroferric acid

For the purposes of understanding the risks associated with the test candidate sulfonitroferric acid, the key identifiers and summary of hazard properties are for a representative formulation are given in Table 3-9 below

Table 3-9: Summary of composition and hazard properties of test candidate for sulfonitroferric acid (including fluoride where reported)

Substance	EC Number	CAS number	CLP classification
Sulphuric acid [(a)]	231-639-5	76644-93-9	Skin Corr. 1A; H314
Nitric acid (≤ 70%) [(a)]	231-714-2	7697-37-2	Ox.Liq.2; H272, Skin Corr. 1A; H314, Acute Tox. 3; H331, EUH071
Ferric sulphate [(b)]	233-072-9	10028-22-5	Acute Tox, Oral 4;H302 Skin Irrit.2; H315 Eye Dam.1; H318 Skin Sens.1; H317
Hydrofluoric acid [(b)]	231-634-8	7664-39-3	Acute Tox.2, Inhalation; H330 Acute Tox 2,Oral; H300 Acute Tox. 1, Dermal; H310 Skin Corr. 1A, H314
Potassium nitrate [(b)]	7757-79-1	231-818-8	Ox.Sol.3, H272

(a) Harmonised classification according to Annex VI of Regulation (EC) 1272/2008 (CLP)
(b) Classified in accordance with REACH Registration dossier

Table 3-9 lists the classification of the component parts of sulfonitroferric acid and fluoride donors that can be used in some proprietary formulation utilising sulfonitroferric acid. These represent a less hazardous alternative to the current pre-treatment processes using Cr(VI), a non-threshold carcinogen. Those members who have undertaken risk assessments of the process using the test candidate have universally identified a reduction in risk, compared to Cr(VI), with adequate control available for the risks which do exist.

The test candidate is a less hazardous option compared to Cr(VI). However, under due diligence inclusion of fluorides as co-formulants may need be assessed against other regulatory obligations, for example the Seveso III Directive 96/82/EC[40], before selecting or implementing affected pre-treatments.

3.5.2.5 Availability of sulfonitroferric acid

As discussed, sulfonitroferric acid is also commercially available as proprietary formulations. These include dual systems where a pre-treatment formulation containing sulfonitroferric acid is specifically formulated to complement a Cr(VI) free main treatment, for example for the main treatment chemical conversion coating. Before the treatment system can be implemented both the pre and main treatment parts need to be qualified; it cannot be assumed that a Cr(VI) free part of the system would be compatible with a Cr(VI) legacy treatment. Also, it is more efficient to qualify the pre and main treatments in parallel. Sufficient stock is believed to be available on the market to allow industrialisation where qualification and certification steps have been achieved.

The main factor impacting availability is qualification of the test candidate for use on all relevant A&D components and substrates. These demand a varying array of performance requirements not all of which will be applicable to all applications of the pre-treatment process. For example, fatigue sensitive components may be incompatible with more aggressive proprietary sulfonitroferric acid formulations containing fluoride. This may delay qualification of the process while operational conditions are optimised to avoid excessive fatigue debit or result in rejection of the test candidate for reasons of performance, safety and/or reliability. Qualification of the supply chain may be required to support the new Cr(VI) free treatment system which may delay full implementation or temporarily block availability for some OEMs. These factors ultimately prevent the test candidate from being an alternative generally available to the A&D sector as a universal alternative for all current Cr(VI) applications in pre-treatment processes.

3.5.2.6 Suitability of sulfonitroferric acid

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. The use of sulfonitroferric acid pre-treatment, when compared to the incumbent process, has been demonstrated to be technically feasible and comparable to Cr(VI) for a wide selection of substrates and component designs. However, development work is ongoing to refine operational process parameters of use for substrate/design configurations where the performance requirements are more demanding. An example includes fatigue sensitive parts which are less tolerant to more aggressive treatments resulting in increased etch rate. Another is to improve adhesion from the etching process with sulfonitroferric prior to bonding. Consequently, more time may be required

[40] EC (2012) available at: Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/ECText with EEA relevance (europa.eu)

where an expanded suite of testing is used to evaluate all bespoke performance requirements across all substrate/design combinations. .

Another restrictive aspect is the tie between pre-treatment and main treatment where both are supplied by the same manufacturer. The benefit is each part should be compatible with one another. However, the need to be introduced in parallel across a wider range of applications of a processes , for example chemical conversion coating, adds complexity and potential for delays in implementation of the new treatment system. Consideration also needs to be made for specific legacy applications where component design parameters cannot be adjusted to accommodate revised operational parameters relevant to the alternative. For the above reasons, although commercially readily available, and technically feasible across a significant number of applications within the ADCR, sulfonitroferric acid is not yet certified for use with all existing applications using Cr(VI) pre-treatments. Therefore, it is not yet generally available across the A&D sector.

3.5.3 Test candidate 2: Nitric/sulphuric acid mixture

3.5.3.1 Introduction

The reported application of nitric/sulphuric acid solutions is for the treatment of copper substrate to remove heavy red-oxide and reported to be in use for this specific application. This treatment process is claimed to be more aggressive than the equivalent chromium trioxide-based treatment but to perform adequately when removing heavy red oxides. Copper substrate surface finish was also satisfactory after treatment yielding the required roughness for subsequent processes. As a consequence of its more aggressive characteristics, applications requiring careful control and/or moderate etch-rate may not be suited to this alternative (CTAC, 2015a).

3.5.3.2 Technical feasibility/Technical Readiness Level of nitric/sulphuric acid mixture

Applications of nitric/sulphuric acid pre-treatments are reported to be for deoxidising, and pickling/etching pre-treatment processes on selected aluminium substrates. Maturity of substitution varies. TRL 4 to 5 for pickling/etching prior to anodising aluminium alloy, and TRL 9 for deoxidising prior to anodising. As reported above, this is an aggressive process and therefore requires careful operational control to ensure removal of surface substrate material is maintained within acceptable limits, for example with fatigue sensitive components. Completion of laboratory testing was in 2022, progressing to TRL 5. Progression to TRL 6, instigating a raft of bespoke test regimes required for qualification, is expected to be complete in 2026, through to TRL 9 and full industrialisation completed by 2028, with the caveat that no iteration of testing is required for whatever reason.

3.5.3.3 Economic feasibility of nitric/sulphuric acid mixture

The cost of the test candidate is reported to be higher than the incumbent Cr(VI) solution, however, this is difficult to quantify. In many cases, it is difficult to accurately predict the indirect costs occurring from substituting in a Cr(VI) free pre-treatment, in some cases the processes are outsourced which could lead to additional complications. Some outsource suppliers may not be able to handle the alternative substance, depending on the size of the supplier there may be issues with financing any new equipment required or problems if more space is needed. Finding new suppliers may be difficult and will most likely come at a cost. Time would be spent finding alternatives, qualifying any new suppliers, and negotiating new contracts.

3.5.3.4 Health and safety considerations related to the use of nitric/sulphuric acid mixture

For the purposes of understanding the risks associated with the test candidate nitric/sulphuric acid mixture the key identifiers and summary of hazard properties are listed in **Table 3-10**.

Table 3-10: Summary of hazard profiles for nitric and sulphuric acids

Substance	EC Number	CAS number	CLP classification
Sulphuric acid [(a)]	231-639-5	76644-93-9	Skin Corr. 1A; H314
Nitric acid (≤ 70%) [(a)]	231-714-2	7697-37-2	Ox.Liq.2; H272, Skin Corr. 1A; H314, Acute Tox. 3; H331, EUH071
(a) Harmonised classification according to Annex VI of Regulation (EC) 1272/2008 (CLP)			

Based on the above, the test candidate would represent a less hazardous alternative to the current process using Cr(VI), a non-threshold carcinogen.

3.5.3.5 Availability of nitric/sulphuric acid mixture

Both nitric acid and sulphuric acid are commercially available in sufficient quantities to satisfy normal demand. Certification is to be completed for some members' application of this test candidate with certain substrates. Where this is the case, and the alternative has not attained TRL 9 status, then nitric/sulphuric acid mixture is not deemed generally available from a regulatory standpoint whilst awaiting certification across all applications currently using Cr(VI).

3.5.3.6 Suitability of nitric/sulphuric acid mixture

As reported, nitric/sulphuric acid mixture is proven to meet technical feasibility for efficiently deoxidising certain substrates, copper, and preparing the surface to receive subsequent treatments, refer to section 3.5.3.1.
Nitric acid and sulphuric acid are readily commercially available and provide a reduction in hazard profile compared to Cr(VI). Although technical feasibility for the purposes of deoxidising substrates such as copper and some aluminium alloys is fulfilled, further work is required to certify this test candidate for use with some alloys if the pre-treatment pickling process is too aggressive; estimated completion is in 2028. Therefore, this is not considered a suitable alternative for all current Cr(VI) pre-treatment applications.

3.5.4 Test candidate 3: Phosphoric acid based solutions

3.5.4.1 Introduction

Phosphoric acid/fluoride mixtures are reported as permitted for the removal of heavy oxides from copper and brass. Technical feasibility was not reported for other substrates for in-line production activities. Phosphoric/fluoride mixtures were qualified for limited localised repair on stainless steel although typically not martensitic steels, as these grades can be affected by intergranular corrosion leading to ruptures (CTAC, 2015c). Limited application of phosphoric/fluoride solutions as a deoxidiser is reported for certain substrates, for example titanium, to support adhesion of a subsequent layer.

Electrolytic pickling/etching, referred to as electropolishing, is a process performed in a chemical electrolyte bath to remove surface flaws. The use of chromium trioxide for the electropolishing of martensitic steel is mandatory. Benefits of the process are that it improves fatigue performance of structural parts and eliminates impurities from previous thermal treatments. It is reported that effective pH control of the electrolyte bath is only achieved with chromium trioxide (CTAC, 2015b)

Development reported by ADCR members focusing on phosphoric acid, is of a mixture of phosphoric and sulphuric acids. This mixture has achieved good results for specific pickling uses, including electropolishing for certain grades of stainless steel, although more specialised grades were reported to be incompatible with this acid mixture.

3.5.4.2 Technical feasibility/Technical Readiness Level of Phosphoric acid based solutions

ADCR members reported development of phosphoric acid solutions with either fluoride or sulphuric acid. A mixture of phosphoric acid and fluoride is identified as technically feasible to act as a deoxidiser achieving TRL 9 for the niche application of pre-treating titanium to enhance adhesion promotion. Development with other substrates in addition to copper and brass, is immature and at an early stage of laboratory evaluation; TRL 1 to 3.

Phosphoric acid/sulphuric acid mixture is identified as achieving good results for specific pickling uses, including electropolishing, for steel and stainless steels. Electropolishing modifies the substrate surface to achieve a target roughness. This targeted roughness separates electropolishing from non-electrolytic pickling/etching and may be outside the typical performance boundaries of other chemical pickling/etching processes. Electropolishing removes or helps to prevent surface contamination in various forms. For example it impedes deposition of organisms, and other forms of contamination in turn contributing to corrosion resistance. A performance requirement of electropolishing, is to not induce degassing from the substrate surface under vacuum Trials with phosphoric/sulphuric acid mixtures have been successful on numerous grades of stainless steel. However, failures are reported for certain grades including at least one austenitic stainless steel grade as required level of decontamination was not achieved in initial testing. Development of this test candidate for the purpose of electropolishing continues. It is anticipated that qualification with required designs could be achieved in 2028 following tests on pre-production parts and reproducibility trials from 2026.

3.5.4.3 Economic feasibility Phosphoric acid based solutions

No significant economic feasibility barriers are reported.

3.5.4.4 Health and safety considerations related to the use of Phosphoric acid based solutions

Table 3-11: Summary of hazard profile for the test candidate

Substance	EC Number	CAS number	CLP classification
Phosphoric acid	231-633-2	7664-38-2	Skin Corr.1B; H314
Sulphuric acid[(a)]	231-639-5	7664-93-9	Skin Corr.1A; H314
Sodium hydrogendifluoride[(a)]	215-608-3	1333-83-1	Acute Tox. 3; H301
Potassium hydrogendifluoride	232-156-2	7789-29-9	Acute Tox.3; H301 Skin Corr.1B; H314
Hydrofluoric acid [(b)]	231-634-8	7664-39-3	Acute Tox.2, Inhalation; H330 Acute Tox 2,Oral; H300 Acute Tox. 1, Dermal; H310 Skin Corr. 1A, H314

(a) Harmonised classification according to Annex VI of Regulation (EC) 1272/2008 (CLP)
(b) Classified in accordance with REACH Registration dossier

Based on the above, each component described within the term phosphoric acid based solutions would represent a reduction in hazard profile compared to Cr(VI), a non-threshold carcinogen. Under due diligence inclusion of hydrofluoric acid as a co-formulant may need be assessed against other regulatory obligations, for example the Seveso III Directive 96/82/EC, before implementation.

3.5.4.5 Availability of Phosphoric acid based solutions

Phosphoric acid/fluoride mixture is reported to have achieved TRL 9 for deoxidising specific substrates; titanium and is currently available for this limited application.

Both phosphoric and sulphuric acids are commercially available in sufficient quantities to satisfy normal demand. Certification is to be completed for some members' application of this test candidate for electropolishing specific sensitive substrates before the test candidate can be implemented for all required substrates subject to electropolishing. Where the test candidate has not attained TRL 9 status, then the mixture is not deemed generally available from a regulatory standpoint; not certified for use for all substrates currently pre-treated with Cr(VI) based solutions.

3.5.4.6 Suitability of phosphoric acid based solutions

Phosphoric acid/fluoride mixtures are reported as permitted for the removal of heavy oxides from copper and brass and also the treatment of titanium to deoxidise and enhance adhesion. Phosphoric and sulphuric acid provide a reduction in hazard profile compared to Cr(VI). Technical feasibility for the purposes of pickling/etching (electropolishing) many steel grades are fulfilled, however further work is required to certify this test candidate for use with some alloys with the pre-treatment; estimated completion in 2028. Therefore this is not considered a suitable alternative for all current Cr(VI) pre-treatment process applications (substrates) subject to electropolishing.

3.5.5 Test candidate 4: Sulphuric acid (including electrolytic sulphuric acid pickling)

3.5.5.1 Introduction

Sulphuric acid is identified in as investigated for the purposed of pickling before bonding of stainless steels and as the electrolyte for electrolytic pickling. Pickling/etching is used for the activation of steel prior to cadmium plating. The selective removal of substrate material or defects from the surface activates it ready for subsequent processes. Initial laboratory test results demonstrated satisfactory technical feasibility for pickling before bonding of stainless steel. However, further testing beyond initial laboratory scale evaluation was still required to assess the potential of this Cr(VI) free technique for industrialisation (CTAC, 2015b) .

3.5.5.2 Technical feasibility/Technical Readiness Level of Sulphuric acid (including electrolytic sulphuric acid pickling)

Members reported the use of sulphuric acid for the reactivation of metallic coatings, for example cadmium, following plating onto steel substrates. As described in section 3.5.5.1 pickling/etching is used for the preparation and activation of surfaces. Sulphuric acid is used to neutralise the pH of the cadmium substrate following deposition to ensure compatibility with any further treatments that may be applied. This process is reported as implemented for some applications, for example after cadmium plating, where it is required for operational reasons. Development is at an advanced maturity with testing expected to be complete on cadmium substrates by 2024 leading to full implementation thereafter.

Further development of sulphuric acid as a standalone treatment for electrolytic pickling was not reported.

3.5.5.3 Economic feasibility of Sulphuric acid (including electrolytic sulphuric acid pickling)

No significant economic feasibility barriers are reported.

3.5.5.4 Health and safety considerations related to the use of Sulphuric acid (including electrolytic sulphuric acid pickling)

For the purposes of understanding the risks associated with the test candidate sulphuric acid the key identifiers and summary of hazard properties are listed in Table 3-12.

Table 3-12: Summary of hazard profiles for sulphuric acid (including electrolytic sulphuric acid pickling			
Substance	EC Number	CAS number	CLP classification
Sulphuric acid [(a)]	231-639-5	7664-93-9	Skin Corr. 1A; H314
(a) Harmonised classification according to Annex VI of Regulation (EC) 1272/2008 (CLP)			

Based on the above, the test candidate sulphuric acid represents a reduction in hazard profile compared to the Cr(VI), a non-threshold carcinogen.

3.5.5.5 Availability of sulphuric acid

Sulphuric acid is commercially available in sufficient quantities to satisfy normal demand. It is reported that testing is ongoing for some applications. Therefore until this is complete, and certification obtained, sulphuric acid is not universally available as a replacement for all applications of Cr(VI) for pre-treatment processes prior to main treatments, for example passivation of non-aluminium metallic coatings. Where the test candidate has not attained TRL 9 status, it is not considered generally available from a regulatory standpoint.

3.5.5.6 Suitability of sulphuric acid

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'. Sulphuric acid has been identified as a technically feasible alternative to Cr(VI) for specific applications. It has been certified for use for the purposes of reactivation via a pickling process on specified substrates as described in section 3.5.5.2. However, this does not represent a technically feasible alternative for all applications of pre-treatments currently utilising Cr(VI). Sulphuric acid represent a reduction in hazard profile compared to Cr(VI) and does not present any economic barriers to use. It is not certified as an alternative for use with a wide array of substrates, components and main-treatments. Therefore is not considered a universally suitable alternative to Cr(VI) pre-treatment processes.

3.5.6 Test candidate 5: Sodium hydroxide containing additives

3.5.6.1 Introduction

Sodium hydroxide containing additives is reported as an acceptable alternative to chromium trioxide-based etching solutions used for aluminium. However, it is not considered acceptable for all alloys and applications, for example removal of welding and brazing flux, localised repairs and for steel substrates (CTAC, 2015c)

3.5.6.2 Technical feasibility/Technical Readiness Level of sodium hydroxide containing additives

Sodium hydroxide is used as a pre-treatment etchant and typically produces a smut residue after use. It is used for non-destructive dye penetrant inspection (ASTM E 1417) check for defects including pits, corrosion products, discolouration, uneven etching, increased surface roughness etc., that could impact subsequent treatment processes. Members report that it is necessary to control the process to mitigate potential intergranular attack. Development of this test candidate as a pre-penetrant etch is reported to have reached TRL 9 and in use for this selected application under carefully controlled conditions.

3.5.6.3 Economic feasibility of sodium hydroxide containing additives

No significant economic feasibility barriers are reported.

3.5.6.4 Health and safety considerations related to the use of sodium hydroxide containing additives

For the purposes of understanding the risks associated with the test candidate sodium hydroxide containing additive the key identifiers and summary of hazard properties are listed in **Table 3-13**

Table 3-13: Summary of hazard profiles for sodium hydroxide containing additives			
Substance	**EC Number**	**CAS number**	**CLP classification**
Sodium hydroxide[a)]	215-185-5	1310-73-2	Skin Corr. 1A; H314
(a) Harmonised classification according to Annex VI of Regulation (EC) 1272/2008 (CLP)			

Based on the above, the test candidate represents a less hazardous alternative to Cr(VI), a non-threshold carcinogen.

3.5.6.5 Availability of sodium hydroxide containing additives

Sodium hydroxide is readily available on the market with no supported supply issues to meet normal demand. It is certified for specific etching applications such as pre-penetrant etch for dye penetrant inspection. Sodium hydroxide containing additives was not reported as certified, and therefore available from a regulatory perspective for other pre-treatment processes or applications.

3.5.6.6 Suitability of sodium hydroxide containing additives

As summarised in Section 3.5.1.1 an alternative must be assessed against defined criteria to determine it can be viewed as 'suitable'. Sodium hydroxide containing additives has been identified as a suitable alternative to Cr(VI) for the specific applications related to inspection procedures, described in section

3.5.6.2. It provides a reduction in hazard profile, with no significant economic barriers to use However, it is reported that this alternative is not suitable for removal of welding and brazing flux and localised repairs (CTAC, 2015c). Its use is with the caveat that residues, or smuts, can result from the use of alkaline treatments. These contaminants require removal with a suitable desmutting process where specified by the design owner. This may limit the extent of use of this alternative beyond that already described, so it cannot be considered a generally available and suitable alternative for all pre-treatment applications of Cr(VI) .

3.5.7 Test candidate 6: Cr(III) for anodic pickling

3.5.7.1 Introduction

A finished metallic component ready for functional chrome plating, electroplating, will typically start to form oxides on its surfaces immediately after exposure to the atmosphere. After a relatively short period of time, days, these oxides will build to a level that will interfere with the electroplating process, impeding adhesion of the metallic chrome coating onto the substrate. If oxide formation is not an issue for certain substrates subject to electroplating, for example plastics, other contaminants such as oil or other organic residues from fabrication processes can also remain on the component. It is imperative that all contaminants are removed to ensure good adhesion of the chrome coating onto the substrate. The prepared surface should be compliant with the requirements of industry specifications, for example MIL-PRF8625[41]. Conventionally, Cr(VI) electroplating baths can be used for the dual purpose of anodic pickling. This is both effective and economical by utilising the chromic acid plating solution to pickle and prepare surfaces prior to electroplating. Pickling is achieved by inverting the polarity of the treatment bath; the component to be treated is the anode. The duration of the pre-treatment process could vary depending on the surface properties required for plating.

Substitution of Cr(VI) with Cr(III) for the main treatment of electroplating has resulted in feasibility studies being conducted to determine if this practice is still technically feasible with trivalent chrome, which are ongoing.

3.5.7.2 Technical feasibility/Technical readiness of Cr(III) anodic pickling

Additives are used to maintain the performance requirements of Cr(III) electrolyte. These form organic complexes of Cr(III) to provide a means of efficient reduction to metallic chrome for electroplating. Pickling ferrous metals introduces iron into the electrolyte solution. Cr(VI) is relatively tolerant of this iron contamination. However, as a result of iron contamination of the Cr(III) electrolyte, the electroplating bath is destabilised. Increased filtration only marginally mitigates this issue due to the sensitivity of Cr(III) to iron contamination. Therefore, increased filtration ceases to be a practical solution. Removing the pickling process for simple designs is possible, however the process is not reliable and not robust enough for more complex designs. Consequently, anodic pickling with Cr(III) electrolyte is not considered technically feasible for the majority of applications.

Dedicated pickling/etching tanks and nickel base layer

To counter the issue described in section 3.5.7.2 where Cr(III) electrolyte is required for electroplating chrome, alternative routes are under investigation. The first is to install separate immersion tanks for degreasing and pickling in-line to clean and prepare the surface of the component to be plated. This is

[41] S&P Global (2022): Available at MIL-PRF-8625 : ANODIC COATINGS FOR ALUMINUM AND ALUMINUM ALLOY (ihs.com), accessed 23 December 2022.

required to minimise iron contamination of the Cr(III) electrolyte when plating ferrous metals. Options reported include the use of acid; sulphuric, including separate sulphuric anodic etching. Etching with sulphuric acid is discussed in section 3.5.5

Another approach is to prepare the surface with a nickel base layer. This is allowable based on the component's geometric tolerance.. Various standards exist for nickel plating including SAE AMS 2403 and SAE AMS2423[42]. This process requires additional infrastructure and therefore more resources and time to implement.

The TRL status reported by members ranges from TRL 3 to 4 with forecasted development to TRL 7 through 9 by 2032.

3.5.7.3 Economic feasibility of Cr(III) anodic pickling / nickel base layer

The direct challenge for the substitution of the current Cr(VI) based pre-treatment by Cr(III) anodic pickling/nickel base layer is the additional infrastructural costs and additional operational costs with increased production times.

Due to the need to reconfigure the production line to avoid the use of anodic pickling, additional costs are incurred from new immersion tanks. Where the nickel base layer is incorporated, additional costs are likely from the installation of supporting equipment, including new electrodes for example. Where nickel plating is not available on-site, or existing equipment is not suitable for plating onto more complex geometries, components may need to be sent to specialist contractors, adding time and cost to the production process.

The operational costs will increase due to the following impacts:

- **Infrastructural costs:** Costs resulting from the construction of new lines to accommodate additional tanks;
- **Longer process times:** Moving to Cr(III)-based alternatives will require the introduction of a two-step industrial process which will lead to an increase in production times and hence reductions in production rates (potentially with consequent impacts on turnover);
- **Raw material prices:** In general, the price of raw materials for the potential candidate is higher than the price of the Cr(VI)-based formulations currently in use. The bath life of the alternatives is shorter, so a higher quantity of the test candidate per annum would be needed;
- **Waste disposal cost:** Potential increases in the volume of waste and therefore disposal costs than current levels.

[42] S&P Global (2022): Available at SAE AMS2403 : Plating, Nickel General Purpose (ihs.com), accessed 23 December 2022.

3.5.7.4 Health and safety considerations related to the use of Cr(III) and nickel base layer

For the purposes of understanding the risks associated with the test candidate Cr(III) and nickel base layer the key identifiers and summary of hazard properties are listed in **Table 3-14**.

Table 3-14: Summary of hazard profiles for Cr(III) and nickel plate base layer

Substance	EC Number	CAS number	CLP classification
Cr(III) (Chromium hydroxide sulphate) [(a)]	235-595-8	12336-95-7	Skin Irrit.2;H315, Eye Irrit.2; H319, Skin Sens.1; H317
Nickel sulphate hexahydrate [(b)]	232-104-9	7786-81-4	Acute Tox.4;H302, Skin Sens.1;H317, Resp.Sens.1; H334, Repr.1B;H360D, STOT RE 1; H372, Skin Irrit.2; H315, Acute Tox 4; H332, Muta. 2; H 341, Carc.1A H350i
Nickel chloride hexahydrate	616-576-7	7791-20-0	Acute Tox.3;H331, Aquatic Chronic 1; H410, Aquatic Acute 1; H400, Resp.Sens.1;H334, Acute Tox. 3; H301, Skin Irrit.2; H315, Carc.1A; H350i, Muta.2;H341, Skin Sens.1; H317, Repr.1B; H360D, STOT RE 1; H372.

(a) REACH registration dossier notifications
(b) Harmonised classification according to Annex VI of Regulation (EC) 1272/2008 (CLP)

Table 3-14 lists the components of nickel plating baths used for producing a nickel base layer prior to hard chrome plating with Cr(III) used as an alternative pre-treatment to replace Cr(VI) anodic pickling. Due to the classification of nickel salts there is a risk of regrettable substitution.

The nickel plating solution can include several components including nickel sulphate, nickel chloride and a buffer to control the pH of the solution.[43]

3.5.7.5 Availability Cr(III) and nickel base layer

Nickel salts are required for deposition of the nickel base layer. These may be dissolved directly into the immersion bath or are available as formulated proprietary products which include excipients such as buffers to control pH. Nickel plating is a well-established, commercially recognised process, with a number of companies supplying the coating solutions and equipment required for the process. This said, there is the potential that more specialised equipment would need to be designed for use with components possessing complex geometries.

3.5.7.6 Suitability of Cr(III) and nickel base layer

Cr(III) anodic pickling is not stable in the presence of iron. Due to the sensitivity of Cr(III) electrolyte, adequate filtration to remove the iron not practical in a production environment. Therefore, Cr(III) anodic pickling is not technically feasible for the vast majority of applications. A separate process combining pickling in a separate bath with an acid and depositing a nickel base layer prior to Cr(III) electroplating may be used. Whilst the process and technology are well-defined, economic feasibility is dependent upon the nature of the equipment required to nickel plate components, access to specialist suppliers providing the nickel plating process. Consideration should also be given to the capacity of existing manufacturing facilities to accommodate additional infrastructure, as well as any limitations of use from the geometric complexity of the component to be plated. Where space to introduce additional

[43] Nickel Institute (2014): Available at nph_141015.pdf (nickelinstitute.org), accessed 23 December 2022

infrastructure is insufficient, and/or specialist suppliers providing this service are not qualified, this may restrict availability for some members. Utilising nickel salts does not represent a reduction in hazard compared to Cr(VI), refer to **Table 3-14** and is a candidate for regrettable substitution in the long-term Consequently, the use of nickel base layer as an alternative to Cr(VI) anodic pickling is not considered a suitable alternative generally available.

3.5.8 Test candidate 7: Mechanical cleaning/Abrasive blast

3.5.8.1 Introduction

Abrasive blast uses the physical effect of a fine particulate abrasive medium such as sand/silica, metallic grit, pumice, and aluminium oxide to remove surface contaminants. The selection of abrasive medium depends upon the nature of the substrate to be cleaned. This provides a uniform surface suitably prepared to receive a subsequent coating or treatment. Substrates treated via this method include corrosion resistant steels for example. The abrasive is accelerated towards the substrate surface within a carrier, typically air or water. Use of this technique is reported as effective for removal of light oxide/scale deposits and heat-tint; a result of exposure to oxygen during welding. However sand and grit-blasting is not always recommended for hint-tint removal (Corrosionpedia, 2023). Not all blasting media are appropriate for all substrates and contaminants. Grit blasting is generally not recommended in all cases for stainless steel as it is either not clean enough, or soon becomes contaminated with abraded material. Grit blasting leaves a rough profile which can encourage corrosion when used in conjunction with stainless steels. Glass beads are an alternative option, although they must be kept clean and not be reused too often to ensure they do not re-contaminate the substrate surface (SSINA, no date). Very stubborn most difficult to remove scale deposits may require additional processing with a supplementary pickling/etching solution; chemical pre-treatment using a chromate (GCCA, 2016a).

Due to its line-of-sight application method, abrasive blast is not suitable for complex geometries, e.g., narrow grooves or channels as non-uniform surface characteristics may result. Irregular surface characteristics, such as roughness, could cause variation in the performance of the component or subsequent treatment if not adequately controlled. In addition, thinner gauge materials are vulnerable to distortion from the force of the abrasive particles striking the surface (GCCA, 2016a). Mechanical pre-treatment may also be applied using abrasive pads to abrade the surface. These are coarse woven material pads which can be immersed in an aqueous suspension of an abrasive material.

3.5.8.2 Technical feasibility/Technical Readiness Level Mechanical cleaning/Abrasive blast

As introduced above, there is a technical limitation for thinner narrow-gauge substrates prone to distortion caused by the abrasive blast process. This precludes components made from these substrates from this process. As a 'line of sight' treatment, assemblies or complex geometry parts are not suited to abrasive blast if non-uniform preparation of the surface would result.

Specification MIL-DTL-5541F, applicable to chemical conversion coating on aluminium and aluminium alloys, prohibits the use of abrasives that contain iron (US DoD, 2006). Therefore, abrasive blast with metallic grit may not be suitable or approved for all substrates or subsequent uses. Other performance requirements may be tighter still and exclude both non-chromated pre-treatments and main treatments. Mechanical preparation of the surface is reported for touch-up processes on aluminium reliant upon Cr(VI)-free chemical conversion coating as a subsequent treatment. This is reported as a mandatory step prior to touch-up with Cr(VI) free chemical conversion coating to achieve the best characteristics from the main treatment.

A feature of abrasive blast, although not commonly used, is to increase surface roughness. This is reported to enhance adhesion of subsequent processes, for example anodising. Mechanical pre-treatment may also be manually applied using abrasive pads, e.g., the proprietary Scotch-Brite™ pad. The pad can be immersed in an aqueous suspension of abrasive particles, for example pumice powder.

Mechanical cleaning via abrasive blast or manual abrading is reported at TRL 9 and implemented for limited applications.

3.5.8.3 Economic feasibility Mechanical cleaning/Abrasive blast

When introduced as an new process, to support Cr(VI) free chemical conversion coating for example, costs attributed to the introduction of mechanical preparation prior to touch-up will be dependent in part upon the required application equipment and/or training and labour to operate it.

For abrasive blast, larger facilities with supporting infrastructure are required to isolate the area where the treatment is applied. It may be necessary to locate the abrasive blast process in a purpose built facility located in a dedicated area separate from the main production line. This is to ensure other production processes cannot be cross-contaminated. Costs will be proportional to the size of these dedicated facilities.

3.5.8.4 Health and safety considerations related to the use of Mechanical cleaning/Abrasive blast

Abrasive blast media are carried in either water or air. The particulate abrasive blast material will vary depending on requirements of the down-stream user, characteristics of the design, subsequent main treatment, and substrate surface to be prepared. Materials reported as used for abrasive blast applications include:

- Pumice;
- Metallic grit;
- Aluminium oxide/white alumina grit;
- Alumina-zirconia;
- Sand/silica; and
- Glass beads

Table 3-15 lists examples of particulates used for abrasive blast and their respective hazard profiles.

Table 3-15: Summary of hazard profiles for abrasive blast media

Substance	EC Number	CAS number	CLP classification
Pumice[(a)]	603-719-3	1332-09-8	Eye Irrit.2; H319, STOT SE 3; H335
Metallic grit e.g. iron[(b)]	231-096-4	7439-89-6	Self-heat.1;H251,Flam.Sol.1;H228
Aluminium oxide[(b)]	215-691-6	1344-28-1	Not classified
Sand/silica[(a)]	231-545-4	7631-86-9	STOT SE 3;H335, Eye Irrit.2; H319, Skin Irrit.2; H315, Acute Tox.4; H332, STOT RE1; H372
Glass beads	920-837-3	308066-74-2	N/A

(a) Notified classification and labelling according to CLP criteria
(b) REACH registration dossier notifications

Each of the above examples of media for abrasive blast applications represents a reduction in hazard profile compared to Cr(VI). With regard to silica, there is potential for serious health impacts as indicated by the STOT RE1, H372 classification. The inhalation of respirable silica, if present, is known to effect the lungs and could result in silicosis. As a consequence some regional jurisdictions place controls on the use of silica for abrasive blast applications (HSE, 2011).

3.5.8.5 Availability Mechanical cleaning/Abrasive blast

Mechanical cleaning via abrasive blast or manual abrasive pads is a recognised and utilised pre-treatment process for selected applications of deoxidising (scale removal). However, its use is either not permitted or restricted in conjunction with specifications such as MIL-DTL-5541F which restricts the type of abrasive blast medium that can be used; iron may not be used for cleaning aluminium substrates to ensure compliance with certain specifications for example[44]. The process may be too aggressive for components made from thinner gauge materials vulnerable to impact deformation as a consequence of abrasive blast. These limitations potentially excluding this process for entire categories of components/designs.

3.5.8.6 Suitability Mechanical cleaning/Abrasive blast

Abrasive blast is reported as limited to deoxidising, removal of light deposits of scale, and hint-tint. It may be necessary to supplement with additional chemical pre-treatment using a chromate. Use is further limited due to its line-of-sight application method preventing use with complex geometries. Narrow gauge substrates vulnerable to impact deformation are also not suitable for this pre-treatment method. Abrasive blast and mechanical cleaning with abrasive pads are approved for use in limited circumstances. Use of manual abrasive pads for pre-treatment of parts is generally limited to smaller scale applications such as pre-treatment prior to touch-up processes. With respect to hazard, all particulates listed in **Table 3-15** represent a reduction in hazard in comparison to Cr(VI). However, respirable silica is controlled in some local jurisdictions due to its effect on the lungs and the potential to cause silicosis, leading to controls on its use in some instances. Although there may be restrictions in use for some types of blast media, there are no reported restrictions in supply, with all being commercially available on the market. However, overall, this test candidate is not considered universally available on grounds of technical feasibility and therefore is not a suitable alternative to Cr(VI) for all a pre-treatment processes and applications.

3.6 Conclusions on shortlisted alternatives

Table 3-16 summarises the current development status of the test candidates to replace Cr(VI) for pre-treatments. It considers the availability to the downstream users and hence the applicant, from the perspective of technical and economic feasibility as well as regulatory requirements that must be met before a test candidate can be qualified, validated, certified, and therefore approved and implemented, and hence how this affects its suitability. To confirm, in all cases 'high' represents an increased level of alignment with the requirement of the individual criteria.

[44] MIL-DTL-5541F, Section 3.2

Table 3-16: Current development status of short-listed test candidates					
Test candidate	**Technical feasibility**	**Economic feasibility**	**Risk reduction**	**Availability**	**Suitability**
Sulfonitroferric acid	Medium/High	Medium	High	Medium/High	Medium/High
Nitric/sulphuric acid	Low/Medium	High	High	Medium	Medium
Phosphoric acid based solution	Low/Medium	High	Medium	Medium	Medium
Sulphuric acid (including electrolytic sulphuric acid pickling)	Low/Medium	High	High	Medium	Medium
Sodium hydroxide containing additives	Low	High	High	Low	Low/Medium
Cr(III) for anodic pickling (and nickel base layer)	Low/Medium	Low/Medium	Low	Low	Low
Mechanical cleaning/abrasive blast	Medium	Low/Medium	Medium	Medium	Medium

Due to the complexity of the substitution process within the A&D sector, described in section 3.1.2 none of the short-listed test candidates can be implemented for all substrates and components prior to the end of the existing review period.

It should also be considered that this process forms part of an overall system which currently utilises formulations containing Cr(VI) at multiple stages. The implementation of a Cr(VI)-free alternative for pre-treatments is, in some cases, being tested alongside main treatment processes which themselves are not yet industrialised.

Sulfonitroferric acid is reported as technically feasible and implemented for a number of substrates utilised for aerospace and defence applications and prior to different main treatments; anodising and chemical conversion coating. It may be prepared in-situ from the constituent chemicals by the downstream user or bought in the form of a two part proprietary formulation to be prepared by the downstream user as required. The proprietary formulation route is reported to provide better storage stability and can also be modified to optimise performance for more difficult to remove oxide deposits, by introducing fluoride. However, close control of the operating parameters is required to ensure that decontamination is not at the expense of fatigue debit for fatigue sensitive parts.
Not all scenarios of use have been approved with sulfonitroferric. For some applications, additional measures such as phosphoric acid anodising are required to achieve the required performance when sulfonitroferric acid is used prior to a non Cr(VI) chemical conversion coating treatment in combination with specific substrates.

Additional steps in the process incur extra costs. Other additional cost drivers include increased raw material costs, additional infrastructure, where new lines or treatment baths are required, and possible increase in waste streams with associated increased treatment costs.
Risk reduction is achieved with a reduction in hazard profile compared to Cr(VI). However, due diligence is required when assessing the inclusion of fluoride donors and any impact they may have on regulatory obligations for a specific site; Seveso III Directive 96/82/EC for example.

Sulfonitroferric acid is readily available on the market either as base constituents or as proprietary formulation marketed for use with compatible main treatments as part of an treatment system. Not all substrates and functions have yet been certified with sulfonitroferric acid with further evaluation required to complete certification requirements. Where this is the case it is not available from a regulatory perspective and therefore not suitable for all pickling/etching and deoxidising processes met with Cr(VI).

Nitric/sulphuric acid mixtures are historically identified for specific purposes relating to the removal of heavy oxide contamination from copper substrates. It is an aggressive treatment requiring careful control of process parameters and as a consequence is not considered suitable for all substrates. Members report selected application for deoxidising and pickling/etching processes on non-fatigue sensitive aluminium substrates. The test candidate has attained TRL 9 for deoxidising prior to anodising, whilst testing has progressed to TRL 6 in 2023, with expectation of progression to TRL 9 in 2028, subject to successful completion of all test requirements for pickling/etching of compatible aluminium alloys. As a consequence of a relatively limited scope of application this test candidate cannot be considered as technically feasible for the majority of substrates subject to deoxidising and pickling/etching processes. Economic feasibility is difficult to quantify, however on balance not considered a barrier to adoption. Nitric/sulphuric acid mixtures do offer a reduction in hazard profile compared to Cr(VI) and both constituents are freely available on the market, however, as yet are not available for all applications, pickling and etching for example, from a regulatory perspective. Therefore, until certification is attained, nitric/sulphuric mixtures do not meet all criteria to be considered suitable alternative to Cr(VI).

Phosphoric acid/fluoride mixtures are implemented for the removal of heavy oxides from copper and brass and also the treatment of titanium to deoxidise and enhance adhesion. These are relatively niche applications not covering the majority of substrates requiring pre-treatments.
Phosphoric and sulphuric acid provide a reduction in hazard profile, with no reported economic barriers to use compared to Cr(VI). However, under due diligence inclusion of fluorides as co-formulants may need to be assessed against other regulatory obligations, for example the Seveso III Directive 96/82/EC , before implementation. Technical feasibility for the purposes of pickling/etching (electropolishing) of many steel grades are fulfilled, however further work is required to certify this test candidate for use with all alloys subject to this process. For example at least one austenitic stainless steel grade failed initial testing as required level of decontamination was not achieved using this test candidate. Evaluation of this test candidate for all affected substrates is estimated to be completed in 2028 subject to no iteration of testing. Therefore, this is not considered a suitable alternative for all current substrates electropolishing process with Cr(VI)

Development of sulphuric acid for the purpose of preparing metallic surfaces has progressed to implementation for some applications, for example preparing cadmium for further processes following plating onto steel whilst remaining uses of this pre-treatment application are anticipated to be complete by the end of 2024.

Sodium hydroxide containing additives has been identified as a suitable alternative to Cr(VI) for the specific applications related to inspection procedures, described in section 3.5.6.2. It provides a reduction in hazard profile, with no significant economic barriers to use. However, this alternative is not suitable for removal of welding and brazing flux and localised repairs. A technical drawback is that residues, or smuts, can result from the use of alkaline treatments. These contaminants require removal with a suitable desmutting process where specified by the design owner. This may limit the extent of use of this alternative beyond that already described, so it cannot be considered a generally available and suitable alternative for all pre-treatment applications of Cr(VI).

Cr(III) anodic pickling is not stable in the presence of iron. Due to the sensitivity of Cr(III) electrolyte, adequate filtration to remove iron evolved in the pickling process is not practical in a production environment. Therefore, Cr(III) anodic pickling is not considered technically feasible for the vast majority of applications, excepting small basic designs. A separate process combining pickling with an acid in a separate bath, followed by deposition of a nickel base layer prior to Cr(III) electroplating, may be used. The process and technology are well-defined. However, economic feasibility is dependent upon the nature of the equipment required to nickel plate components, and access to specialist suppliers providing the nickel plating process. There may be restrictions in the capacity of existing manufacturing facilities to accommodate additional infrastructure, as well as technical limitations of use from the geometric complexity of the component to be plated. Where space to introduce additional infrastructure is insufficient, and/or specialist suppliers providing this service are not qualified, this may restrict availability for some members. Utilising nickel salts does not represent a reduction in hazard compared to Cr(VI), refer to Table 3-14 which represent potential regrettable substitution. Consequently, nickel base layer as an alternative to pickling is not considered a suitable alternative to Cr(VI) anodic pickling for the vast majority of applications in the long-term.

Abrasive blast is used for deoxidising and removal of light deposits of scale and hint-tint. Additional chemical pre-treatment using a chromate may sometimes be necessary for very difficult to remove scale deposits. Use is further limited due to its line-of-sight application method preventing use with complex geometries. Narrow gauge vulnerable substrates may deform under impact from abrasive blast medium prohibiting its use with components made from these materials. Therefore, abrasive blast and mechanical cleaning with abrasive pads are approved for use in limited circumstances. Use of manual abrasive pads for pre-treatment of parts is generally limited to smaller scale applications such as pre-treatment prior to touch-up processes. All blast media listed in **Table 3-15** represent a reduction in hazard in comparison to Cr(VI). However, special consideration must be paid if respirable silica is present in sand based media. This is controlled in some local jurisdictions due to its effect on the lungs and the potential to cause silicosis, leading to controls on its use in some instances limiting availability. Although there may be restrictions in use for some types of blast media, there are no reported restrictions in supply, with all being commercially available on the market. Economic barriers may exist if bespoke isolation facilities need to be built to house the abrasive blast equipment as the process should be kept separate from other parts of the manufacturing line to prevent possible cross-contamination from used fine particulate abrasive blast material. Overall, this test candidate is not considered suitable on grounds of technical feasibility and regulatory availability and therefore is not a suitable alternative to Cr(VI) for all a pre-treatment processes and applications.

3.7 The substitution plan

3.7.1 Introduction

3.7.1.1 Factors affecting the substitution plan

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

- Functionality and ability to meet performance requirements (technical feasibility);
- Availability, and suitability of the alternative;
- Process changes such as equipment, training, health and safety (*Technical challenges and economic feasibility*);
- A substitution process which is subject to regulatory control, legal constraints, and customer requirements;

- Economic feasibility, including the capital and operational costs of moving to an alternative and the costs of implementing the alternative across the supply chain; and
- Progress and alignment with other REACH substitution workstreams.

Each factor will contribute to the achievement of milestones that must be met to realise delivery of the substitute(s) to Cr(VI) for 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 pre-treatments that is uniquely reflective of their individual situation. Additionally, an individual member often has multiple substitution plans for pre-treatments, 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 pre-treatment, 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 alternative and prioritisation of certain types of component or substrate.

3.7.1.3 Interplay with pre-treatments and main treatments

Development of substitution plans for alternatives to Cr(VI) for pre-treatments are fundamentally related to and impacted by the compatibility of the pre-treatment process with subsequent down-stream uses, for example conversion coating, anodising, passivation of stainless steel and electroplating. The progression and success of the development of alternatives to Cr(VI) in pre-treatments can depend on the successful implementation of alternatives to Cr(VI) in the whole treatment system. In most cases, substitution of Cr(VI) from the pre-treatment the main treatment is implemented at the same time. It cannot be guaranteed that a Cr(VI)-free pre-treatment will be compatible with all scenarios of use of the subsequent main treatment. A pre-treatment containing fluoride may not be compatible with all aluminium alloy substrates subject to anodising for example as fluoride may increase susceptibility to corrosion. A more aggressive etch from pickling processes containing fluoride may be suitable for non-fatigue sensitive components but in contrast be detrimental where fatigue sensitivity is a performance requirement. It is reported that nitric acid based pre-treatments are not compatible with some aluminium alloys containing copper used to fabricate fatigue sensitive designs. If used prior to chemical conversion coating of aluminium alloys containing copper intermetallic sites, interaction with nitric acid creates a copper rich layer on the surface of the substrate which can impact corrosion performance of conversion coatings in neutral salt spray tests.

Separate from the potential technical feasibility considerations, it is more practical and efficient to substitute all parts of the treatment system together. This is particularly important where pre-treatments and main treatments are proprietary and common to the same formulator i.e., must be used together for optimum performance. Testing across all substrate/service environment combinations for individual component families is still required for these treatment systems to ensure key functions and performance requirements are met.

3.7.2 Substitution plan for ADCR in pre-treatment

3.7.2.1 Substitution plans

The expected progression of ADCR members' substitution plans to replace Cr(VI) in pre-treatments is shown in Figure 3-8 below. The progressive stages of the substitution plan (development, qualification, validation etc.) are shown in the diagram and described in detail in section 3.1.2. Implementation and progression of substitution plans ultimately leads to reduced Cr(VI) usage. MRL 10 is the stage at which manufacturing is in full rate production/deployment and is therefore where it is expected that Cr(VI) will be fully substituted under the relevant plan.

The data in the figure show the expected progress of 24 distinct substitution plans for Cr(VI) in pre-treatments, 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 pre-treatments for the ADCR consortium as a whole.

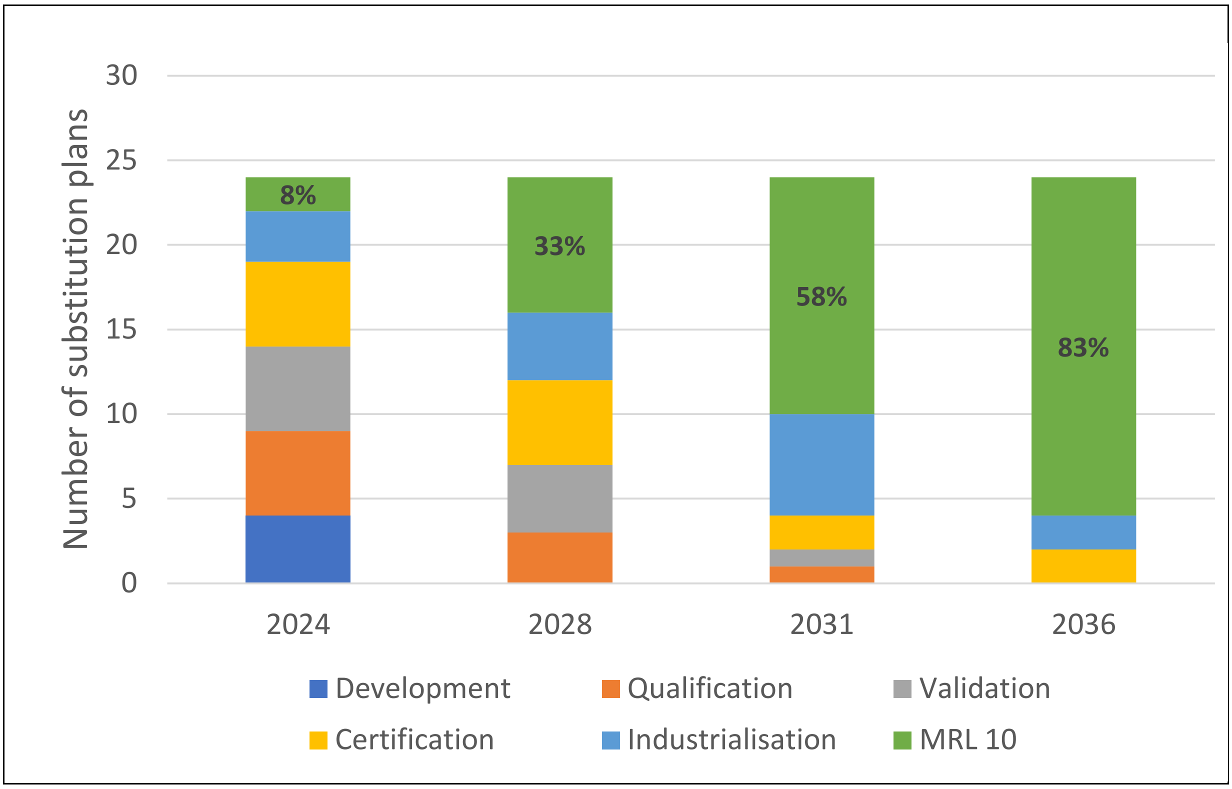

Figure 3-8: Expected progression of substitution plans for the use of Cr(VI) in pre-treatment, by year. The vertical axis refers to number of substitution plans (some members have multiple substitution plans for pre-treatment processes). The percentage value shown on each of the green bars indicates 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 that Cr(VI) will be fully substituted under the relevant plan.
Source: RPA analysis, ADCR members

The above summary shows:

- Variation in the status of different substitution plans in each of the years (this variation is due to issues such as technical feasibility, types of substrates, types of components, and harmonisation of a single pre-treatment process with different/multiple downstream uses); 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 3-8**.** The actual status of the substitution plans 12 years from now could be different to our expectations today.

Many members have multiple substitution plans for pre-treatment processes some of which may be interdependent where multiple downstream uses rely on the same pre-treatment process. Often these separate downstream processes must be substituted together to ensure a stable treatment and production process for a given component family. It is feasible for those substitution plans not expected to have achieved MRL 10 by a given date, that a proportion could benefit from successful delivery of other substitution plans progressing in parallel. This would accelerate delivery of other substitution activities, subject to the usual compliance and certification requirements. This highlights the complexity of delivering multiple substitution plans within members portfolios resulting from differences in, for example, type of pre-treatment process, number of down-stream uses utilising common pre-treatment processes, types of component/design, and type of test candidate being developed.

There are challenges which limit members' progression of the substitution plans beyond the stages indicted in Figure 3-8. Technical challenges include ensuring the reproducibility and bath stability associated with the pre-treatment processes, as well as the logistical issues presented to organisations who need to add additional equipment or suppliers to support pre-treatment processes. Running both the old and new process in parallel is often not practicable due to, limitations on floor space for example. In these cases switch over to the Cr(VI)-free process will need to wait until all relevant substitution plans have reached fruition, as discussed above.

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

The timeframes associated with the activities presented in Figure 3-8 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 3-8 that despite ongoing and concerted efforts of the members to develop alternatives to Cr(VI) in pre-treatments, 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 (42%) are not anticipated to have achieved MRL 10 and are expected to be at the qualification, validation, certification, or industrialisation stage. For these substitution plans there is still expected to be a need for the use of Cr(VI).

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

4 Continued Use Scenario

4.1 Introduction

Section 3 provided an analysis of the alternatives with respect to the technical feasibility, economic feasibility, availability and suitability of alternatives. The assessment highlights the importance of Cr(VI) to the mode of action for corrosion resistance and other key functions delivered by pre-treatment, in combination with main treatments in to prepare a variety of substrates. Although some of the companies supporting this use have implemented alternatives at the industrial level (e.g., sulfonitroferric acid) for some components and substrates, this is not the case in all circumstances.

Until alternatives which are also compatible with pre- and post-treatment steps as relevant, and which deliver an equivalent level of functionality (as required), qualified, validated and certified to produce individual components and products, use of the chromates in pre-treatment will continue to be required; their use is essential to meeting airworthiness and other safety requirements. Therefore, there are no alternatives which can be considered “generally available” in the context of A&D.

In some cases, alternatives are technically qualified and certified, but time is needed to industrialise and implement them across all industrial sites in the value chain. Given the large numbers of BtP suppliers and MROs involved in the use of pre-treatment, implementation itself may take several years (e.g., 6-8 within the larger value chains).

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

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

The Continued Use Scenario can be summarised as follows:

Continued use of Cr(VI) in pre-treatments whilst substitution plans progress	Continued use for production, repair and maintenance of parts and components
-> R&D on substitutes and progression to MRL 10 continues, with members aiming to be at MRL 10 by 2036	-> 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 that are certified and industrialised	-> R&D into the adoption of more sustainable technologies continues
-> Update of Maintenance Manuals to enable substitution in MRO activities	-> Employment in the sector is retained while worker exposures and risks decline over time
-> Continued production, repair and maintenance of aircraft and other final products ensured	-> Impacts on civil aviation, emergency services and military mission readiness is minimised

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

- The market analysis of downstream uses in the A&D markets;
- Annual tonnages of the chromates used in pre-treatment, including projected tonnages over the requested review period;
- The risks associated with the continued use of the chromates.

4.2 Market analysis of downstream uses

4.2.1 Introduction

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

- The ability to carry out the specific processes required to manufacture, maintain, and repair A&D components and products in the EEA/UK; and

- Continuity of supply of critical products containing hexavalent chromium.

The requirements of the ADCR members – as downstream users - supporting this application have been carefully identified and analysed, taking as the starting point the parent authorisations and the substance-use combinations covered by these. Over the lifetime of the ADCR consortium, the number of uses identified as requiring authorisation and the number of OEMs and downstream users supporting each use has decreased (including the continued need for use of the different chromate substances), to ensure that authorisation is only sought for those cases where there is no substitute that is fully qualified as per stringent airworthiness requirements and industrialised by 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.

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

4.2.2 Overview of the European aerospace and defence sector

In 2020, the European A&D industry was comprised of over 3,000 companies of all sizes and employed over 880,000 highly skilled employees (with these figures including the UK[45]). As noted by the European Commission, the industry is "characterised by an extended supply chain and a fabric of dynamic small- and medium- sized enterprises throughout the EU, some of them world leaders in their domain"[46]. Figure 4-1 provides details of turnover and employment for the industry in 2020, based on the A&D Industries Association of Europe (ASD) publication "2021 Facts & Figures".[47] These figures

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

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

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

are lower than the comparable figures for 2019, at around 405,000 jobs and €130 billion in revenues[48], leading to exports amounting to around €109 billion.

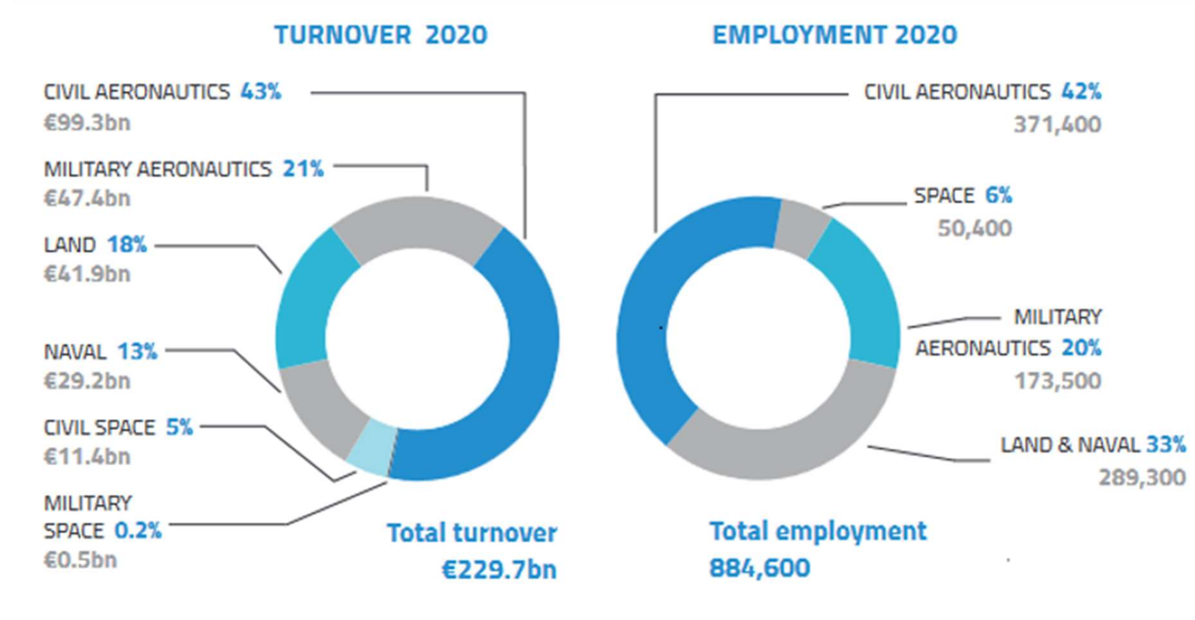

Figure 4-1: Turnover and Employment for the European A&D Industry in 2020 (snip taken from ASD, 2021)

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

As can be seen from Figure 4-1, civil and military aeronautics alone accounted for 64% of turnover and 62% of employment in 2020.

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

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

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

- Aircraft and other products remain in services 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

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

existing aircraft and equipment, as well as for models that are still in production for long periods after the first aircraft or military products were placed on the market;

- A&D technologies take many years to mature. Product development is a five- to ten-year process, and it can take 15 years (or more) before the results of research projects are applied in the market. As part of the development and roll-out of new A&D products, OEMs have to be ready to demonstrate fully developed technologies, or they risk losing contracts that may have a lasting effect on business.[49]

- The long product development process applies not only to the introduction of new technologies, but also to any activities aimed at adapting existing technologies as required for the substitution of the uses of the chromates. As indicated below with respect to R&D activities, research on substitution of the chromates has been underway for several decades, with the substitution of the chromates in pre-treatment has provided a difficult task for some products (and in particular some military final products).

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

4.2.3 Economic characteristics of companies undertaking pre-treatment

4.2.3.1 Profile of downstream users

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

Pre-treatment 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 also be carried out on a variety of other substrates such as steels, magnesium, nickel, copper, and their alloys. Examples of the types of parts treated by pre-treatment include:

- Fuselage skins and bulkheads;
- Wing skins, panels and covers;
- Stabilisers; and
- Wheels and landing gear links.
- Gearbox and engine inlet cases

SEA questionnaire responses were provided by 37 A&D companies undertaking pre-treatment, with these companies operating across 35 sites in the EEA and 18 sites in the UK (53 in total).

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

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

Table 4-1: Numbers of SEA respondents undertaking pre-treatment

Role	Number of companies/sites undertaking pre-treatment *	Company Size[50]	
		EEA	UK
Build-to-Print	18/22	1 small 3 medium 3 large	6 small 3 medium 2 large
Design and build	6/7	2 small 1 medium 2 large	1 medium 1 large
MRO only	6/7	1 small 1 medium 4 large	
OEM *	6/17	5 large	2 large
Total *	37/53		

*Some of the OEMs have sites in both the EEA and UK. In total, 37 companies provided a response, but some reported for the purposes of both EEA and UK REACH. There is therefore overlap in the number of companies but there is no overlap in the figures given for the number of sites.

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

4.2.3.2 Economic characteristics

Table 4-2 provides a summary of the number of companies identifying their activities against different NACE codes, which are used here to develop the economic characteristics of the "typical" OEM, DtB, DtP or MRO company. Companies may have indicated more than one NACE code as being relevant to their activities, with the result that the number of relevant NACE code counts is higher than the number of SEA responses relevant to pre-treatment 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.

50 https://ec.europa.eu/growth/smes/sme-definition_en

Table 4-2: Economic characteristics of "typical" companies by NACE in sectors involved in pre-treatment (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	27	20.88	54,000	35,500	15.5%
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.	9	57.20	65,000	43,200	9.7%
C2732 - Manufacture of other electronic and electric wires and cables	1	34.39	76,000	51,700	4.8%
C2815 - Manufacture of bearings, gears, gearing and driving elements	5	284.64	72,000	44,500	7.9%
C3030 - Manufacture of air and spacecraft and related machinery	7	1,214.65	98,000	76,400	11.2%
C3040 - Manufacture of military fighting vehicles	4	1,214.65	99,000	64,800	9.8%
C3316 - Repair and maintenance of aircraft and spacecraft	12	71.33	85,000	56,400	8.4%
Other	1	NA	NA	NA	NA
Total count	71				
Note: The count total is by number of NACE code identifications by company and not by sites, with 37 companies providing data					

Turnover is calculated as the weighted average by company size, as this is the most appropriate means of reflecting the level of turnover across the EEA (including UK) linked to pre-treatment and taking into account the size distribution of the companies[51] that are involved in such activities. GVA per employee, numbers of employees, and average personnel costs are given as the sector average and not per company size for several of the NACE codes, so it was not possible to calculate weighted averages for these. Note that the count total is by company and not by site.

Data on Gross Operating Surplus[52] (GOS) as a percentage of turnover (the GOS rate) is also used here to provide an indication of the profits associated with the turnover generated by these sites. This is based on a figure of 11% which is an average across the various NACE codes weighted by the number of companies declaring each NACE code.

As can be seen from Table 4-3, the 53 sites for which data were collected via the SEA questionnaire represent an estimated €23 billion in turnover and €2.4 billion in GOS as a proxy for profits. Across all 100 sites (80 in the EEA and 20 in the UK) expected to be undertaking pre-treatment, these figures rise to over €34 billion in turnover and €3.6 billion in GOS.

Table 4-3: Key turnover and profit data for market undertaking pre-treatment (based on 2018/2019 Eurostat data)

Sites covered by SEA responses/Extrapolated number of sites	Estimated turnover based on weighted average € million	Gross operating surplus (estimate based on 11%) € million
35 EEA Sites	19,488	2,046
18 UK sites	3,401	357
Extrapolation to all sites involved in chromate-based pre-treatment in the EEA or UK		
80 EEA sites	28,099	2,950
20 UK sites	5,831	612
Source: Based on SEA questionnaire responses, combined with Eurostat data Note: See Section 2.3.3.6 for basis of extrapolation to the 100 sites in the EEA and UK combined		

4.2.3.3 Economic importance of pre-treatment to revenues

Pre-treatment accounts for a proportion of the calculated revenues, GVA and jobs associated with a given process flow. To understand the importance of pre-treatments to the activities of individual companies, a series of questions were asked regarding other processes carried out, production costs, and the share of revenues generated from the use of chromates in pre-treatment.

As the supply chains covered by this SEA vary from manufacturers of small components to producers of much larger components (e.g., components for landing gear versus doors and/or interstage skirts), the responses vary significantly across companies. Of key importance is that for the design owners

[51] 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.

[52] 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).

pre-treatment continues to be a critical surface treatment, the loss of which would result in loss of a significant level of turnover due to the inability to meet airworthiness requirements, even though as a process it accounts for only a very small percentage of production costs.

Pre-treatments are a vital step in the value stream. Every company carrying out a main treatment precedes it with a pre-treatment process. The combination of pre-treatment, main treatment and post-treatment using the chromates are important with respect to the overall production process.

Given the importance of pre-treatments in preparing substrates for the main treatment, their loss would have a far greater impact on revenues and the financial viability of companies than suggested by their share of production costs.

The combination of these activities has been taken as the relevant process flow for assessing the economic impacts, regardless of whether pre-treatments and subsequent main treatments are chromate or non-chromate based, as it is the series of processes, and the profits and employment linked to them as an overall activity, that is relevant for this SEA.

Table 4-4 provides a summary of responses on the revenues generated by the combination of chromate using activities. OEMs carrying out pre-treatment using chromium trioxide and sodium dichromate indicate that each of the chromate linked processes contribute to less than 10% of their aerospace and defence related revenue, as indicated in below.

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

	<10%	10% - 25%	25% - 50%	50% - 75%	Total
Build-to-Print	0	0	0	14	14
Design-to-Build	0	0	0	7	7
MROs only	1	1	1	3	6
OEMs*	6	0	0	0	6

Note: 4 non-responses not included
*These responses cover multiple sites and only reflect those companies carrying out the activities

As shown above, the majority of companies reported that more than 50% of their revenues are generated by or linked to the set of chromate using processes.

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

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

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

4.2.3.4 Investment in R&D, risk management measures and monitoring

OEMs

The OEMs have carried out R&D into the substitution of the chromates for over 30 years. Further information on the R&D carried out by these companies is provided in Section 3.4. This includes collaborations such as IAEG.

With respect to capital investments relating to pre-treatment as part of the overall system, the following investments have taken place:

- Research into replacement of surface anti-corrosion system aircraft materials with more environmentally friendly technologies equating to €1.7 million;
- Investment of new paint booth and media blast facilities equating to €300k; and
- Investment of new test lines and research pending certification equating to €165k.

Design-to-Build suppliers

Three DtB companies have invested in new equipment including baths on the sites as part of the system of production, these investments ranged from €45,000 to €35,000 with a 25 years and 20 years expected minimum life.

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

Build-to-Print suppliers

Build-to-Print suppliers rely on their customers (OEMs and/or DtBs) to mandate the requirements of the products they manufacture, with this including the use of chromates in pre-treatment. As a result, BtP suppliers have little involvement in R&D activities, unless they are supporting R&D activities such as pilot testing the use of an alternative.
One Build-to-Print supplier indicated total expenditure of over €1.35 million as their contribution to collaborative EU Research programmes on substitution of the chromates.

Several of the Build-to-Print suppliers have undertaken investments in the period from 2007 to 2021 relevant to their use of the chromates. Examples include investments carried out in 2012/13 to improve processing lines (including improved air extraction and filtration systems) and to expand processing capacity in response to the then increasing demand for aircraft deliveries. These investments ranged from ca. €30k to €1 million (with an average of 15 years expected lifetime). Since

2012, several companies have also invested in improved emissions control equipment (stack improvements, LEV and tank lids).

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

MROs

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

More generally, investments have included expenditure to both reduce worker exposures and/or environmental emissions and on R&D aimed at reducing or eliminating the use of the chromates. Three of the MROs of relevance to pre-treatment as part of the system of production spent roughly €1 million each on investment on capital facilities such as improving production lines.

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

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

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

4.2.4 End markets in civil aviation and defence

4.2.4.1 Importance to end markets

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

Because chromate-based pre-treatment cannot be fully substituted at present, it plays a critical role in ensuring the reliability and safety of final products. Thus, although the economic importance of the chromates in pre-treatment is indirect in nature, its significance is clear with respect to:

- The ability of MROs (civilian and military) to undertake their activities within the EEA and UK, with this including the ability to carry out repairs with short turn-around times;

- The importance of timely MRO services to airlines and military fleets, reducing the amount of time that aircraft are grounded or are out of service;
- The impacts that increased groundings (Aircraft on the Ground – AoG) would have on the availability and costs of flights for passengers and for cargo transport, with reductions in passenger km and cargo km translating into significant economic losses not just within the EEA and UK but globally; and
- Impacts on defence operations, including the potential unavailability of critical equipment and impaired operations during military missions, which could only otherwise be guaranteed by the purchase of additional aircraft and weapon systems to compensate for AoG or systems out of service.

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

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

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

4.2.4.3 Civilian aircraft

Demand for new civilian aircraft is expected to grow into the future. Projected global compound annual growth rates (CAGR) for different aircraft classes for the period 2020-2031 are given in the figure below[53], with this suggesting CAGR from 2020 to 2031 of around 2.5%.

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

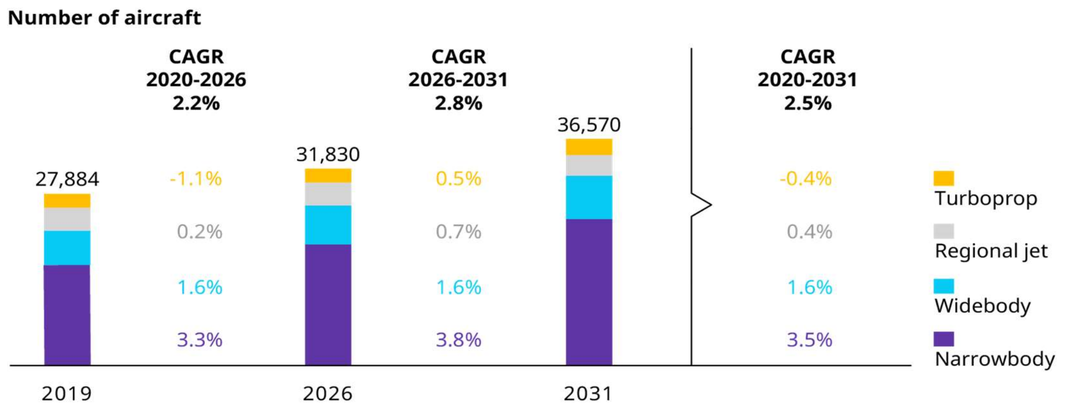

Figure 4–2: Global fleet forecast by aircraft class, 2020-2031
Source: Oliver Wyman analysis

Market reports issued by Airbus and Boeing indicate that future growth is expected to extend beyond 2031. Airbus' Global Market Forecast for 2022-2041 predicts that passenger air traffic will grow at 3.6% CAGR and freight traffic will grow at 3.2% CAGR globally. By 2041, there will be some 46,900 aircraft in service, with this including an estimated 39,500 new passenger and freighter aircraft (and the retirement of some of the older aircraft. This includes delivery of new aircraft for the European market, as well as the Asian and Chinese markets.[54]

Boeing's 2022 Commercial Market Outlook[55] 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 majority of commercial aircraft in operation will be of the latest generation[56]. Projections based on generic neutral seating categories (100+ seater passenger aircraft and 10 tonnes + freighters) are given in **Table 4-5** below.

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

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

56 2022-2041 GMF Presentation (airbus.com)

Table 4-5: Airbus Global Market Forecast: projected new deliveries 2021-2040								
Pax Units								
Category	**Africa**	**Asia-Pacific**	**CIS**	**Europe**	**Latin America**	**Middle East**	**North America**	**Total**
Small	860	13,660	1,160	5,220	2,170	1,570	5,050	**29,690**
Medium	140	2,350	120	1,040	180	420	640	**4,890**
Large	80	1,380	80	600	100	980	340	**3,560**
Total	**1,080**	**17,390**	**1,360**	**6,860**	**2,450**	**2,970**	**6,030**	**38,140**
Freight Units								
Small	-	-	-	-	-	-	-	**-**
Medium	10	120	40	40	10	20	210	**450**
Large	10	110	40	60	-	30	180	**430**
Total	**20**	**230**	**80**	**100**	**10**	**50**	**390**	**880**
Total Units								
Small	860	13,660	1,160	5,220	2,170	1,570	5,050	**29,690**
Medium	150	2,470	160	1,080	190	440	850	**5,340**
Large	90	1,490	120	660	100	1,010	520	**3,990**
Total	**1,100**	**17,620**	**1,440**	**6,960**	**2,460**	**3,020**	**6,420**	**39,020**
Source: Ascend, Airbus (undated): Global Market Forecast 2021 – 2040. Available at: https://www.airbus.com/en/products-services/commercial-aircraft/market/global-market-forecast								

When considering these figures, it is important to recognise that the European aerospace sector is a global exporter of aircraft, and A&D products make a significant contribution to the overall balance of trade. For example, France and Germany alone had export markets totalling over US$ 57 billion (€50.4 billion, £44.3 billion) in 2020, while the UK export market was around US$13.2 billion (€11.7 billion, £10.3 billion) in 2020.[57]

However, unless operations in the EEA and UK can remain financially viable in the short to medium term, the ability of EEA/UK based OEMs to carry out manufacturing at the levels implied by these compound annual growth rates is unlikely to be feasible. As a result, manufacture of these newer generations of aircraft and military products may shift to locations outside the EEA/UK with a consequent loss in Gross Value Added (GVA) to the EEA and UK economies, with enormous impacts on employment.

4.2.4.4 The MRO market

Not only would the manufacture of new aircraft in the EEA and UK be impacted but anticipated growth in the aftermarket parts segment would also be affected. The aircraft spare components/final products market encompasses the market for both new and used rotable[58] 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. Projected

57 https://www.statista.com/statistics/263290/aerospace-industry-revenue-breakdown/

58 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.

Growth is due to the increase in the commercial aircraft fleet as well as the need for timely MRO services to keep aircraft in service.

The MRO market was significantly affected by COVID-19 in 2020 but saw a gradual increase in demand as travel restrictions were lifted in 2021 and is expected to see positive growth over the next five to 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.[59, 60]

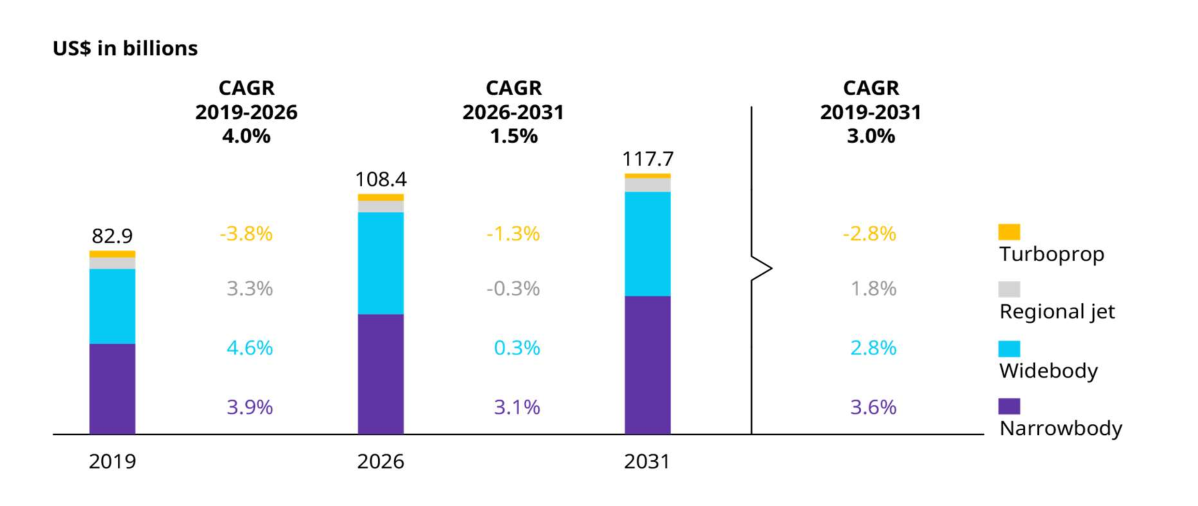

Figure 4–3: MRO market forecast by aircraft class, 2019-2031
Source: Oliver Wyman analysis

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 five years will also lead to a continued growth in demand for maintenance and repair activities.

4.2.4.5 The defence market

The war in Ukraine has led to several EEA countries and the UK to revisit their defence expenditure. Several countries that are NATO members and which previously did not meet the target of spending 2% of GDP on defence are now committed to meeting that target. This compares to Eurostat figures for total general government expenditure on defence in 202 of around 1.3% of GDP for the EU[61]. The increase in investment will equate to hundreds of billions of Euros (e.g. Germany alone has pledged €100 billion in defence spending).

Similarly, defence spending in the UK is expected to increase to over 2%, with projections in June 2022 suggesting 2.3% of GDP but Government commitments announced in October 2022 aiming for a target

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

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

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

of 3% of GDP by 2030[62]. 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 pre-treatment 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%[63].

4.3 Annual tonnages of the chromates used

4.3.1 Consultation for the CSR

As part of preparation of the CSR, site discussions were held with ADCR members and some of their key suppliers. This work included collection of data on the tonnages of the different chromates used per site. The tonnages assumed in the CSR range from 0 to 200 kg Cr(VI) per year per site using multiple chromates, with tonnages for individual sites as follows:

- 0 to 700 kg chromium trioxide used per year, translating to a maximum of 364 kg Cr(VI);
- 0 to 18,000 kg sodium dichromate used per year, thereof up to 7,200 kg Cr(VI);

4.3.2 Consultation for the SEA

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

Based on the maximums found in the CSR work and the upper bound figures quoted in the SEA responses, estimates of the tonnages of the individual chromates used by the anticipated 80 EEA and 20 UK sites for pre-treatment have been derived. These are figures for 2024 (assuming no decline from 2022 levels):

- EEA tonnage for 80 sites in ADCR supply chain: up to 25 tonnes per annum CT and 45 tonnes per annum SD; and

[62] 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

[63] 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

- UK tonnage for 20 sites in ADCR supply chain: up to 10 tonnes per annum CT and five tonnes per annum SD.

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

4.3.3 Article 66 notifications data

Under Article 66 of REACH, downstream users covered by an authorisation up their supply chain must notify ECHA of their use. As of 31 December 2021, ECHA had received 908notifications relating to the REACH Authorisations listed above covering 1127 sites across the EU-27 (and Norway).

A key difficulty in using the Article 66 data is that reporting is based on tonnage bands rather than actual tonnage information. It is therefore difficult to derive estimates of annual tonnages based on this information, especially as actual tonnages used at individual sites making notifications may be significantly lower than the upper limit for each of the tonnage bands. In addition, the notifications data covers multiple treatments and hence its use for pre-treatment alone would be misleading.

The distribution of notifications by substance and authorisation is summarised below[64].

Table 4-6: Number of downstream users using chromium trioxide and sodium dichromate notified to ECHA as of 31 December 2021

Substance	Authorisation	Authorised Use	Notifications	Sites
Chromium trioxide	20/18/7-13	Surface treatment of metals	526	619
	20/18/14-20	Surface treatment of metals	263	357
Sodium dichromate	20/5/3-5	Surface Treatment for aerospace	61	84
	20/4/1	Surface treatment of metals	58	67
Totals			908	1127

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

Since there are more sites than notifications, it is assumed that some notifications cover more than one site this is due to the reporting as a legal entity rather than site Some sites may, of course, use more than one of the two chromates.

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

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

4.3.4 Projected future use of the chromates

4.3.4.1 Introduction

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

Where possible, requirements for chromate-based pre-treatment in new designs is being phased out, however aircraft that require its use remain in production and it remains important to the protection of multiple substrates.

4.3.4.2 OEMs

The continued use of chromates in pre-treatment over time varies across the different OEMs. Two OEMs noted that use has increased over the past seven years due to an increase in aircraft deliveries. In contrast another company indicates that chromates use over the last seven years has decreased by 5-40 % due to substitution, while another indicated that use has remained steady over this period.

Chromates use in pre-treatment will remain at 2021/22 levels in 2024 but there is an expected decrease by 2030 and ongoing decreases thereafter. Importantly, however, some of the OEMs (those producing final products for military use) expect to continue to require the use of the chromates for an extended period, although demand should decrease post 2032.

4.3.4.3 Design-to-Build

The utilisation rates of pre-treatment lines across the DtB companies have remained high with levels of between 70% to 100% for four DtBs. As a result, the quantities of the chromates used have remained steady given that these are identified as being required by customers' specifications. Looking to the longer term, five DtBs indicated that they expected consumption of the chromates to decrease after 2030. The other respondents indicated an increase between 3 to 10%.

All these companies indicated that the use of the Cr(VI) is necessary to meet customers' performance requirements and/or as part of certification. In some cases, use may also be required by DtBs own designs and certified processes, or that continued use is required as part of maintenance, repair and overhaul activities (i.e., is specified in Maintenance Manuals and must therefore be followed for work to be legally compliant).

4.3.4.4 Build-to-Print

The aerospace industry has had many challenges which have had a lasting impact. Over the last several years, four respondents indicated a decrease in chromate utilisation rates by 5% to 25%. In some cases, companies were operating at low utilisation rates with one company only achieving 30% utilisation. Most of the companies indicated that they were impacted by the COVID-19 pandemic, and this may also have impacted their demand for the chromates.

In terms of expected future usage, nine of the BtP companies indicated that they did not know how their usage will likely change in 2030. Two companies indicated that they expected to increase consumption in 2030, while one expected chromate consumption to increase. All BtP companies noted that they used Cr(VI) to meet their customers' certification requirements.

It should be noted though that BtP suppliers will often have no knowledge of their customers R&D or substitution plans. As a result, one would expect that their consumption of chromates in pre-treatment to decrease at the same rate as for the OEMs.

4.3.4.5 MROs

Three MROs (covering multiple sites) stated that they had been impacted by COVID-19, with decreases in consumption of the chromates of between 6 - 66%, although they all expect consumption to return to normal. One MRO indicated that consumption remained steady over the last seven years, another indicated that consumption increased by 20%.

With regard to future trends, two MRO indicated that they expected chromate consumption to increase after 2032. There was uncertainty with two respondents indicating that they didn't know if consumption would change after 2032 and one indicated that consumption would remain the same.

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

4.3.4.6 Summary

Overall, responses to the SEA questionnaire indicate a downward future trend in the use of the chromates in pre-treatment over the requested review period. However, as indicated by the substitution plan, it is also clear that some of the respondents will require a further 12 years to finalise R&D, testing, qualification, validation and certification of alternatives and to implement them at an industrial level where the latter also includes making changes to process specifications, drawings and Maintenance Manuals. Part of the reason cited for the 12-year period relates to complexity of what needs to be achieved. As noted by respondents:

- *"Such a long review period to allow sufficient time to develop alternatives and test them before implementation".*

- *"We operate as a build and finish to print company for the aerospace sector. The identified processes are out of our control. A sufficient time will be necessary to allow us to modify our process once the OEM's have identified their alternatives and got them passed airworthiness procedures".*

- *"A 12-year review period is desired to ensure that alternatives can be implemented; however, the alternative's implementation depends on the approval of aircraft producer".*

If substitution proceeds as currently planned, significant reductions should be realised within seven years and use should cease by 2036, assuming that there are no setbacks.

4.4 Risks associated with continued use

4.4.1 Classifications and exposure scenarios

4.4.1.1 Human health classifications

The two chromates covered by this combined AoA/SEA were included into Annex XIV of Regulation (EC) No 1907/2006 due to their intrinsic properties (mutagenic, carcinogenic, toxic for reproduction; depending on the chromate).

Chromium trioxide is classified as a Carcinogen 1A and a Mutagen 1B under the CLP Regulation. The most important route of exposure and target organs are inhalation causing lung cancer and oral exposure causing intestinal cancer. The substance is also classified as a Skin and Respiratory Sensitiser 1 and is a Reproductive Toxicant 2.

Sodium dichromate is classified as a Carcinogen 1B and a Mutagen 1B under the CLP Regulation. The most important route of exposure and target organs are inhalation causing lung cancer and oral exposure causing intestinal cancer. The substance is also classified as a Skin and Respiratory Sensitiser 1 and a Reproductive Toxicant 1B.

The hazard evaluation follows recommendations given by RAC [65]:

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

4.4.1.2 Overview of exposure scenarios

All A&D sites that perform pre-treatment within the ADCR supply chains are specialised industrial sites being active in the EEA or the UK. They have rigorous internal, health, safety and environment (HSE) organisational plans. A mix of technical, organisational and personal-protection-based 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 pre-treatment activities. See the CSR for further details of measures in place.

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

[65] 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

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

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

With respect to worker exposures, Table 4-7 lists all the exposure scenarios (ES) and contributing scenarios assessed in the CSR.

Table 4-7: Overview of exposure scenarios and their contributing scenarios		
ES number	ES number	ES number
ES1-IW1	Deoxidising, pickling, etching and/or desmutting – use at industrial site	
Environmental contributing scenario(s)		
ECS 1	Deoxidising, pickling, etching and/or desmutting - use at industrial site not leading to inclusion (of Cr(VI) or the reaction products) into/onto article	ERC 6b
Worker contributing scenario(s)		
WCS 1	Line operators	PROC 9, PROC 13, PROC 28
WCS 2	Storage area workers	PROC 5, PROC 8b, PROC 28
WCS 3	Laboratory technicians	PROC 15
WCS 4	Maintenance workers and/or cleaning workers	PROC 28
WCS 5	Incidentally exposed workers	PROC 0
Exposure scenario for industrial end use at site: ES1-IW1		

4.4.2 Exposure and risk levels

The CSR provides details of the approach and assumptions underlying calculation of exposures and risks from the use of the chromates in pre-treatment. 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 4-8**, which presents the excess lung cancer risks to workers involved in pre-treatment. 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 for pre-treatment are usually involved in numerous activities related to the pre-treatment process. Most of their working time they spend in a hall where the pre-treatment tanks are located and where the immersion process takes place, either on activities with direct or indirect Cr(VI) exposure;
- WCS2: Storage area workers who decant liquids and measure solids, clean containers, handle solid wastes, undertake bath make-up and cleaning of baths as part of bath renewal;
- WCS3: Laboratory technicians may be involved in activities related to pre-treatment with potential for Cr(VI)-exposure, such as undertaking sampling laboratory analysis of treatment bath solutions;
- WCS4: Maintenance and/or cleaning workers who maintain pipes, pumps, sensors, scrubbers, electrical systems installed in treatment baths, and LEV systems; and
- WCS5: 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 4-8 sets out the excess lifetime cancer risk for workers involved in each of the above tasks.

Table 4-8: Excess lifetime cancer risk by SEG

#	SEG	Average number of workers	Excess lifetime lung cancer risk [1/υg/m³]
WCS1	Line operators	5 per site	2.08E-03
WCS2	Storage area workers	4 per site	6.96E-05
WCS3	Laboratory technicians	4 per site	NA
WCS4	Maintenance and/or cleaning workers	3 per site	3.84E-04
WCS5	Incidentally exposed workers	6 per site	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 (ECB, 2005). The approach to not perform a regional assessment for human Cr(VI) exposure via the environment as part of AfAs for chromate uses was also supported in compiled RAC and SEAC (Socio-economic Analysis Committee) opinions, for example in the Opinion on an Application for Authorisation for Use of sodium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites and sealings of anodic films (ID 0043-02). This reference states that regional exposure of the general population is not considered relevant by RAC.

The assessment presented in the CSR is based on measured data for emission to air and wastewater. For this assessment combined exposure of humans via the inhalation (air) and the oral (uptake of water and fish) route is considered. The resulting 90th percentile risk estimates are presented in the **Table 4-9.**

Table 4-9: Excess lifetime cancer risk estimates for humans via the environment (general population, local assessment)				
Inhalation		Oral		Combined
Local Cr(VI) PEC in air [µg/m3]	Inhalation risk	Oral exposure [µg Cr(VI)/kg x d]	Oral risk	Combined risk
1.21E-09	3.50E-05	6.45E-04	5.16E-07	3.54E-05
a) RAC dose-response relationship based on excess lifetime lung cancer risk (ECHA, 2013): Exposure to 1 µg/m3 Cr(VI) relates to an excess risk of 2.9x10-2 for the general population, based on 70 years of exposure; 24h/day. b) RAC dose-response relationship based on excess cancer risk for tumours of the small intestine (ECHA, 2013): Exposure to 1 µg/kg bw/day Cr(VI) relates to an excess risk of 8x10-4 for the general population, based on 70 years of exposure; daily exposure.				

4.4.3 Populations at risk

4.4.3.1 Worker assessment

Numbers of workers exposed based on Article 66 data

The Article 66 data on numbers of staff – or workers – exposed to the chromates is summarised in Table 4-10 for those Authorisations relevant to continued use in pre-treatment. The Authorisations which will expire in 2024 and whose holders will not be seeking re-authorisation for the aerospace supply chain relevant to ADCR. As there is the potential for the applicants of this combined AoA/SEA to begin supply to downstream users who are not supporting the ADCR, the numbers of exposed staff relevant to all the original CTAC and CCST parent authorisations is presented here.

Taking a simple total of the figures for the number of staff exposed would result in an over-estimate given that some of the Authorisations cover multiple types of surface treatment.

No similar data are publicly available for the UK.

Table 4-10: Number of workers exposed - Article 66 Notifications data		
Substance	Authorisation number	Staff Exposed
Chromium trioxide	20/18/7-13	689
	20/18/14-20	1107
Sodium dichromate	20/5/3-5	77
	20/4/1	408
Source: Staff exposed as notified to ECHA by 31 December 2021, data available from https://echa.europa.eu/du-66-notifications		

Number of workers based on SEA questionnaire data

Responses to the SEA questionnaire indicated that 456 workers (full time equivalent) are directly involved in pre-treatment across the 53 sites for which data were provided. This is broken down in **Table 4-11** below by role in the supply chain, and as extrapolated out to the 80 EEA and 20 UK sites.

Table 4-11: Employees linked to chromate-based pre-treatment activities across all EEA and UK sites

Number of workers at sites	Number of sites EEA	Number of sites UK	No of employees EEA	No of employees UK	Total
Number of workers 53 sites involved in pre-treatment					
Build-to-Print	10	12	39	51	90
Build to design	4	3	51	32	83
MRO only	6	1	116	3	119
ADCR members	15	2	162	3	165
Total 53 sites	**35**	**18**	**367**	**89**	**456**
Number of workers at 100 sites involved in pre-treatment					
Build-to-Print	32	12	125	51	176
Build to design	10	3	128	32	160
MRO only	18	1	347	3	350
ADCR members	20	4	216	6	222
Total 100 sites	**80**	**20**	**814**	**92**	**906**

In total, this translates to a potential 814 exposed workers across the 80 EEA sites and 92 across the 20 UK sites. These figures are significantly lower than the number implied by the CSR assumptions on the average number of workers exposed but may be more consistent with the Article 66 notifications.

To ensure that the assessment is conservative, the average figures assumed in the CSR are extrapolated out to the total numbers of sites to act as the basis for the assessment. This gives the figures set out in Table 4-12 as the number of workers exposed under each WCS.

Table 4-12: Number of employees undertaking pre-treatment across the EEA and UK				
Worker Contributing Scenarios		Average No. Exposed from CSR	80 EEA sites	20 UK sites
WCS1	Line operators	5	400	100
WCS2	Storage area workers	4	320	80
WCS3*	Laboratory technicians	4	320	80
WCS4	Maintenance and/or cleaning workers	3	240	60
WCS6	Incidentally exposed workers	6	480	120
Total		**22**	**1760**	**440**
***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 EEA/UK;
- The population density per km^2 for each relevant EEA country and the UK;
- The relevant distance from sites for the local assessment, taken as the default assumption of a 1,000m radius (or 3.14 km^2).

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

The resulting estimates of the number of people exposed within the general population are given in Table 4-13 for the EEA and UK. The allocation of sites is based on information collected from the SEA questionnaires and from ADCR members on the location of their supply chains. The estimated total number of humans exposed via the environment in the EEA is around 37,000, with the UK figure being under 27,000 (with the UK figure appearing disproportionately high due to its high population density).

As noted above, no assessment of risks for humans via the environment at the regional level has been carried out based on RAC's previous opinion that regional exposure of the general population is not relevant.

Table 4-13: General public, local assessment exposed population from pre-treatment across the EEA and UK			
Countries with DUs	**No. Sites per country**	**Population density per km²**	**Exposed local population within 1000m radius**
France	27	118	10,009
Germany	11	232	8,017
Italy	10	200	6,283
Spain	6	92	1,734
Poland	7	123	2,705
Czech Republic	3	135	1272
Sweden	2	23	145
Finland	1	16	50
Netherlands	2	421	2,645
Belgium	1	376	1,181
Denmark	1	135	424
Hungary	1	105	330
Norway	1	14	44
Romania	1	82	258
Bulgaria	1	64	201
Ireland	1	69	217
Greece	1	82	258
Lithuania	1	43	135
Portugal	1	112	352
Slovakia	1	111	349
Total EEA	**80**	**-**	**36,609**
UK	**20**	**424**	**26,641**

4.4.4 Residual health risks

4.4.4.1 Introduction

Under the Applied-for-Use Scenario, use of Cr(VI) in pre-treatment will continue after the end of the current review period for a total of 12 years(and beyond in some cases).

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[66]. 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

[66] 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).

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.

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[67] cancer cases were derived from the Cancer Today database, see Table 4-14 below.

Table 4-14: Estimated incidence and mortality of cancers across the EU-27 and the UK, both males and females (in 2020)

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

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

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

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

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

In a similar fashion, the figures from Cancer Today reported in Table 4-14 above are applied to the estimates to calculate the total number of additional fatal and non-fatal intestinal cancer cases[68].

(2) $(0.55/0.45) \times \delta = \eta$

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

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

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

Total excess cancer risk cases are based on the excess lifetime risk estimates derived in the CSR for the different worker contributing scenarios (WCS) as presented in Table 4-8. 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 cancer cases is calculated by multiplying the number of workers assumed to be exposed in each task by the value of the excess cancer risk given above adjusted for the requested review periods, i.e., over 12 years. This value is then multiplied by the number of workers exposed in each WCS to calculate the total excess cancer

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

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

cases arising from the continued use of chromates in pre-treatment. **Table 4-15** and Table 4-16 provide a summary of the results across all WCS for EEA and UK workers.

Note that WCS3 related to laboratory technicians is not considered here as the handling of substances in laboratories for quality control purposes under controlled conditions and in amounts below one tonne per annum falls under the REACH Art. 56(3) exemption[69]. Furthermore, the sampling activities that may be carried out by lab technicians are covered under other WCS.

Table 4-15: Number of excess lifetime cancer cases to EEA workers

WCS	Number of persons exposed	LUNG CANCER - Excess lifetime cancer risk	Excess number of lifetime cancer cases	LUNG CANCER - Number of excess lifetime fatal cancer cases	LUNG CANCER - Number of excess lifetime non-fatal cancer cases
WCS1	400	2.08E-03	**0.83**	**0.66**	0.175
WCS2	320	6.96E-05	**0.02**	**0.02**	0.005
WCS4	240	3.84E-04	**0.09**	**0.07**	0.019
WCS5	480	1.00E-03	**0.48**	**0.38**	0.101
		Years - Lifetime	**40.00**	**1.13**	0.300
		Years - review period	**12.00**	**0.34**	0.090
		Years - Annual	**1.00**	**0.03**	0.007

Table 4-16: 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	100	2.08E-03	**0.21**	**0.16**	0.044
WCS2	80	6.96E-05	**0.01**	**0.00**	0.001
WCS4	60	3.84E-04	**0.02**	**0.02**	0.005
WCS5	120	1.00E-03	**0.12**	**0.09**	0.025
		Years - Lifetime	**40.00**	**0.28**	0.075
		Years - review period	**12.00**	**0.08**	0.022
		Years - Annual	**1.00**	**0.01**	0.002

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 4-13 is multiplied by the excess cancer risk estimates to calculate the total excess cancer cases arising under

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

the Continued Use scenario. The results are given in Table 4-17. The basis for estimating the number of people exposed per country is the percentages of Article 66 notifications made to ECHA per country, as described in Section 4.2.

Table 4-17: 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	27	118	10009	3.54E-05	**3.54E-01**	**0.28**	**0.07**
Germany	11	232	8017	3.54E-05	**2.84E-01**	**0.22**	**0.06**
Italy	10	200	6283	3.54E-05	**2.22E-01**	**0.18**	**0.05**
Spain	6	92	1734	3.54E-05	**6.14E-02**	**0.05**	**0.01**
Poland	7	123	2705	3.54E-05	**9.58E-02**	**0.08**	**0.02**
Czech Republic	3	135	1272	3.54E-05	**4.50E-02**	**0.04**	**0.01**
Sweden	2	23	145	3.54E-05	**5.12E-03**	**0.00**	**0.00**
Finland	1	16	50	3.54E-05	**1.78E-03**	**0.00**	**0.00**
Netherlands	2	421	2645	3.54E-05	**9.36E-02**	**0.07**	**0.02**
Belgium	1	376	1181	3.54E-05	**4.18E-02**	**0.03**	**0.01**
Denmark	1	135	424	3.54E-05	**1.50E-02**	**0.01**	**0.00**
Hungary	1	105	330	3.54E-05	**1.17E-02**	**0.01**	**0.00**
Norway	1	14	44	3.54E-05	**1.56E-03**	**0.00**	**0.00**
Romania	1	82	258	3.54E-05	**9.12E-03**	**0.01**	**0.00**
Bulgaria	1	64	201	3.54E-05	**7.12E-03**	**0.01**	**0.00**
Ireland	1	69	217	3.54E-05	**7.67E-03**	**0.01**	**0.00**
Greece	1	82	258	3.54E-05	**9.12E-03**	**0.01**	**0.00**
Lithuania	1	43	135	3.54E-05	**4.78E-03**	**0.00**	**0.00**
Portugal	1	112	352	3.54E-05	**1.25E-02**	**0.01**	**0.00**
Slovakia	1	111	349	3.54E-05	**1.23E-02**	**0.01**	**0.00**
Total	**80**		**36609**	**3.54E-05**	**1.30**	**1.02**	**0.27**
				Years – Lifetime cases	**70.00**	**1.02E+00**	**2.72E-01**
				Years - review period	**12.00**	**1.76E-01**	**4.67E-02**
				Years - Annual	**1.00**	**1.46E-02**	**3.89E-03**
UK	**20**	**424**	**26641**	**3.54E-05**	**9.43E-01**	**0.75**	**0.20**
				Years – Lifetime cases	**70.00**	**7.45E-01**	**1.98E-01**
				Years - review period	**12.00**	**1.28E-01**	**3.40E-02**
				Years - Annual	**1.00**	**1.06E-02**	**2.83E-03**

4.4.5 Economic valuation of residual health risks

4.4.5.1 Economic cost estimates

In order to monetise human health impacts, a timeframe that goes from 2024 (inclusive of the end of 2024) to the end of 2036 (i.e., a 12 year review period) has been adopted and a 4% discount rate has been employed for calculating net present values[70]. 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 the alternative proceeds. Combined with the investment in risk management measures put in place by the sites to protect workers as a result of the conditions placed on continued use by the initial authorisations, this should ensure that excess lifetime cancer risks reduce over the review period.

The economic valuation of the health impacts takes into account two important welfare components, the costs associated with mortality and morbidity. The basis of our calculations is the study led by the Charles University in Prague[71] 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[72]. 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[73]. This suggests that the aforementioned figures should be multiplied by a factor of 1.12. Thus, the following values are employed in the analysis below:

- Value of statistical life (mortality): €3.5 million × 1.12 = €3.92 million (rounded); and
- Value of cancer morbidity: €0.41 million × 1.12 = €0.46 million (rounded).

In addition to these valuations, for the purpose of quantifying human health impacts, consideration has also been given to annual medical treatment costs for morbidity. A range of studies were identified that provide estimates of the costs of medical treatment for patients surviving lung and intestinal cancer. These are summarised in **Table 4-18.**

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

[71] 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.

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

[73] https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=teina110&plugin=1

Table 4-18: Alternative estimates of medical treatment costs			
Study	**Year for prices**	**Average direct costs in original units (per annum)**	**Direct costs in € 2021**
Lung cancer[74]			
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)[75]			
Luo et al (2010)	2000 (assumed)	US$29,196	€36,230
Lang et al (2009)	2006	US$28,626	€31,740
York Health Economics Consortium (2007)	2004	£8,808	€12,180
York Health Economics Consortium (2007)	2004	£12,037	€16,410

The average cost across the lung cancer studies is €16,807 per annum (2021 prices). The average cost figures reported for intestinal cancer are based on figures produced for colon, rectal and colorectal cancer in the US and UK. The US figures are high compared to the UK data; as a result, the average across the two UK studies is taken here, with this being around €14,295 per case in 2021 prices, taking into account price inflation.

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

74 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.

75 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.

76 These values are based on a study conducted by Cancer Research UK on adults aged 15-99 in England and Wales. https://www.cancerresearchuk.org/health-professional/cancer-statistics/statistics-by-cancer-type/lung-cancer/survival.

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

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

(4) (δ × (€ 3,920,000)) + (η × (€ 460,000 + €84,790)) = Total intestinal cancer costs

4.4.5.2 Predicted value of excess cancer cases with continued use: workers

Table 4-19 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 €493,000 for the EEA and €123,000 for the UK, based on the assumption that chromate-based pre-treatment 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 4-19: Present value and annualised economic value of mortality and morbidity effects to workers (discounted over 12 years @4% per year, 20 year lag, figures rounded)

	EEA Workers		UK Workers	
	Mortality	Morbidity	Mortality	Morbidity
Total number of lung cancer cases	3.38E-01	8.99E-02	8.45E-02	2.25E-02
Annual number of lung cancer cases	2.82E-02	7.49E-03	7.04E-03	1.87E-03
Present Value (PV, 2024)	€ 478,362	€ 14,922	€ 119,591	€ 3,730
Total PV costs	**€ 493,284**		**€ 123,321**	
Total annualised cost	**€ 113,879**		**€ 28,470**	
Source: *Derived estimates from responses to the SEA questionnaire, Article 66 data, Eurostat data and CSR*				

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

Table 4-20 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 €257,000 for the EEA and €187,000 for the UK, based on the assumption that pre-treatment 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 4-20: Present value and annualised economic value of mortality and morbidity effects to the general population, local assessment (discounted over 12 years @4% per year, 20 year lag, figures rounded)				
	EEA General Population		UK General Population	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cancer cases	0.18	0.03	0.13	0.03
Annual number of cancer cases	0.01	0.00	0.01	0.00
Present Value (PV, 2024)	€ 248,347	€ 8,461	€ 180,724	€ 6,157
Total PV costs	**€ 256,808**		**€ 186,881**	
Total annualised cost	**€ 59,286**		**€ 43,143**	
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

Pre-treatment with chromates results in no hexavalent chromium being present on the end components or products. As a result, workers in downstream life cycle stages are not exposed to Cr(VI) through pre-treatment.

4.4.7 Summary of human health impacts

Table 4-21 provides a summary of the economic value of the human health impacts across the worker and local populations. When considering these figures, it should be remembered that they relate to continued use of the chromates in pre-treatment across the sector at an estimated 80 EEA sites and 20 UK sites covered by this combined AoA/SEA.

Table 4-21: Combined assessment of health impacts to workers and general population value of mortality and morbidity effects to workers (discounted over 12 years @4% per year,20 year lag, figures rounded)				
	EEA		UK	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cancer cases	0.51	0.12	0.21	0.06
Annual number of cancer cases	0.04	0.01	0.02	0.00
Present Value (PV, 2024)	€ 726,709	€ 23,383	€ 300,315	€ 9,887
Total PV costs	**€ 750,092**		**€ 310,202**	
Total annualised cost	**€ 173,166**		**€ 71,613**	
Source*: Derived estimates from responses to the SEA questionnaire, Article 66 data, Eurostat data and CSR*				

5 Socio-Economic Analysis of Non-Use

5.1 The Non-Use Scenario

5.1.1 Summary of consequences of non-use

The inability of companies to undertake pre-treatment across the EEA and in the UK using one or more of the chromates would be severe. This use is critical to a range of key functions associated with pre-treatment processes and the multiple main treatments that rely on them used across a broad range of components and assemblies. This includes application to newly produced components and for ensuring on-going corrosion protection, and other beneficial properties, following maintenance and repair activities.

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

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

↓

Due to certification and airworthiness requirements, downstream users would be forced to undertake chromate-based pre-treatment activities – as well as main treatments dependent upon these- outside the EEA/UK or shift to suppliers outside of the EEA/UK

↓

OEMs would shift manufacturing outside the EEA/UK due to the need for pre-treatment to be carried out in sequence with other treatments. It would be inefficient and costly to transport components and products outside the EEA/UK for pre-treatment only (and especially so for repairs)

↓

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

↓

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

↓

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

↓

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

↓

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

↓

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

As indicated in the above diagram, because pre-treatment must be followed promptly and in sequence and are intrinsic to deliver of key functions and performance requirements provided by the treatment system, there would be significant subsequent effects for other parts of the aerospace and defence supply chains. The most likely outcome would be the relocation of large portion of the value chain (production, repair and maintenance) outside of the EEA/UK, as summarised below.

5.1.2 Identification of plausible non-use scenarios

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

These discussions acted as the basis for a series of questions in the SEA questionnaire aimed at pulling out information on the role of different types of companies, how these impacts on why they use chromates in pre-treatment, past investments and R&D, and the most likely impacts of a refused re-authorisation. Information on the first three of these was summarised in Section 4 as part of the description of the continued use scenario.

Moving to a poorer performing alternative was ruled out based on the unacceptability of such an option to the OEMs due to safety and airworthiness requirements, as detailed further below. Follow-up questions were asked to establish why producing components overseas and shipping them back to the EEA/UK was not feasible, with this then ruled out based on the answers received regarding the logistic difficulties and economic infeasibility. These were considered to be non-plausible scenarios and are discussed in Section 5.1.3 below.

Table 5-1 below presents the choices presented in the SEA questionnaire and a count of the number of companies selecting each (37 companies in total provided responses, covering the 53 sites).

Respondents were asked to provide further comments to support their responses, and to explain any other possible responses not included in the above list. These comments are presented below and demonstrate the differences that exist within the aerospace supply chain and hence how the most plausible scenarios will vary by role.

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

Table 5-1: Company responses to SEA survey on most likely non-use scenarios				
	OEM	Build-to-Print only	Design-to-Build only	MROs – only
The decision is up to our customer	1	5	1	
We may have to cease all operations as the company will no longer be viable	2	6		4
We will focus on other aerospace uses or on non-A&D uses		1		
We will shift our work outside the EEA/UK	2	1	2	1
We will stop undertaking use of the chromate(s) until we have certified alternative	1	4	4	
It is unclear at this time	1	1		

5.1.2.1 OEMs

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

With respect to the plausibility of the different non-use scenarios identified above, the following are clear from consultation with the OEMs across the 17 sites for which data was provided in the SEA questionnaire responses:

- **We will shift our work involving chromates to another country outside the EEA.** This is the most plausible scenario for two of the OEMs directly involved in pre-treatment. Given the reliance on the use of chromate-based pre-treatment in supply chains, it is also the most likely response for those OEMs companies who rely on suppliers carrying out pre-treatment processes. This would be accompanied by losses in turnover of around 60% at the sites operated by these OEMs. The ability of one of these OEMs to shift its manufacturing relevant to pre-treatment outside the EEA/UK may be restricted, however, as it manufactures final products for the defence sector.

- **We will stop using the chromates until we have certified alternatives:** Some of the OEMs will be able to move to substitutes within a seven-year period, assuming that their current progression of alternatives does not face any setbacks in the final qualification, validation and certification stages. For others, substitution and especially the industrialisation phase of moving to alternatives will not be completed within a seven year timeframe across all components. The current "road map" for substitution and industrialisation cannot be sped up, and some margin is needed to allow for any delays or likely failures. Thus, under the non-use scenario, the potential for seven year production stoppages would not be economically feasible for the relevant sites, with turnover losses of between 30 - 100% identified.

- **We may have to cease all operations as the company will no longer be viable.** If shifting work to countries outside the EEA is unacceptable due to the costs or timeframe involved in setting up the required manufacturing sites and supporting infrastructure, then a cessation of all operations may be the ultimate outcome for at least one of the OEMs with multiple sites in both the EEA and UK.

As a result, the OEMs indicated that if the viable alternatives are not qualified and implemented (or able to be implemented by the end of the current review period (i.e. September 2024) for chromium trioxide and sodium dichromate, then their **most plausible response under the non-use scenario would be to relocate all or some of their manufacturing activities outside of the EEA or UK** (it may also not be realistic given the efforts and expenditure involved in such relocation, which may be more likely to result in the complete closure of OEMs or divisions within them, with consequent impacts for the EEA/UK economies).

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

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

Particular difficulties would be faced by companies in the defence sector. Possibilities for relocating some activities outside the EEA/UK are limited due to the difficulties related to achieving specific customer requirements, national security considerations, work share agreements, and financial restrictions. As a result, it is likely that there would need to be requests for "defence exemptions" so that those activities that contractually must be maintained in their current location could continue within the EEA/UK.

5.1.2.2 Design-to-Build

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

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

5.1.2.3 Build-to-Print

BtP companies rely on their customers to define the production methods that they must use. As a result, the potential responses of Build-to-Print companies to the non-use scenario are uncertain. Five companies confirmed that the choice of whether to use chromates in pre-treatment in not theirs but their customers. Some noted the that they could not shift to alternatives for pre-treatment processes until these were qualified and certified for use in the production of components by their customers and the authorities, and that the alternatives were suitable and sustainable for their customers' uses.

It is also a concern that customers may each qualify and certify a different alternative, raising economic feasibility concerns in terms of capital investments, site infrastructure, etc. Others commented that if they could not undertake chromate-based pre-treatment in the EEA/UK, then they would have to either cease operations, sub-contract out some the whole process or transfer multiple processes outside the EEA (more feasible for the larger companies). The subsequent effects would include redundancies and losses in turnover for EU operations, as well as the potential loss of NADCAP support.

It is of note that a supplier may be requested to sign a manual or code of conduct by the OEM, to ensure expectations for work 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 sites, the construction of sites, or switching to a different site (including a different supplier's site).

5.1.2.4 MROs

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

When components enter under the services of an MRO, the required maintenance effort, including which surface treatment processes may be required, is not directly foreseeable. Very often, the level of work required only becomes clear after disassembling the component. The surface treatment steps required for any given component is dependent on its condition and can differ for each maintenance event. As a result, not every component will pass through all potential surface treatment processes. Even where they do, levels of throughput are also dependent on the size and complexity of the component - processing times can range from five minutes to several days. Within these process flows, even if pre-treatment using the chromates is only required to a very limited extent, it may remain essential as part of maintenance and repairs carried out to ensure that airworthiness regulations are met.

The inability to undertake pre-treatment to the requirements set out in Maintenance Manuals may make repair and overhaul services unviable for MROs. There is no scope for them to operate outside the requirements detailed in the OEMs' service manuals, which are based on the qualified and approved uses of substances for pre-treatment. Where these requirements mandate the use of chromium trioxide or sodium dichromate, then the MRO must use the chromate as instructed unless the manuals also list a qualified alternative.

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

The MRO that indicated they would cease using the Cr(VI) in pre-treatment at their sites until certified alternatives were available also noted that this may have significant impacts on their customers, as well on their own operations and turnover.

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

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

5.1.3 Non-plausible scenarios ruled out of consideration

Move to a poorer performing alternative

Moving to a poorer performing alternative would not be acceptable to the OEMs, either from a Design Organisation Approval (DOA) perspective as approved by EASA[77], MoDs and the European Space Agency (ESA), or from an engineering perspective taking airworthiness safety requirements into consideration.

As noted in the parent Applications for Authorisation, the scenario of moving to a poorer performing alternative would mean that OEMs would have to accept an alternative that is less efficacious in delivering key functions and performance requirements, including corrosion protection, where no alternative provides an equivalent level of performance to the chromates. The use of a less effective alternative would downgrade the performance of the final product, and the reduction in the functional performance of the alternative would give rise to several unacceptable risks/impacts:

- The highly likely risk of EASA (airworthiness authorities) and MoDs not accepting a downgrade in performance;
- Increased maintenance operations, leading to an increase in the downtime of aircraft and military equipment, increased costs of maintenance, less flying hours, etc.; and
- Increased risks to passengers, cargo operators and operators of military equipment.

[77] 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.

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

Additionally, as discussed in Section 3, corrosion resistance (or any of the other key functionalities), cannot be considered in isolation. For example, achieving corrosion resistance should not impact adhesion promotion, or at least be comparable to the benchmark Cr(VI) solution. A poorer performing alternative may provide one of the key functionalities, but not provide another key functionality or attribute which as a consequence leads to increased maintenance.

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

- Substantial increase in inspections – both visual checks and non-destructive evaluations, such as ultra-sound crack tests, etc. Some inspections are very difficult or hazardous to perform (e.g., inside fuselage/wing structures). All aircraft using 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; and

- Defence systems would have similar impacts adversely affecting the continuity of national security.

Aerospace components are portions of major systems (fuselage; wings; engines etc.) and the components in these systems are designed to withstand similar criteria between overhauls. For example, a system is designed to achieve 25,000 cycles between overhauls and a new component is only rated for 5,000 cycles because of a Cr(VI)-free coating. By default, the entire system would now be de-rated to 5,000 cycles. Take a compressor blade that is located in the middle of an engine. If that blade can only survive for a portion of the life of an engine due to limitations of a new coating, the engine would require disassembly to access the blades. This means taking the engine off the wing, sending it to a repair centre, disassembling the engine and replacing the components at much shorter intervals than needed for the remainder of the engine. This adds inherent inspection, maintenance, and repair costs to the manufacturers, operators, and end use customers who will also be impacted by increased out of service times.

The lack of experience with Cr(VI)-free solutions can have a critical safety impact. The aerospace industry has a permanent learning loop of significant events and failure analysis and decisions for safety improvements. Part of this improvement is the introduction of the Maintenance Steering Group 3 Analyses (MSG-3), specifically developed for corrosion. MSG-3 provides a system for OEMs and the regulators to identify the frequency of inspection with respect to the stress corrosion, protection and environmental ratings for any component or system.

Without adequate experience and proven success, and therefore possible unknown or hidden properties, the performance of a 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 an alternative. This objective cannot be achieved, however, without sufficient testing and flight (or other) data surrounding the use of alternatives. Without such data, the necessary approvals cannot be gained as the safety risk becomes too great, whether related to civil aviation or military aircraft. The benefits provided by pre-treatment are crucial to the manufacture of the relevant aircraft components in the EEA/UK; if there are no qualified alternatives certified for the use on components then such manufacturing work would cease.

Overseas production followed by maintaining EEA/UK inventories.

To be competitive, companies must keep inventory as low as possible ("just-in-time" delivery). Maintaining inventory clearly involves substantial capital costs (as elaborated below) and ties up cash. Stockpiling is also clearly not feasible for the repair and maintenance side of the business because the main aim of repair is to make components serviceable rather than replace them by spare components (which would run counter to the sectors drive towards increased sustainability).

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

- If no certified alternative is available or is likely to become available within months after the end of the review period, then there is no clarity on how long such inventories of components must be available. For legacy aircraft, inventories will certainly be required for the next 20 years or more. Additionally, there is no visibility or clarity on customer demand in the short or longer term. Planned maintenance can be considered, but it is not possible to anticipate which components will be needed for unplanned maintenance and repair. Consequently, an assumption regarding the inventory that needs to be available for a sufficient duration would have to be made, leading to the risk of wasted resources or aircraft/equipment becoming obsolescent due to inadequate inventories;

- Stockpiling results in increased costs and would reduce the opportunity to invest in other projects/R&D, etc. The inventory costs would also have to be added to product costs and would therefore reduce competitiveness for operations in the EEA/UK;

- The costs of building adequate warehouse facilities in the EEA and the UK would be prohibitive and would not be economically feasible. In the UK, an industrial warehouse without climate control (which would be required for the storage of some A&D inventory) costs around €1000 per m^2 to construct (a conservative estimate). It's assumed here that warehouses that would act as a hub for storing inventory would be around 10,000 m^2 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.[78] If such facilities are required at around 100 sites across the EEA and UK (to cover civilian and military requirements for storage of passivated and other components affected by a refused authorisation), then warehousing costs alone would lead to €1 billion in expenditure. These costs would be on top of the losses in profits that would occur from the need to subcontract manufacture to companies located outside the EEA/UK and the consequent profit losses and increased costs of shipping, etc;

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

- Existing facilities are not sized to store the amount of multi-year inventories required. Companies will need to build/invest in additional secure, high-quality warehouses to store the inventory. However, it is important to recognise that this scenario is not feasible at all for many components, such as airframes, because these parts 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 aircraft is not airworthy, the effort and cost relating to transportation alone (e.g., from Belgium to Egypt) would be overwhelming;

- Being dependent upon inventories and non-European suppliers (and in turn vulnerable to local economic and political issues affecting non-EEA countries or the UK), and thus unable to reliably fulfil MRO activities, will lead to inevitable delays and potential cancellation of flights, fines due to longer turn-around times and aircraft on ground scenarios;

- Companies make design modifications for single components as part of their normal course of business (for reasons other than chromate substitution). In these cases, all existing inventory would need to be written off for a loss. Furthermore, companies would not be able to produce the modified components in the EEA/UK anymore (if pre-treatment 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; and

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

- 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.

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.

Given the above, this scenario was not considered plausible by the OEMs and MROs due to the need for components to have surface treatments applied quickly after pre-treatment. It was confirmed though that such an approach may be feasible for a small range of components for civilian aircraft and for a limited number of parts for military aircraft and equipment. However, as an overall strategy, it would not be feasible.

5.1.4 Conclusion on the most likely non-use scenario

The most likely non-use scenario is driven by the responses of the OEMs to the non-use scenario. They are the customers that carry out the R&D and testing (sometimes in collaboration with their chemical suppliers) to determine whether an alternative is technically feasible, qualify and gain approvals for components using that alternative and then certify their suppliers against its use. In some cases, they also help their suppliers meet the financial costs of adapting existing treatment plant to enable them to move to the alternative.

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

1. EEA and UK suppliers of the chromates would be impacted by the loss of sales, with the market relocating outside the EEA/UK. In the short term at least, i.e., two to four years, this would result in a loss of revenues and profits from sales in the EEA/UK. Over the longer term, some of the market may return to the EEA/UK but it is also likely that a significant proportion will have relocated more permanently;

2. OEMs that carry out pre-treatment as part of their own manufacturing would move a significant proportion of their manufacturing operations outside the EEA/UK, with the consequent loss of significant levels of turnover and employment. They will move those manufacturing activities reliant on the use of pre-treatment where there is no qualified alternative or where implementation across suppliers after qualification and certification have been achieved is expected to require several years after the end of the current review period. The losses to the EEA/UK would range from around 30% - 50% of manufacturing turnover for some sites, rising to 65% - 100% of manufacturing turnover at others. On average it is assumed losses at affected sites would be around 60% of manufacturing turnover, with associated losses in jobs;

3. OEMs who do not carry out pre-treatment themselves may still move some of their manufacturing operations outside the EEA/UK due to the desire to have certain treatment and production activities co-located within a region (i.e., to form clusters). This would facilitate the integration of manufacturing activities and associated maintenance and repair activities. As a result, there would be losses in turnover and employment associated with these companies also relocating. An alternative option would be increasing the capacities of existing non-EEA/UK suppliers that are already qualified by OEMs;

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 – see below) suppliers who have moved operations from the EEA/UK to other countries in order to continue supplying the OEMs. Those DtBs that undertake surface treatments for sectors other than A&D and using non-chromate-based alternatives where these are certified, are less likely to cease activities in the EEA/UK and hence as a group would be associated with a reduced level of profit losses. Overall, for the DtB companies, it has been assumed that turnover losses of around 65% would be realised based on the SEA data and discussions with key design owners. It must be recognised that this level of turnover loss implies that some companies losing a high percentage of turnover would still be able to cover their fixed costs and to remain financially viable;

6. A significant proportion of the existing BtP companies involved in pre-treatment do not supply other sectors and are reliant on the A&D sector; furthermore, the types of products that they manufacture are specific to the aerospace sector. This applies to those who indicated they "don't know" what the most plausible scenario would be for them and those that would cease trading or move outside the EEA/UK. There will also be significant loss of turnover for those that indicated they would cease pre-treatment until a certified alternative was available or that they would shift to other activities. Given the spread of losses reported in responses to the SEA questionnaire and interdependency of these companies with decisions made by the OEMs, it has been assumed that turnover losses across the BtP suppliers of around 70% would occur;

7. MRO sites that carry out pre-treatment as part of their services will also be severely hit and the larger operators indicated that they will either cease trading or move operations outside the EEA, due to the need to maintain vertical integration across the surface treatment processes that they are able to carry out. On this basis, it is estimated that around 55% of turnover at affected sites would occur;

8. The re-location of MRO activities will have consequent impacts for civil aviation and military forces, as well as for the maintenance of defence products, space equipment and aero-derivative products;

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 due to the inability to carry out repairs and/or maintenance activities according to manufacturers' requirements; and

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.

The justification for this NUS takes into account that OEMs and DtBs will not have all components with certified alternatives which have been fully implemented across their supply chains by September 2024. Many will require a further 12 years to have fully implemented alternatives across all components/final products and EEA/UK supply chains. The regulatory requirements placed on the sector mean that unless components have certified alternatives there is no substitute which can be considered "generally available"[79].

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 pre-treatment, but the associated main treatments and post-treatment activities due to the potential for corrosion of unprotected surfaces during transport to another place.

The impacted operations and socio-economic impacts to industry under the non-use scenario will therefore go far beyond production of just the specific components that require pre-treatment. In the first box, a component reliant on pre-treatment 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.

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

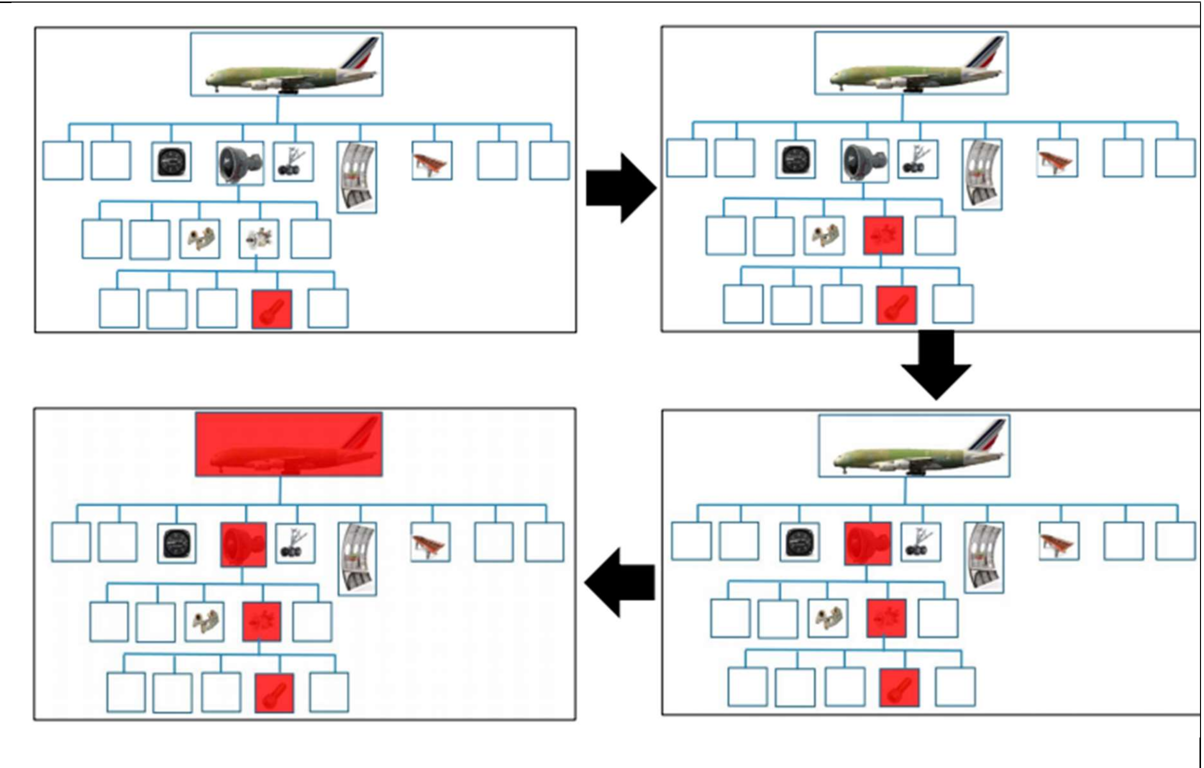

Figure 5–1: Interdependency of component availability in the manufacture of a final product
***Source*: (GCCA, 2017)**

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 **Figure 5-3**), with smaller suppliers located around the sites operated by the larger OEMs. Not all of these smaller sites, including those of critical suppliers, would be able to shift their activities outside the EEA/UK, leading to OEMs having to create entirely new supply chains outside the EEA/UK. This scenario also implies a huge economic investment would be carried out by the OEMs as well as their EEA/UK suppliers. This level of investment is unlikely to be feasible and, in the meantime, the OEMs would have to cease manufacturing activities in the EEA/UK until the new industrial facilities were in place and ready to operate outside the EEA/UK.

5.2 Economic impacts associated with non-use.

5.2.1 Economic impacts on applicants

Under the non-use scenario, all applicants, and the formulator would be impacted by the loss of sales of the two chromates for use in pre-treatment. At the specific supplier level, these impacts may vary in their significance, as the importance of the different chromates used in pre-treatment to their revenues varies across the suppliers (as does the level of supply of chromates for use in other treatment processes).

In the short term (i.e., first two years under the non-use scenario), the losses will be in the order of (Euro /Pound sterling) tens of millions per annum to the applicants and their downstream formulators. Over time, as consumption of the chromates reduces in line with companies' substitution plans, sales and hence revenues will continue to decrease.

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 pre-treatment activities outside the EEA/UK due to already existing supply chain sites in other countries, for example, the USA, Canada, China, Mexico, Morocco, etc., and to outsource manufacturing as the supply chain is spread around the world. There are several obstacles to such a scenario, however, which would make this economically unattractive even if it is the most plausible scenario. Firstly, the due diligence principle will continue to the apply to supply chain and would be exacerbated in case of relocation out of EEA/UK. Secondly, when activities are shifted to another site, there is an inevitable phase of technical and industrial preparation (site design, capital procurement and installation, worker training, pilot trials) and qualification to ensure the sustainability of these activities, including an assessment of the technical capability to deliver stringent airworthiness and certification requirements. Moreover, once the qualification phase is over, it is essential to get the right ramp up in order to meet the manufacturing rate objectives.

In the remaining time before the end of the initial review period, even if alternatives were qualified and certified across the manufacture of components and products, these two aspects are not realistic; it would require a huge economic investment that would significantly affect businesses with detrimental economic impacts. As a result, OEMs have indicated that they probably would be forced to stop manufacturing activities until the new industrial facilities and infrastructure is in place and ready to operate outside of the EEA/UK, with consequent impacts on the entire value chain. Given the current levels of civil aviation and anticipated growth, this would be catastrophic for aviation in the EEA/UK and globally.

5.2.2.2 Approach to assessing economic impacts

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

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

1. **Estimates based on loss of jobs**: The first approach takes as its starting point the number of jobs that would be lost at the sites of SEA questionnaire respondents, based on their most likely response to the Non-Use Scenario. This includes loss of jobs directly linked to use of the

chromates and losses in jobs at the site reliant upon the continuation of their use, i.e., jobs in related manufacturing and assembly activities. Importantly, it excludes losses in employment at local sub-contractors providing support services. The numbers of jobs lost are multiplied by the average Gross Value Added - GVA - per job (taking into the 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; and

2. **Estimates based on loss of turnover**: The second approach takes as its starting point the anticipated losses in terms of percentage of turnover reported by the respondents to the SEA questionnaire. Lost operating surplus is then calculated as an average per company based on role in the supply chain and Eurostat data on GOS as a percentage of turnover.

Both approaches provide proxy estimates of profit losses based on current levels of employment and turnover. They do not account for foregone future turnover under the continued use scenario due to the inability of the EEA/UK aerospace sector to respond to growth in the global demand for air traffic or to increased military and defence spending as a result of either a cessation in manufacturing activities or their relocating outside the EEA/UK.

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

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

The SEA questionnaire collected data on the number of employees who would lose their jobs under the NUS. This includes both those whose job directly involves use of the chromates and those whose jobs would be affected due to a cessation of production activities or due to companies moving outside the EU. The resulting figures are presented in Table 5-2 below.

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

- Extrapolated out to the total 100 expected to be carrying out pre-treatment: 36,000 jobs (around 30,000 in the EEA and 6,000 in the UK) due to the cessation of pre-treatments and linked manufacturing activities across product lines or to the cessation of MRO services, including as a result of companies moving operations outside the EU.

Table 5-2: SEA survey responses and extrapolations on numbers of jobs lost under the Non-Use Scenario						
	No. Company Responses		Direct job losses – workers undertaking pre-treatment and linked processes		Additional direct job losses – due to a cessation of manufacturing/MRO activities	
From SEA Survey	EEA	UK	EEA	UK	EEA	UK
Build-to-Print	10	12	248	227	539	92
Design-to-Build	4	3	354	810	342	3,000
MROs	6	1	1,191	398	4,611	758
OEMs	15	2	1,522	250	2,909	150
Total 53 sites	35	18	**3,315**	**1,685**	**8,401**	**4,000**
Job losses - Extrapolation of job losses under the Non-Use Scenario to the estimated 100 sites undertaking pre-treatment treatments						
Build-to-Print	32	12	794	227	1,725	92
Design-to-Build	10	3	885	810	855	3,000
MROs	18	1	3,573	398	13,833	758
OEMs	20	4	4,420	500	3,879	300
Total sites 100	80	20	**9,672**	**1,935**	**20,291**	**4,150**
Total EEA direct and indirect across 80 sites			**29,963**			
Total UK direct and indirect across 20 sites			**6,085**			

It is important to note, that these losses do not equate to 100% of the jobs at these sites, as there would not be a full cessation of activities at all sites. This can be clearly seen by the UK figures which assume no additional direct job losses. Although these figures may appear high, they should be seen within the context of the roughly 890,000 employees (2019[80]) within the European aerospace sector, considering the critical importance of the chromates in pre-treatment.

These predicted job losses have been combined with Eurostat data on Gross Value Added (GVA) per employee to the EEA/UK economy as part of calculating the economic losses under the Non-Use scenario. A weighted GVA has been used for BtP and DtB suppliers and NACE code specific GVAs have been used for OEMs and MROs. The resulting estimated losses are given in **Table 5-3**.

The estimated losses in GVA across the 100 sites equate to:

- €2,600 million per annum for the 80 EEA sites due to the cessation of pre-treatment, related treatments and associated manufacturing and assembly activities; and
- €420 million per annum for the 20 UK sites due to the cessation of pre-treatment, related treatments and associated manufacturing and assembly activities.

For comparison, turnover for the EU A&D industry is around €259 billion[81] per annum, while that for the UK A&D sector is around €57 billion (£50 billion) in 2020[82]. Thus, although these figures may appear high, they are considered to be underestimates by the ADCR members (particularly the OEMs) given the potential for much larger segments of the sector to move outside the EEA /UK should chromate-based pre-treatment no longer be permitted.

In order to convert these GVA losses to an estimate of lost operating surplus (profits), personnel costs for each lost job are subtracted. The results of this calculation are given in Table 5-4**.** Personnel costs are based on Eurostat data for the relevant NACE codes, with an average weighted personnel cost adopted for BtP and DtB; the average personnel costs by NACE code from Eurostat for OEMs and MROs are adopted in these cases.

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

- Loss of jobs at the 80 EEA sites: €2,500 million per annum; and
- Loss of jobs at the 20 UK sites: €410 million per annum.

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

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

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

Table 5-3: GVA losses per annum under the Non-use scenario (2022 job figures, GVA data for 2018)						
	GVA per worker assumed by role		GVA lost per annum due to loss of pre-treatment and linked jobs € million		GVA lost per annum due to a cessation of manufacturing/MRO activities - € million	
	EEA	UK	EEA	UK	EEA	UK
Build-to-Print	59,660*	59,660*	14.80	13.54	32.16	5.49
Design-to-Build	59,660*	59,660*	21.12	48.32	20.40	178.98
MROs	85,000	85,000	101.24	33.83	391.94	64.43
OEMs	98,500	98,500	149.92	24.63	286.54	14.78
Total 53 sites			**287.07**	**120.32**	**731.03**	**263.67**
GVA losses - Extrapolation to the estimated 80 EEA and 20 UK sites undertaking pre-treatment treatments						
Build-to-Print	59,660*	59,660*	47.35	13.54	102.90	5.49
Design-to-Build	59,660*	59,660*	52.80	48.32	51.01	178.98
MROs	85,000	85,000	303.71	33.83	1,175.81	64.43
OEMs	98,500	98,500	435.37	49.25	382.05	29.55
Total sites 100			**839.22**	**144.95**	**1,711.76**	**278.45**
Total EEA across 80 sites			**€ 2,551 million per annum**			
Total UK across 20 sites			**€ 424 million per annum**			
*Weighted average GVA calculated for Build-to-Print and Design-to-Build companies as the GVA multiplied by the NACE code counts across responding companies, divided by the total number of relevant companies. MRO and OEM GVA figures direct from Eurostat (2018) for EU/UK as available.						

Table 5-4: Operating surplus losses due to a cessation of manufacturing/MRO activities under the Non-Use Scenario						
	Total GVA losses due to lost jobs - Direct all € millions		Total personnel costs all lost jobs due to a cessation of manufacturing/MRO activities - € millions per annum		Implied operating surplus losses due to a cessation of manufacturing/MRO activities - € millions per annum	
	EEA	UK	EEA	UK	EEA	UK
Build-to-Print	46.95	19.03	1.84	0.74	45.12	18.29
Design-to-Build	41.52	227.30	1.62	8.89	39.90	218.42
MROs	493.17	98.26	19.28	3.84	473.89	94.42
OEMs	436.45	39.40	17.06	1.54	419.39	37.86
Total 53 sites	**1,018.10**	**383.99**	**39.80**	**15.01**	**978.30**	**368.98**
Operating surplus losses - Extrapolation to the estimated 80 EU and 20 UK sites undertaking pre-treatment treatments						
Build-to-Print	150.25	19.03	5.87	0.74	144.37	18.29
Design-to-Build	103.81	227.30	4.06	8.89	99.75	218.42
MROs	1,479.51	98.26	57.84	3.84	1,421.67	94.42
OEMs	817.42	78.80	31.96	3.08	785.46	75.72
Total sites 100	**2,550.98**	**423.39**	**99.73**	**16.55**	**2,451.25**	**406.84**
***Weighted average GVA calculated for Build-to-Print and Design-to-Build companies as the GVA multiplied by the NACE code counts across responding companies, divided by the total number of relevant companies. MRO and OEM GVA figures direct from Eurostat (2018) for EU/UK as available.**						

5.2.2.4 Estimates based on lost turnover

The SEA questionnaire also asked companies to provide information on the impacts that a refused authorisation would have on turnover/revenues. Fewer companies responded to this question, although the responses provided by the OEMs (as the end customer) and MROs enable estimates of the likely percentages of turnover lost by role to be developed. These estimates take into account the number of companies indicating that they also carry out activities other than chromate-based pre-treatment for the A&D sector, as well as surface treatment and other processes for other sectors. They also account for potential loss in turnover from subsequent manufacturing and assembly activities.

Estimates of lost revenues per site are based on Eurostat data by NACE code with weighted averages used for BtP and DtB companies, and NACE code specific data for OEMs and MROs. Note that the weighted averages exclude micro-enterprises as few suppliers within the sector will fall into this size category. Gross operating surplus losses are then calculated by applying GOS rate data for the different NACE codes from Eurostat for 2019. The resulting losses are given in Table 5-5.

Table 5-5: Turnover and GOS losses under the Non-Use Scenario – (avg. 10.6% losses across all roles)

	Turnover lost per annum € millions		GOS losses per annum € millions per annum	
	EEA	**UK**	**EEA**	**UK**
Build-to-Print	413	496	53	63
Design-to-Build	154	116	20	15
MROs	239	40	20	3
OEMs	10,531	1,404	1,106	147
Total 53 sites	**11,337**	**2,055**	**1,198**	**229**
Extrapolation of turnover and GOS losses to the estimated 100 sites undertaking pre-treatment treatments				
Build-to-Print	1,322	496	168	63
Design-to-Build	385	116	49	15
MROs	716	40	60	3
OEMs	14,041	2,808	1,474	295
Total sites 100	**16,465**	**3,459**	**1,752**	**376**
*Weighted average turnover and GOS calculated for Build-to-Print and Design-to-Build companies as the GOS multiplied by the NACE code counts across responding companies, divided by the total number of relevant companies. MRO and OEM figures direct from Eurostat (2018) for EU/UK as available.				

5.2.2.5 Comparison of the profit loss estimates

The figures presented in Table 5-5 are lower than **Table 5-4** for both the EEA and UK, with the greatest differences being in the estimates for OEMs and MROs. This is considered to be due to the turnover-based estimates taking better account of the loss in associated manufacturing, maintenance or repair activities, given the importance of chromate-based pre-treatment to both of these sets of companies.

- GVA based approach estimates of lost operating surplus:
  - Losses of €2,500 million per annum for the EEA
  - Losses of €400 million per annum for the UK
- Turnover based approach of lost operating surplus:

- Losses of €1,800 million per annum for the EEA
- Losses of €400 million per annum for the UK

These two sets of figures are used in this SEA to provide lower and upper bound estimates of losses in producer surplus, with the ratios between the two sets of estimates for the different roles shown in Table 5-6. It is important to note that these losses apply to commercial enterprises only. No data was provided by any of the military organisations reliant upon the continued use of chromate-based pre-treatment which could be used in this analysis. These organisations simply stated that they would have to cease undertaking MRO related activities in their home country, resulting in severe impacts on their military forces.

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

	Total job losses at sites undertaking pre-treatment		% Turnover lost		Ratio of lost profits based on turnover approach to lost operating surplus based on jobs (Based on €billions lost)	
	EEA	UK	EEA	UK	EEA	UK
Build-to-Print	2,518	319	69%	69%	1.17	3.45
Design-to-Build	1,740	3,810	64%	64%	0.49	0.07
MROs	17,406	1,156	56%	56%	0.04	0.04
OEMs	8,299	800	58%	85%	1.88	3.89
Total sites 100	29,963	6,085	€16.5 billion	€3.5 billion	0.71	0.92

5.2.2.6 Offsetting profit losses and impacts on rival firms

The losses in operating surplus given above would result not only from a cessation of manufacturing activities, but also from the premature retirement of existing capital equipment. Some of this capital equipment would be replaced in any event as part of substitution, over the next four to 12 years, with any such investment in new equipment would be focused on facilitating substitution (while the capital equipment associated with the continued use of the chromates over the next seven to 12 years would not be expected to be replaced).

As there are no suitable alternatives which are generally available, following SEAC's latest guidance, consideration has been given to the need to offset the profit losses for downstream users against the potential resale or scrappage value of the sector's tangible EEA and UK assets. However, given the potential scale of the impacts of a refused authorisation for the sector as a whole, any possible market for redundant equipment is likely to be overwhelmed by the number of sites ceasing activities, including related processes. As a result, it is not possible to estimate the potential scrappage value of equipment (e.g., immersion baths), especially as its current use for chromate-based treatments may further reduce its value.

Because this is a sectoral application and the ability to shift to alternatives is driven by qualification and validation by OEMs and obtaining certification approval by airworthiness authorities, the issue of potential impacts on by rival firms undertaking pre-treatment using alternatives is not relevant. The

OEMs determine whether there are alternatives that can be used, not individual downstream users. Furthermore, as previously indicated, the ADCR is a sectoral consortium and downstream user members include competitors, which may also act as suppliers to each other, while the larger companies share many of the same BtP and DtB suppliers (an estimated 15-25% overlap in suppliers exists across some OEMs). Relationships between the OEMs and BtP and DtB are developed over time and often reflect long-term commitments given the need for OEMs and DtB companies to certify their suppliers in the manufacturing of components. As a result, rival suppliers cannot readily step in and replace their production activity.

The economic losses are therefore based on consideration of losses in operating surplus/profits only. These have been estimated over three time periods in line with SEAC's new guidance for those cases where there are not suitable alternatives available in general. Discounted losses over one, two, four, seven and 12 years are given in Table 5-7.

As discussed earlier, these losses are based on Eurostat turnover figures for 2018 (most recently available by company size). They therefore represent an underestimate of the losses in turnover that would arise over the review period under the Non-Use scenario, given the anticipated level of future growth in turnover for the sector due to the importance of the EEA and UK in the global manufacture of aerospace and defence products (as highlighted by the publicly available forecasts of the demand for new aircraft cited earlier).

Table 5-7: Discounted profit /operating surplus losses under the Non-Use Scenario (discounted at 4%, year 1 = 2025)

	Lost EBITDA/Profit € millions		GVA-based Operating Surplus Losses € millions	
	EU	UK	EU	UK
1 year profit losses (2025)	1,752	376	2,451	407
2 year profit losses (2026)	3,304	709	4,623	767
4 year profit losses (2028)	6,360	1,365	8,898	1,477
7 year profit losses (2031)	10,515	2,257	14,712	2,442
12 year profit losses (2036)	16,442	3,530	23,005	3,818

5.2.2.7 Other impacts on Aerospace and Defence Companies

Under the Non-use Scenario there would be an enormous impact on the A&D sector in the EEA/UK, leading to a second wave of negative impacts on the EEA market. These impacts have not been quantified here but would include as a minimum:

- Cancelled future orders and loss of contracts for new products if supplies are significantly interrupted;
- Customer penalties for late/missed delivery of products;
- Extended durations of maintenance, repair and overhaul operations for products in service leading to e.g., "aircraft on the ground" (AoG) and other out-of-service final products, with consequent penalties and additional impacts on turnover;
- Increased logistical costs; and
- Reputational damages due to late delivery or cancelled orders.

5.2.3 Economic impacts on competitors

5.2.3.1 Competitors in the EEA/UK

This combined AoA/SEA has been prepared to enable the continued use of the CT and SD in pre-treatment across the entirety of the EEA and UK A&D sectors. It is non-exclusive in this respect. It has been funded by the major (global) OEMs and DtB manufacturers in the EEA and the UK, with additional support provided by their suppliers and by Ministries of Defence, to ensure functioning supply chains for their operations.

As a result, there should be no economic impacts on competitors, especially as the major global OEMs and DtBs act as the major design owners which determine the ability of all suppliers to move to an alternative. As design owners they validate, qualify and certify components and products with new alternatives and gain new approvals (e.g. approvals from EASA, ESA or MoDs). Once these design owners have certified new alternatives in the manufacture of components, these alternatives will be implemented throughout their value chain.

5.2.3.2 Competitors outside the EEA/UK

Under the NUS, it is likely that some of the major OEMs and DtB suppliers would move outside the EEA/UK, creating new supply chains involving BtP and MROs. This would be to the detriment of existing EEA/UK suppliers but to the advantage of competitors outside the EEA/UK. These competitors would gain a competitive advantage due to their ability to continue to use chromate-based pre-treatment and due to their proximity to the OEMs and DtB, thus minimising logistic and transport issues.

5.2.4 Wider socio-economic impacts

5.2.4.1 Impacts on air transport

Under the Non-Use Scenario there would be significant impacts on the ability of MROs to undertake repairs and to follow normal maintenance and overhaul schedules. As indicated previously, MROs are legally bound to adhere to the requirements set out in the OEMs' manuals under airworthiness and military safety requirements. Where maintenance or overhaul activities would require chromate-based pre-treatment, they would have to be performed outside the EEA/UK until the OEMs have gained approvals and certifications for the use of alternatives on components and have adapted the manuals setting out maintenance and overhaul instructions.

If an aircraft needs unscheduled repairs (i.e., flightline or "on-wing" repairs), it will be grounded at the airport until these take place due to airworthiness constraints. This would result in AOGs and could result in an aircraft having to be disassembled and transported outside the EEA/UK for repairs, with dramatic financial and environmental impacts.

Should MRO facilities be relocated outside the EEA/UK, airlines will also experience additional delays to routine aircraft maintenance due to transport requirements and capacity constraints at MRO facilities outside the EU. Indeed, it may take some time to build up capacity to accommodate additional demand from EU-based operators, potentially resulting in many aircraft being grounded until maintenance checks can be completed.

As a result, airlines would need to have additional spare components/engines/planes to account for the added time that aircraft would be out of commission due to extended MRO times. Airports may also have to build up large inventories of spare components to replace products that currently can be repaired, with this going against the desire to ensure sustainability within the sector.

The need to have maintenance carried out outside the EEA/UK would also lead to additional operational costs being incurred through increased fuel use. Small planes (e.g., business jets) that do not have the fuel capacity or airworthiness approvals for long haul flights would need to make multiple stops enroute to non-EEA MRO facilities and back to the EEA/UK. The impacts for larger aircraft would also be significant. For example, flying from Western Europe to Turkey or Morocco adds approximately 3,000 km each way and for a Boeing 737 this would take slightly less than four hours. For an airline which has 50 aircraft requiring a "D check" (heavy maintenance inspection of most 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 EEA passenger aircraft fleet, which stands at approximately 6,700, suggests lost revenues in the tens of millions per annum just due to the need to have around 700 aircraft which require a "D check" each year. Using the above estimate for a fleet of 50 aircraft, this would amount to €20 million in revenue lost by European airlines for "D checks" alone. This figure excludes the costs of fuel and personnel, as well as the fact that additional flights bring forward maintenance interval requirements and impact on the total lifespan of an aircraft.

In addition, based on a leasing cost for a large passenger jet of around $500,000/month in 2021 (€421,500, £362,250)[83], 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[84] 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-19 estimates suggesting that demand for air transport would increase by an average of 4.3% per annum over the next 20 years, as illustrated 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.

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

[84] https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf

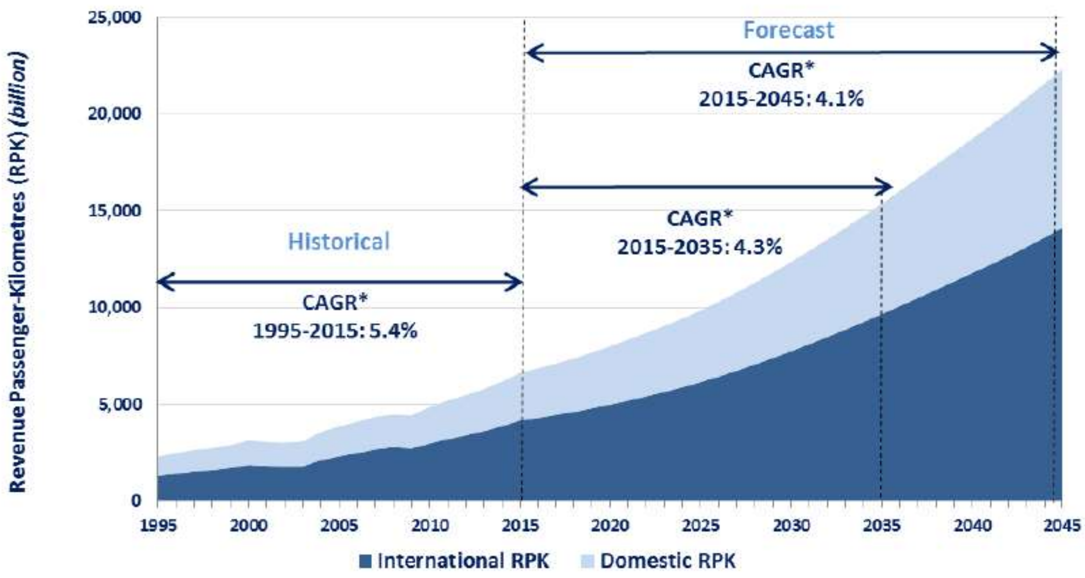

Figure 5–2: Forecast compound annual growth rates – Revenue Passenger-kilometres

Post COVID-19, projections are for a lower rate of increase in air traffic, with Airbus suggesting a growth rate between 2019 and 2040 of around 3.9% CAGR.[85] The impact of COVID-19 has resulted in an expected 2-year lag in growth, but the forecast remains unchanged with passenger numbers expecting to increase in line with the forecasts. This growth rate is relevant to global air traffic, with Europe expected to realise a lower compound annual growth rate of about 3.3% for total traffic[86] (covering inter-regional and intra-regional/domestic) for the period between 2018 to 2038.

This level of growth in EEA air traffic, together with the jobs and contributions to GDP that it would bring, could be impacted under the NUS. Impacts on the ability of MROs to undertake repairs and carry out maintenance where this would require the use of chromate-based pre-treatment to ensure the continued airworthiness of aircraft could impact on the realisation of such growth. No quantitative estimate of the level of impact can be provided, but it is clear that the closure of EU-based MRO operations in particular could impact on the availability of aircraft and hence passenger and freight transport until substitution has taken place as expected over the review period (unless airlines responded by buying more planes or stockpiling of components, which would inevitably give rise to increases due to the costs of holding spares and/or bringing spare planes on-line).

5.2.4.2 Defence-related impacts

Defence related impacts under the NUS would have two dimensions: impacts on military forces; and impacts on companies acting as suppliers to military forces.

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

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

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

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

It is also worth noting that Governments are likely to be reluctant to send military final products to MRO facilities located in non-EEA countries, although the US, Canada and Turkey are NATO members, and as such may be suitable candidates to service European military aircraft. There would be impacts on mission readiness if repairs cannot be done locally. This could, in fact, be far more impactful than the economic impacts linked to the defence sector.

As a result, it is likely that under the NUS, companies manufacturing components for and servicing military products would have to apply for defence exemptions under Article 2(3) of REACH; although for some companies, the turnover generated by military contracts alone may not be sufficient to maintain current production levels and it may not be economically feasible to operate dual manufacturing lines for military and civilian customers.

Companies in the European defence sector represent a turnover of nearly €100 billion and make a major contribution to the wider economy. The sector directly employs more than 500,000 people of which more than 50% are highly skilled. The industry also generates an estimated further 1.2 million jobs indirectly. In addition, investments in the defence sector have a significant economic multiplier effect in terms of the creation of spin-offs and technology transfers to other sectors, as well as the creation of jobs. For example, according to an external evaluation of the European Union's Seventh Framework Programme, through short-term leverage effect and long-term multiplier effects each euro spent by the Seventh Framework Programme (FP7) generated approximately an additional €11 of estimated direct and indirect economic effects through innovations, new technologies and products.[87]

Indeed, the European Commission announced in July 2022 that it plans to grant a total EU funding of almost **€1.2 billion** supporting **61 collaborative defence research and development projects** selected following the first ever calls for proposals under the European Defence Fund (EDF).[88] The aim will be to support high-end defence capability projects such as the next generation of fighter aircrafts, tanks and ships, as well as critical defence technologies such as military cloud, Artificial Intelligence, semiconductors, space, cyber or medical counter-measures. It will also spearhead disruptive technologies, notably in quantum technologies and new materials and tap into promising SMEs and start-ups. Some of these gains may not be realised if the main EEA defence OEMs must divert resources into shifting part of their manufacturing base outside of the EEA.

However, under the NUS, companies manufacturing components for defence and servicing military aircraft and other derivative defence products would most likely apply for defence exemptions; although for some companies, the turnover generated by military contracts alone may not be sufficient to maintain current production levels and it may not be economically feasible to operate dual manufacturing lines for military and civilian customers. If some production moved out of the

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

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

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

If Governments did allow the manufacture and servicing of military aircraft and other defence products to move out of the EEA/UK under the NUS, then some proportion of such multiplier effects would be lost to the EEA/UK economy. In addition, the ability of the EEA/UK to benefit from some of the innovations and technological advances in products ahead of other countries could be lost, if the shift in manufacturing remains permanent and extends to new products.

5.2.5 Summary of economic impacts

Table 5-8 provides a summary of the economic impacts under the Non-Use scenario.

Table 5-8: Summary of economic impacts under the Non-Use scenario (12 years, @ 4%)

Economic operator	Quantitative	Qualitative
Applicants	• Not assessed for substances - see formulation SEA	Not assessed
A&D companies	Annualised lost profits: • EEA: €1,800 – 2,500 0 million • UK: €380 - 410million 12 year lost profits: • EEA: €16,400 – 23,000 million • UK: €3,500 - 3,800 million	Relocation costs, disruption to manufacturing base and future contracts, impacts on supply chain coherence, impacts on future growth in the EEA and UK sectors, loss of skilled workforce, impacts on R&D (and potential to deliver new more sustainable technologies)
Competitors	Not anticipated due to sectoral coverage of the application	Not anticipated due to sectoral coverage of the application
Customers and wider economic effects	Not assessed	• Impacts on airlines, air passengers, customers, cargo, and emergency services, and thus society as a whole • Impacts on military forces' operation capacity and mission readiness • Lost employment multiplier effects due to impacts on civil aviation and loss of defence sector spending • Loss of spin-off effects – innovation and new technologies

5.3 Environmental impacts under non-use

As well as leading to increases in operating costs and lost revenues to airlines, the increased distances that airlines would need to fly aircraft for them to undergo normal maintenance and overhaul schedules would lead to significant increases in fuel consumption and hence CO_2 emissions.

The most plausible non-use scenario in the event of a refused Authorisation - even if it may not be practical and would involve huge levels of investment - would be to shift pre-treatment to another country (outside the EEA or UK).

Under this scenario, as noted above, the environmental impacts would be real and the effects enormous. If manufacturing activities using chromates and not using chromates are separated on both sides of the European border, huge logistics and transport related requirements would have to be introduced with dramatic impacts on the aerospace and defence sectors' environmental footprint.

For MRO activities, each time an aircraft would need a repair requiring the use of chromate-based pre-treatment, it would force the manufacturer to go to a non-European site. In the case of a major repair, aircraft that could not fly would become stranded or, less likely, would have to be dis-assembled for transport to a non-European site. Some stranded final products would become obsolete prematurely, due to the lack of the components 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. The industry has been active in trying to decrease buy-to fly ratio (the ratio of material inputs to final component output), and the non-use scenario would significantly undermine these efforts as the more frequent production of new components would increase the waste and scrappage generated. Scrap is the material that is wasted during the production process.

Today, the civil aviation industry strives to develop new technologies to reduce the amount of CO_2 emissions by 15 - 20% on each generation of in-service aircraft (make aircraft movements emission-free).

Even despite the impact that the COVID-19 pandemic had on air traffic and the whole civil aviation industry, aviation is expected to double in the next 20 years. Consequently, a refused authorisation renewal would lead to aircraft manufacturing and MRO activities involving chromate uses to move outside the EEA. In addition to the socio-economic consequences this would have, the drastic increase in CO_2 emissions, would outweigh all the benefits achieved by aviation efforts to reduce fuel consumption and CO_2 emissions of in-service aircrafts.

5.4 Social impacts under non-use

5.4.1 Direct and indirect job losses

5.4.1.1 Estimated level of job losses

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 53 sites in total. Direct job losses will impact on workers at the site involved in pre-treatment and linked pre-treatment, main treatments (i.e., anodising) and post-treatment processes, as well workers involved in subsequent manufacturing and assembly steps and related activities (e.g., lab workers, etc.). These are all referred to here as direct job losses (for avoidance with confusion of multiplier effects).

While redundant workers are expected to face a period of unemployment, in line with ECHA's guidance it is assumed that such a period would be only temporary. However, the length of the average duration of unemployment varies greatly across European countries, as do the costs associated with it.

It should be noted that the ECHA methodology has been followed here even though the impacts across the A&D sector may make it difficult for workers to find another job, especially as there may be a skill mismatch if there are large scale levels of redundancies).

Estimates of the job losses that would arise at downstream users' sites under the NUS were presented above. For ease of reference, the totals are repeated in **Table 5-9** below. The magnitude of these figures reflects the importance of pre-treatment, as well as to maintenance and repairs of such parts at a subset of MRO facilities. No consideration is given to job losses at those companies providing services that are contracted to provide cleaning and other services to the BtPs, DtBs, MROs and ORMs.

As context, the civil aeronautics industry alone employees around 405,000 people in the EU, with the defence sector employing more than 500,000 and supporting a further 1.2 million[89]. The figures in **Table 5-9** indicate that approximately 36,000 A&D jobs would be in jeopardy under the NUS.

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

Role	Job losses directly linked to use of the chromates		Additional job losses due to cessation of other manufacturing		Total A&D job losses under the NUS	
	EEA	UK	EEA	UK	EEA	UK
Build-to-Print	794	227	1,725	92	2,518	319
Design-to-Build	885	810	855	3,000	1,740	3,810
MROs	3,573	398	13,833	758	17,406	1,156
OEMs	4,420	500	3,879	300	8,299	800
Total sites 100	9,672	1,935	20,291	4,150	29,963	6,085

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[90]).

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[91] as a whole that varies according to the mean duration of unemployment. These vary by country, with the mean duration of unemployment

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

90 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

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

weighted by the number of employees for each country relevant to A&D sector productions sites varying from seven months to 1.6 years.

These figures are combined with the ratio of social costs per job loss provided in Dubourg (2016) and annual wages to calculate the social costs per lost job. Data were collected in the SEA questionnaire on the average salary for workers involved in the use of the chromates. The typical range given is from €30k to 50k, rising to an average maximum of around €76k, across all the companies and locations. For the purposes of these calculations, a figure of €40k has been adopted and applied across all locations and job losses. This figure is based on the NACE code data provided by companies but may underestimate the average salary given that A&D jobs are higher paid than those in other industries.

The resulting estimates of the social costs of unemployment are given in **Table 5-10** based on consideration of the geographic distribution Article 66 notifications, the location of SEA respondents, and the location of suppliers in the ADCR members' supply chains, as well as MROs. The estimated social costs under the NUS are around €3.45 billion for the EEA and €610 million for the UK due to the cessation of the pre-treatment and linked manufacturing activities.

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

Country	Employment losses due to cessation or relocation of manufacturing	Social costs of unemployment (€)
France	10,113	1,282,269,438
Poland	2,622	246,446,223
Italy	3,745	453,940,460
Germany	4,120	428,471,853
Spain	2,247	251,689,760
Czech Republic	1,124	123,148,204
Netherlands	749	70,413,207
Sweden	749	66,817,639
Norway	375	40,749,771
Belgium	375	98,346,528
Finland	375	26,067,868
Denmark	375	26,217,683
Romania	375	35,805,865
Ireland	375	36,704,757
Hungary	375	41,199,217
Portugal	375	42,397,739
Slovakia	375	38,951,987
Bulgaria	375	33,558,635
Lithuania	375	67,836,384
Greece	375	39,251,617
Total EU	**29,963**	**3,450,284,834**
United Kingdom	**6,085**	**610,447,200**
	36,048	**4,060,732,034**

5.4.2 Wider indirect and induced job losses

5.4.2.1 Aerospace and defence related multiplier effects

Employment in one sector is often the input to employment in another sector, so that fluctuations in employment of the latter will inevitably affect the former. It is clear under the NUS, there could be significant wider impacts on jobs given the likelihood that some of the largest players in the EEA/UK A&D sector would relocate their activities elsewhere with a partial or full cessation of manufacturing in the EEA/UK.

A UK Country Report on the "Economic Benefits from Air Transport in the UK" produced by Oxford Economics (2014) indicates the following with respect to the aerospace sector's contribution to UK employment in 2012:

- Indirect employment effects: 139,000 jobs implying a multiplier effect of 1.36 indirect jobs for every direct job;

- Induced employment effects: 86,000 jobs implying an additional multiplier effect of 0.84 induced jobs for every direct job.

Indirect employment effects will to a degree be captured by the estimates of lost jobs presented in **Table 5-9** given that it includes the loss of jobs at suppliers to the aerospace OEMs. The figures exclude other service providers to these companies whose services would no longer be required. Induced effects are not captured by the above estimates and an employment multiplier of 0.84 suggests that they may be significant given the predicted numbers of jobs that would be lost across the key countries in which aerospace-related manufacturing takes place.

The loss of jobs within those companies that serve the defence industry would have their own multiplier effects. The external evaluation of FP7 referenced above[92] quotes an employment multiplier of between 2.2 to 2.4, with this covering both indirect and induced employment effects. The sector is identified as bringing a major contribution to the wider economy.

To successfully compete at a global level, the European and UK A&D industries have formed regional and industry clusters that includes local and national government partners. The clusters are part of the European Aerospace Cluster Partnership[93](EACP) which focuses on the exchange of experiences concerning both cluster policy and the implementation of effective solutions needed to address various challenges faced by the partners. It has members located in 44 aerospace clusters across 18 countries, thus covering the entire A&D value chain in Europe**.** **Figure 5-3** below is a "snip" taken from the EACP website highlighting the location of these different hubs across Europe, to provide an indication of where effects may be experienced at the regional level.

Under the non-use scenario, the economic impact on each region could have severe consequences. For example, Aerospace Wales consists of over 180 members which employ 23,000 employees with a

[92] 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

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

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 clusters are an essential part of the local economy.

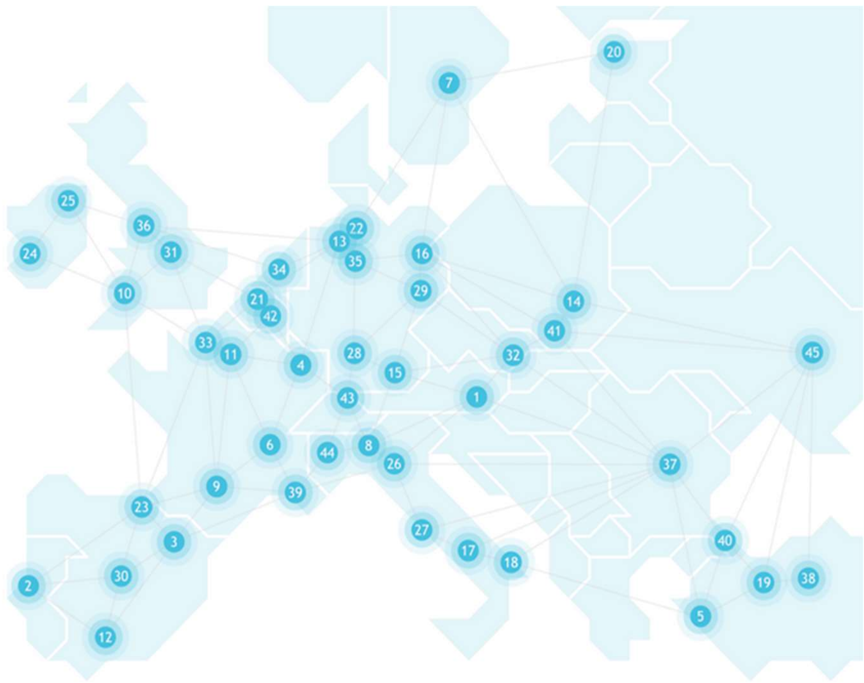

Figure 5-3: Aerospace clusters across Europe
Source: https://www.eacp-aero.eu/about-eacp/member-chart.html

5.4.2.2 Air transport multiplier effects

A 2019 "Aviation Benefits Report"[94] 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 .

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

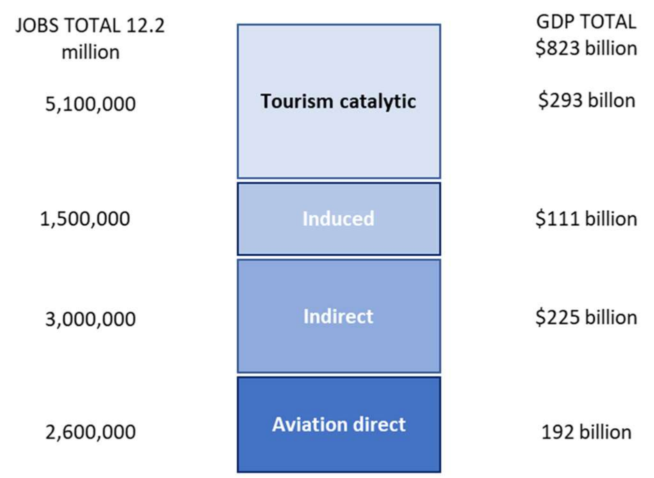

Figure 5-4: Aviation related multiplier effects
Source: Based on: ***https://www.icao.int/sustainability/Documents/AVIATION-BENEFITS-2019-web.pdf***

The potential employment losses associated with a decline in European aviation can be seen by reference to the impacts of COVID-19[95]. A "COVID-19 Analysis Fact Sheet" produced by Aviation Benefits Beyond Borders reports the following:

- A reduction from 2.7 million direct aviation jobs in Europe supported pre-COVID to 2.1 million jobs post-COVID (i.e. at the end of 2021); and

- 13.5 million jobs in supported employment pre-COVID in Europe to 8.1 million at the end of 2021.

Although one would not expect the losses in supported employment (i.e., indirect, induced, and catalytic effects) to be as great due to the loss of pre-treatment alone, it is clear a disruption to civil aviation could have significant employment impacts.

5.4.3 Summary of social impacts

In summary, the social impacts that would arise under the NUS include the following:

- Job losses at A&D companies:
  - Around 30,000 jobs in the EEA due to the loss of pre-treatment, linked surface treatments, assembly and/or manufacturing activities, and
  - Around 6,000 jobs in the UK.
- Social costs of unemployment:
  - €3.45 billion for the EEA associated with direct job losses; and
  - €0.61 billion for the UK associated with direct job losses.

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

5.5 Combined impact assessment

Table 5-11 sets out a summary of the societal costs associated with the Non-Use scenario. Figures are provided as annualised values, with costs also presented as a PV over a two-year period as per ECHA's latest guidance; note that restricting losses to only those occurring over the first two years of non-use will significantly underestimate the profit losses to the A&D companies as well as the applicants. Most A&D companies would incur losses for at least a four-year period, with over 60% incurring losses for seven years and 55% for the full 12-year period as design owners work continues towards development, testing, qualification, validation, certification, and industrialisation of alternatives.

Table 5-11: Summary of societal costs associated with the Non-Use Scenario		
Description of major impacts	**Monetised/quantitatively assessed/qualitatively assessed impacts**	
1. Monetised impacts	**PV @ 4%, 2 years**	**€ annualised values**
Lost producer surplus[1]: Impacts on applicants - Lost profits EEA - Lost profits UK Impacts on A&D companies[1]: - Lost profits EEA - Lost profits UK	Applicants: not quantified See also formulation SEA A&D companies EEA: €3,300 – 4,600 million UK: €710 – 770 million	Applicants: not quantified See also formulation SEA A&D companies EEA: €1,800 – 2,500 million UK: €380 – 410 million
Relocation or closure costs	Not monetised	Not monetised
Loss of residual value of capital	Not quantifiable	Not quantifiable
Social cost of unemployment: workers in A&D sector only[2]	EEA: 30,000 jobs UK: 6,000 jobs	EEA: 30,000 jobs UK: 6,000 jobs
	EEA: €3,500 million UK: €610 million	EEA: €1,700 million UK: €310 million
Spill-over impact on surplus of alternative producers	Not assessed due to sector level impacts	Not assessed due to sector level impacts
Sum of monetised impacts (PV)	EEA: €6,800 – 8,100 million UK: €1,300 – 1,400 million	EEA: €3,500 – 4,200 million UK: €690 – 720million
2. Additional qualitatively assessed impacts		
Impacts on A&D sector	Impacts on R&D by the A&D sector, impacts on supply chain, impacts on technological innovation	
Civilian airlines	Wider economic impacts on civil aviation, including loss of multiplier effects, impacts on airline operations, impacts on passengers including flight cancellations, ticket prices, etc.	
Ministries of Defence	Impacts on the operational availability of aircraft and equipment, premature retirement of aircraft and equipment, impacts on mission readiness	
Other sectors in the EEA	Loss of jobs due to indirect and induced effects; loss of turnover due to changes in demand for goods and services and associated multiplier effects. Loss of jobs in other sectors reliant on aeroderivative uses of the chromates, such as the energy sector (e.g., use of pre-treatment on turbine blades and engine components including wind turbines) Impacts on emergency services and their ability to respond to incidents. Impacts on cargo transport	
1) Lower bound figures represent lost EBITDA estimates, upper bound lost operating surpluses. 2) Estimated using the approach set out by Dubourg		

6 Conclusion

6.1 Steps taken to identify potential alternatives

Potential alternatives to Cr(VI) for pre-treatment should be "generally available"[96]. At present, this condition has not been met, as there are not alternatives which have met the strict regulatory requirements within the A&D industry for all components onto which pre-treatments containing Cr(VI) are currently applied.

Alongside the various R&D activities as described in Section 3.4.1 and information reported in academic literature and patent reports as described in Sections 3.4.3, members of the ADCR have undertaken extensive testing into alternative technologies and processes with many programmes still ongoing. The steps taken by members in the implementation of a substitute for Cr(VI)-based pre-treatment are shown in Figure 6-1:

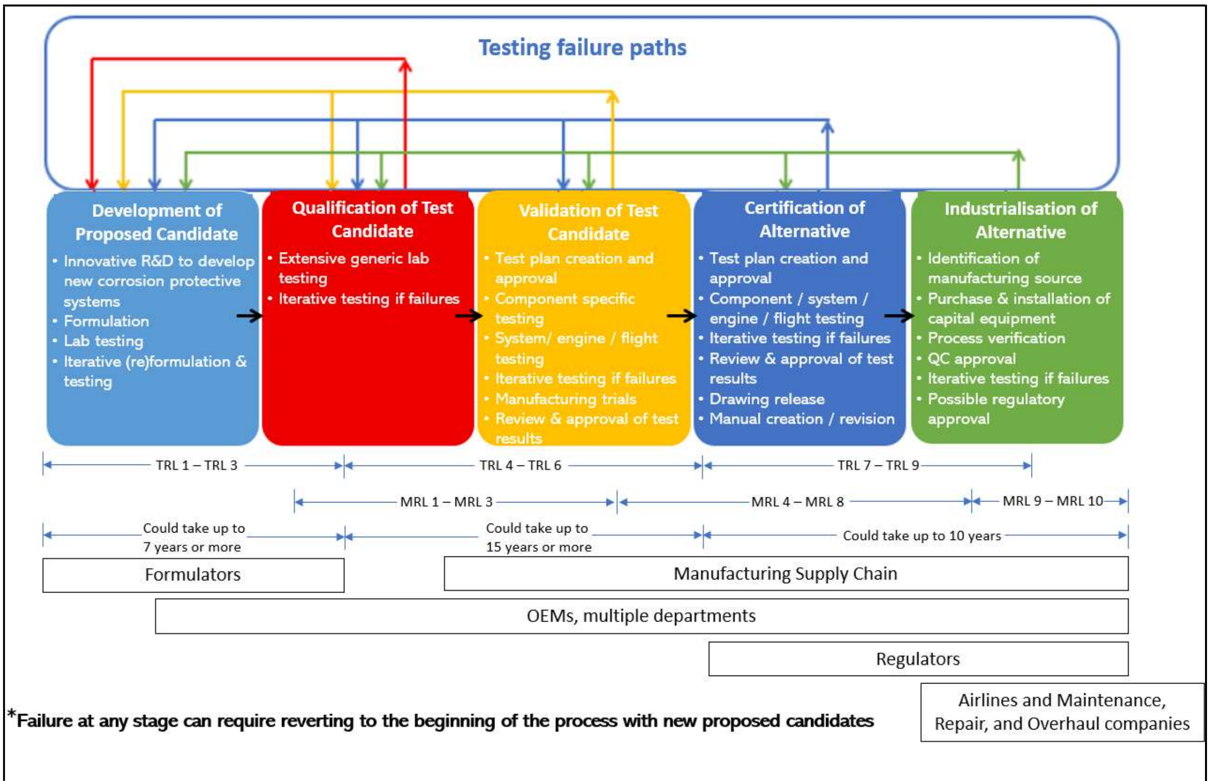

Figure 6-1: Schematic showing the key phases of the substitution process.
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note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

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

Activities undertaken include:

- Development of test alternatives in laboratory environments up to TRL 6;
- Qualification of test alternatives and suppliers including:
  - Modification of drawings
  - Updating specifications
  - Introduction of new processes to suppliers
  - Negotiation of supplier(s) contracts
- Demonstration of compliance followed by industrialisation; and
- Certification or approval.

6.2 The substitution plan

ADCR member companies have ongoing substitution plans in place to develop test candidates with the intent of replacing Cr(VI) in pre-treatment. Individual members often have multiple substitution plans within pre-treatment, reflecting the complexity of different components to be treated, the various substrates, and the different performance resulting from test candidates in these different situations. While there have been successes, with some members having been able to implement alternatives to Cr(VI) in certain limited situations, for certain substrates, and in combination with certain main treatment processes, thereby reducing their Cr(VI) usage, many technical challenges remain.

As discussed in Section 3.7.2 and shown in Figure 6-2 below, of the 24 distinct substitution plans for pre-treatment assessed in this combined AoA-SEA, 8% of them are expected to have achieved MRL 10 by 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 33% in 2028, 58% in 2031, and 83% in 2036. The potential need for more than 12 years has been identified by some OEMs due to their failure to identify any technically feasible alternatives to date, or due to the need by MROs and MoDs for continued use in the maintenance and repair of in-service (legacy) final A&D products.

In 2031 (equivalent to seven years beyond the expiry date for the existing applications), while many substitution plans are expected to have successfully progressed to industrialisation phase or MRL 10 and the consortium is expected to have reduced its Cr(VI) use, a proportion are not expected to have achieved MRL 10. For these substitution plans (which are from several member companies), there is still expected to be a need for the use of Cr(VI).

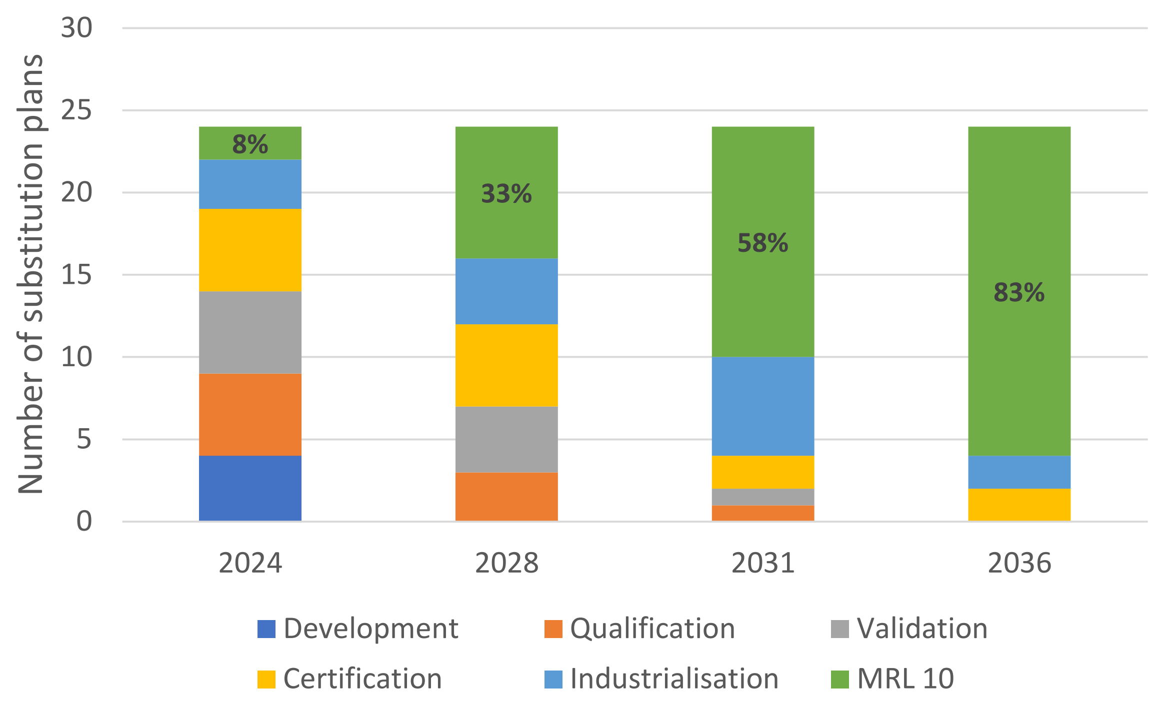

Figure 6-2: **Expected progression of substitution plans for the use of Cr(VI) in pre-treatment, by year**
The vertical axis refers to number of substitution plans (some members have multiple substitution plans for pre-treatment). The percentage value shown on each of the green bars indicates the proportion 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

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

6.3 Comparison of the benefits and risk

Table 6-1 summarises the socio-economic benefits of continued use of the chromates in pre-treatment by companies in the A&D sector. Overall, net benefits of over €6.8 to €8.1 billion for the EEA and €1.3 to €1.4 billion for the UK (Net Present Value social costs over two years/risks over 12 years, @4%) can be estimated for the continued use scenario. These figures capture continued profits to the applicants and the A&D companies and the social costs of unemployment.

As can be seen from Table 6-1, the ratio of the benefits of continued use to the monetised value of the residual health risks is around 9,005 on the lower bound assumptions for the EEA and 4,254 on the lower bound assumptions for the UK.

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

Societal costs of non-use		Risks of continued use
Monetised profit losses to applicants	Losses in profits from reduced sales of the chromate substances	Health risks to workers at formulation sites over the review period, considering the reduction in

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	
	and associated formulations. Losses quantified in the Formulation SEA	risks due to adherence to the conditions placed on the initial authorisations. These risks are quantified and monetised in the Formulation SEA	
Monetised profit losses to A&D companies	EEA: €3,300 – 4,600 million (£2,800 - £4,000 million) UK: €710 – 770 million (£610 – 660- million)	Monetised excess risks to directly and indirectly exposed workers. (€ per year over 12 years)	EEA: €0.50 mill (£0.43 mill) UK: €0.12mill (£0.10 mill)
Social costs of unemployment	EEA: €3,500 million (£3,000 million) UK: €600 million (£520 million)	Monetised excess risks to the general population. (€ per year over 12 years)	EEA: €0.26 mill (£0.22 mill) UK: €0.19 mill (0.16 mill)
Qualitatively assessed impacts	Wider economic impacts on civil aviation, impacts on cargo and passengers. Impacts on armed forces including military mission readiness. Impacts on R&D and technical innovation. Impacts from increased CO_2 emissions due to MRO activities moving out of the EEA/UK; premature redundancy of equipment leading to increased materials use.		
Summary of societal costs of non-use versus risks of continued use	- NPV (2 years societal costs/12 years residual health risks): o EEA: €6,800 – 8,100 million (£5,800 – 7,000 million) o UK: €1,300 – 1,400 million (£1,100 -1,200 million) - Ratio of annualised societal costs to residual health risks: o EEA: 9,005: 1 to 10,763 : 1 - UK: 4,254: 1 to 4,441 : 1		

It should be appreciated that the social costs of non-Authorisation could be much greater than the monetised values reported above, due to the likely 'knock-on' effects for other sectors of the economy:

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

↓

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

↓

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

↓

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

Build-to-Print suppliers in the EEA would be forced to cease pre-treatment processes reliant upon pre-treatment; as a result, BtP suppliers in the EEA/UK would be replaced by suppliers outside the EEA/UK

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

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

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

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

Overall, it is clear the benefits of the continued use of the chromates in pre-treatment significantly outweigh the residual risks from continued use.

Three further points are relevant. **Firstly, the use of the two chromates in pre-treatment is required (and may be required beyond 12 years) to ensure the operational capabilities of the military and the ability to comply with international obligations as partner nations at the EEA level and in a wider field, e.g., with NATO.**

Secondly, the requirements of the ADCR members – as downstream users - have been carefully identified and analysed, taking as the starting point the parent authorisations and the substance-use combinations covered by these. Over the lifetime of the ADCR consortium, the number of uses identified as requiring authorisation and the number of OEMs and downstream users supporting each use has decreased (including the continued need for use of the different chromate substances), to ensure that authorisation is only sought for those cases where there is no substitute that is fully qualified and certified as per stringent airworthiness requirements and industrialised by all members and within their supply chains. The continual re-visiting of supply chain requirements fed into the narrowing of the substance-use combinations requiring re-authorisation compared to the original applications for authorisation.

Finally, the non-use scenario would involve the relocation of economically and strategically important manufacturing processes. This would be in contradiction to the EU policy on "Strategic dependencies and capacities", which highlights the need to minimise such dependencies where they could have a significant impact on the EU's core interests, including the access to goods, services and technologies.[97] 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.[98]

6.4 Information for the length of the review period

6.4.1 Introduction

In a 2013 document, the ECHA Committees outlined the criteria and considerations which could lead to a recommendation of a long review period (12 years) (ECHA, 2013):

1. *The applicant's investment cycle is demonstrably very long (i.e., the production is capital intensive) making it technically and economically meaningful to substitute only when a major investment or refurbishment takes place.*
2. *The costs of using the alternatives are very high and very unlikely to change in the next decade as technical progress (as demonstrated in the application) is unlikely to bring any change. For example, this could be the case where a substance is used in very low tonnages for an essential use and the costs for developing an alternative are not justified by the commercial value.*
3. *The applicant can demonstrate that research and development efforts already made, or just started, did not lead to the development of an alternative that could be available within the normal review period.*
4. *The possible alternatives would require specific legislative measures under the relevant legislative area in order to ensure safety of use (including acquiring the necessary certificates for using the alternative).*
5. *The remaining risks are low, and the socio-economic benefits are high, and there is clear evidence that this situation is not likely to change in the next decade.*

In the context of this combined AoA/SEA, it is assumed that qualification and certification requirements combined with the need for approvals from EASA, the ESA and MoDs are consistent with the requirements under criterion 4 above.

Further discussion was held at the 25th Meeting of Competent Authorities for REACH and CLP (CARACAL) of 15 November 2017. A document endorsed by CARACAL suggests that "*in order to 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*

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

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

recommend additional conditions for the authorisation. In the case of applications for threshold substances, the appropriateness and effectiveness of the applied risk management measures and operational conditions should clearly demonstrate that risks are adequately controlled, and that the risk characterisation ratio is below the value of one. For applications for non-threshold substances, the applied risk management measures and operational conditions should be appropriate and effective in limiting the risks and it should be clearly demonstrated that the level of excess lifetime cancer risk is below $1x10^{-5}$ for workers and $1x10^{-6}$ for the general population. For substances for which the risk cannot be quantified, a review period longer than 12 years should normally not be considered, due to the uncertainties relating to the assessment of the risk.

7. *As evaluated by the SEAC, the analysis of alternatives and the third party consultation on alternatives should demonstrate without any significant uncertainties that there are no suitable alternatives for any of the utilisations under the scope of the use applied for and that it is highly unlikely that suitable alternatives will be available and can be implemented for the use concerned within a given period (that is longer than 12 years)"* (EC, 2017).

As far as the second criterion above is concerned, the same document provides some relevant examples, one of which (Example (d)) reads as follows:

"(…) *the use of the substance has been authorised in accordance with other EU legislation (e.g. marketing authorisation, certification, type-approval), the substance being specifically referred to in the authorisation/certification granted and substitution, including the time needed for modification of the authorisation/certification/type-approval, would not be feasible within 12 years and would involve costs that would jeopardise the operations with regard to the use of the substance*".

6.4.2 Criterion 1: Demonstrably Long Investment Cycle

The aerospace and defence industry is driven by long design and investment cycles, as well as very long in-service time of their products, which are always required to meet the highest possible safety standards. As noted in Section 4.4, the average life of a civil aircraft is typically 20-35 years, while military products typically last from 40 to >90 years. Furthermore, the production of one type of aircraft or piece of equipment may span more than 50 years.

These long investment cycles and long product lives have been recognised in the FWC Sector 26 study on the Competitiveness of the EU aerospace industry[99]. They are a key driver underlying the difficulties facing the sector in substituting the use of the chromates in pre-treatment across all affected components within final products. The long service life of aircraft and other products makes it difficult to undertake all 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; as it would require testing at multiple levels (components, sub-assemblies, assemblies, final aircraft/defence equipment).

The ADCR would like to emphasise the crucial role every single component within an A&D product plays with respect to its safety. For example, an aircraft is a complex system involving not only design of the aircraft itself, but also its use and maintenance history in varied climates and service. An aircraft

99 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.

engine is exposed to massive forces and extremely high stress levels due to high velocities and environmental impacts. Therefore, every single component needs to be designed and manufactured with serious attention and care.

In a complex system, change introduces new forms of failure. Any change will bring failures that can be anticipated – and some that are unanticipated. The components in an A&D product need to be adjusted to each other very precisely on the design as well as on the manufacturing level. When in the early design phase for completely new engines, for example, there is an opportunity to consider introducing a material change. Mostly such a material change will be a step improvement on a previous design, in line with the principle of proven engineering. Very rarely is a substantial design change introduced into an existing product, as this would involve substantial cost and risk.

Even where such a small change is considered feasible in principle, the implications are significant and highly complex; time consuming, systematic TRL-style implementation is required to minimise the impact of unanticipated failures and the serious repercussions they might cause. Even when an OEM has been able to undertake the required testing and is in the process of gaining qualifications and certifications of components with a substitute, it may take up to seven years to implement the use of a substitute across the value chain due to the scale of investment required and the need for OEMs to undertake their own qualification of different suppliers.

In addition, MoDs rarely revise specifications for older equipment, which must nevertheless be maintained and repaired. MROs servicing military equipment therefore must undertake any maintenance or repairs in line with the OEMs' original requirements. Similarly, MROs in the civil aviation field are only legally allowed to carry out maintenance and repairs in line with OEMs' requirements as set out in Maintenance Manuals. Long service lives therefore translate to on-going requirements for the use of the chromates in the production of spare parts and in the maintenance of those spare components and the final products and aircraft/equipment they are used in.

As such, a review period of at least 12 years is warranted and requested for the highly complex systems the ADCR is addressing in this Combined AoA/SEA. A 12-year review period in itself may not be sufficient for the aerospace and defence industry to fully replace the chromates across all uses of pre-treatment; however, the industry is committed to the goal of substitution. A 12-year review period will enable the implementation of the significant (additional) investment in R&D, qualification and certification of design/drawing changes and industrialisation required across the various OEMs.

6.4.3 Criterion 2: Cost of moving to substitutes

Cr(VI) coatings were validated/certified in the 1950s and 60s and extensive in-service performance has demonstrated the performance of chromated materials. This includes modifications to design practice and material selection based upon resolution of issues noted in service. Chromate-based pre-treatment, due to its extensive performance history, represents the baseline that alternatives must match to demonstrate equivalence.

For example, modern commercial aircraft (including helicopters) in their entirety consist of between 500,000 to 6 million components, depending on the model. Depending on the materials of construction, 15-70% of the entire structure of an aircraft requires treatment using Cr(VI) at some point during the manufacturing process. Older models generally require a larger percentage of Cr(VI) surface treatments as the aerospace industry has worked diligently to incorporate new base materials and Cr(VI)-free protective coatings in newer models wherever it is safe to do so.

There are literally billions of flight hours' experience with components protected from corrosion by chromate-based pre-treatment. Conversely, there is still limited experience with Cr(VI)-free alternatives on components. It is mandatory that components coated using a Cr(VI)-free alternative are demonstrably every bit as safe as they had been when coated using a Cr(VI) product. The performance of Cr(VI)-free products can sometimes be demonstrated at the laboratory step but then fails at industrial scale, as it is impossible to replicate all in-service conditions in a laboratory. As a result, the time taken to progress through the TRL process may be increased until it is possible for the performance of the alternative to be demonstrated as per safety requirements at the aircraft level when operating under real life conditions.

Flight safety is paramount and cannot be diminished in any way. Take, for example, a compressor blade that is in the middle of an engine. If that blade can only survive for a portion of the life of an engine because of service life (and hence maintenance requirement) limitations due to a new coating, the engine would need to be disassembled to be able to access the blades. That means taking the engine off the wing, sending it to a Repair Center, disassembling the engine and replacing the components at much shorter intervals than previously needed for the remainder of the engine. This would add inherent maintenance time and costs to the manufacturers, operators, and eventually end-use customers.

Where possible, and for specific components and final products, some new designs have been able to utilize newly developed alloys that do not require a Cr(VI)-based coating (as typically used to provide corrosion protection on metallic legacy components). However, even in newer designs there may still be a need for the use of chromate-based pre-treatment, due to safety considerations.

These technical hurdles are a fundamental reason why the A&D industry requests a review period of at least 12 years.

6.4.4 Criteria 3 and 7: Results of R&D on alternatives and availability of alternatives over the longer term

Research into the substitution of the chromates has been on-going for several decades. Although use continues, it should be recognised that significant achievements have been made over this period in the substitution of the use of the chromates by alternative substances or technologies. This is illustrated by the achievements of one of the OEMs in reducing by 75% (reduction by weight) of their level of dependency on use of the chromates across all processes (see Figure 6-3).

This 75% reduction in the use of the chromates by weight reflects the massive efforts and investment in R&D aimed specifically at substitution of the chromates. Although these efforts have enabled substitution across a large range of components and products, this OEM will not be able to move to substitutes for chromate-based pre-treatment (its single most important on-going use of the chromates) across all components and products for at least 12 years, and perhaps longer for those components and products which must meet military requirements (including those pertaining to UK, EEA and US equipment).

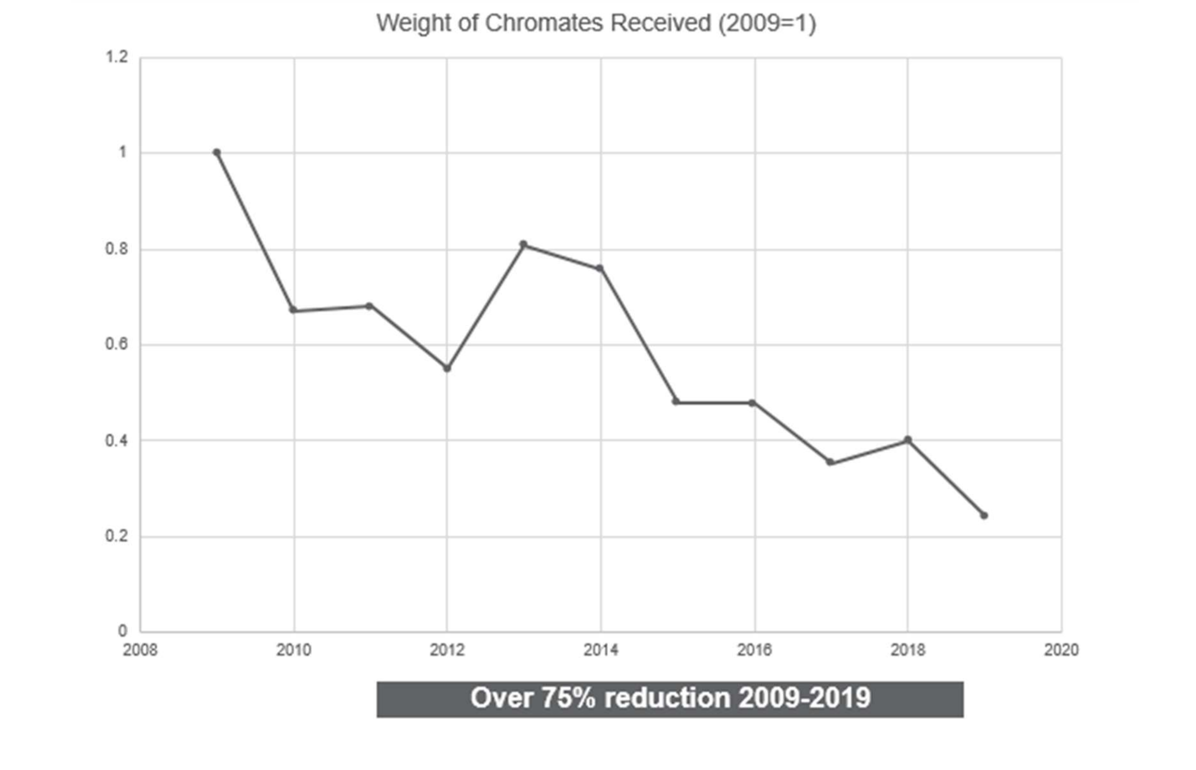

Figure 6-3: Reductions in chromate dependency over the period 2009 -2019

The European aerospace and defence security industry is heavily regulated to ensure passenger/operator safety. The consequence is that there are very long lead times and testing cycles before technologies developed from a research project can be implemented into real products. Technologies which are available on the market today are the result of extensive research, including research funded by grants and conducted over the last 25+ years. In 2020, the European A&D industries spent an estimated €18 billion in Research & Development (with an approximate 40:60 split between civil and military activities, and investment in R&D in the US roughly four times higher)[100].

A PricewaterhouseCoopers (PwC) study[101] refers to the high risks of investments in the aerospace industry: "Historically, step changes have been the norm in aircraft R&D. But recent development efforts have been so expensive that it is unclear whether the companies will earn the anticipated return on their investments. Furthermore, slips in the program schedule have worsened the economics."

Corrosion prevention systems are critical to aircraft safety. Testing in environmentally relevant conditions to assure performance necessarily requires long R&D cycles for alternative corrosion prevention processes. A key factor driving long timeframes for implementation of fully qualified components using alternatives by the aerospace and defence industry is the almost unique challenge of obtaining relevant long-term corrosion performance information. In the case of pre-treatment, it requires testing of changes in a process of corrosion protection, which may include changes in pre-treatments, main treatments and post-treatment surface coatings.

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

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

Aerospace companies cannot apply a less effective corrosion protection process as aviation substantiation procedures demand component performance using alternatives to be equal or better. If such performance is not achieved, then the alternatives cannot be used. The implications for repair, replacement and overhaul must also be understood before moving to an alternative. In particular, it must be recognised that the performance delivered by one component is dependent upon the performance of other components; thus, the performance delivered by a final product is dependent upon the components used. The number of configurations of components and final products is immense, and each configuration may differ from the next in terms of its behaviour with a Cr(VI) alternative.

As noted previously, there is a complex relationship between each component and its performance requirements within its own unique design parameters, which requires component certification for each individual substitution.

6.4.5 Criterion 4: Legislative measures for alternatives

As discussed in detail in section 3.1.2, the identification of a technically feasible Cr(VI)-free formulation is only the first stage of an extensive multi-phase substitution process leading to implementation of the alternative. This process, illustrated below, requires that all components, materials and processes incorporated into an A&D system must be qualified, validated, certified and industrialised before production can commence. Each phase must be undertaken to acquire the necessary certification to comply with airworthiness and other safety-driven requirements.

From start to finish, significantly more than 12 years is required to move from Phase 1 to Phase 5 (i.e., to identify, qualify, validate, certify and industrialise alternatives) for all critical A&D applications. The ADCR OEMs and DtBs as design owners are currently working through this process with the aim of implementing chromate-free pre-treatment by 2036; their current substitution plans are designed to ensure they achieve TRL9 and MRL10 within the next 12 years or sooner. This includes gaining airworthiness certification or military safety approvals, both of which can take up to several years to ensure safety and reliability.

In addition, several of the ADCR members note that military procurement agencies prefer key components of defence equipment to be produced in the EEA, although there are also international agreements enabling manufacture in partner countries. In contrast to other industry sectors, shifting production to a non-EEA territory and import of finished surface treated components or products into the EEA is more complex, as it could create a dependence on a non-EEA supplier in a conflict situation.

They also note that the provision of defence exemptions, as allowed for in Article 2 (3) of the REACH regulation, is **not** a suitable instrument to ensure the continued availability of the chromates for pre-treatment 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 pre-treatment by several actors in several EU member states (i.e., it often relies on a transnational supply chain). In contrast, defence exemptions are valid at a national level and only for the issuing member state. Furthermore, the defence exemption process cannot be used as an alternative to the normal authorisation process unless this is necessary for confidentiality reasons and in the interest of defence. Thus, defence applications also need to be covered by the normal authorisation process.

Finally, the EEA defence sector requires only small quantities of chromates in pre-treatment. On the basis of a defence exemption alone, the quantities demanded would not be sufficient for manufacturers, formulators and surface treatment companies to continue to offer their services and products. As a result, pre-treatment as a surface treatment on military aircraft and equipment would not continue in the EEA or UK if other civilian applications were not also possible. This can only be ensured by the granting of an authorisation.

6.4.6 Criterion 5 and 6: Comparison of socio-economic benefits and risks to the environment and effective control of the remaining risks

As demonstrated by the information collected by the SEA questionnaire, A&D companies have invested in monitoring and the installation of additional risk management measures in response to the conditions placed on the continued use of the chromates under the initial (parent) authorisations. This has resulted in reduced exposures for both workers and reduced emissions to the environment. As substitution progresses across components and assemblies and the associated value chains, consumption of the chromates will decrease, and exposures and emissions will reduce further over the requested 12 year review period. As a result, the excess lifetime risks derived in the CSR for both workers and humans via the environment will decrease over the review period. These risks will also be controlled through introduction in 2017 of the binding occupational exposure limit value on worker exposures to Cr(VI) at the EU level under the Carcinogens and Mutagens Directive[102].

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 workers were employed in 2020[103]) and Europe's trade balance (55% of products developed and built in the EEA are exported).

Civil aeronautics alone accounted for around €99.3 billion in revenues, with military aeronautics accounting for a further €47.4 billion in turnover; overall considering other defence and space turnover, the sector had revenues of around €230 billion. Of the €99.3 billion in civil aeronautics turnover, €88.3 billion represented exports from the EU.

Both acknowledged market reports of Airbus and Boeing find a growing trend in the aerospace industry. Passenger air traffic is predicted to grow at 3.6% CAGR for 2022-2041 and freight traffic to grow at 3.2% CAGR globally, according to Airbus' Global Market Forecast. By 2041, there will be some 46,900 aircraft in service, with this including an estimated 39,500 new passenger and freighter aircraft (and the retirement of some of the older aircraft. This includes delivery of new aircraft for the European market, as well as the Asian and Chinese markets in particular.[104]

[102] 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

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

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

Boeing's 2022 Commercial Market Outlook[105] indicates a similar level of increase, noting that the global fleet will increase by around 80% through to 2041 with the forecast value of new airplane deliveries at around US $7.2 trillion (based on a slightly higher growth in traffic at around 3.8% CAGR.

The socio-economic benefits of retaining the key manufacturing base of the EEA and UK A&D industries are clearly significant, given that they will be major beneficiaries of this growth in demand. As demonstrated in the socio-economic analysis presented here, even without accounting for such growth in demand under the Continued Use Scenario, the socio-economic benefits clearly outweigh the associated risks to human health at social costs to risk ratios of over 3,560 to one for the EEA and 1,426 to one for the UK.

6.5 Substitution effort taken by the applicant if an authorisation is granted

As the AoA shows, where alternatives have been proven as technically feasible – on a component-by-component basis – they have been or are in the process of being implemented. However, there are still many cases where components do not have technically feasible alternatives available. **Figure 3-3** highlights the actions that are being taken by A&D design owners to develop, qualify, validate, certify and industrialise alternatives for individual components.

This work will continue over the requested review period with the aim of phasing out all uses of chromate-based pre-treatment. As illustrated in Section 4, on-going substitution is expected to result in significant decreases in the volumes of the two chromates used in pre-treatment within the next seven years. However, technically feasible alternatives are still at the development phase (Phase 1 out of the 5 phases) for some components and final products, where alternatives have not been found to meet performance requirements.

6.6 Links to other Authorisation activities under REACH

This combined AoA/SEA is one of a series of applications for the re-authorisation of the use of chromium trioxide in surface treatments carried out by the A&D industry. This series of Combined AoA/SEAs has adopted a narrower definition of uses original Authorised under the CTAC, CCST and GCCA parent applications for authorisation. Please see the Explanatory Note for further details.

In total, the ADCR will be submitting 11 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-aluminium metallic coatings

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

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

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8 Annex 1: Standards applicable to pre-treatment

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

Table 8-1: Examples of standards applicable to pre-treatment

Standard Reference	Standard Description	Key function
ASTM B117[(a)]	Standard Practice for Operating Salt Spray (Fog) Apparatus	Corrosion resistance
ISO 9227[(b)]	Corrosion tests in artificial atmospheres - Salt spray tests	Corrosion resistance
EN 3665[(c)]	Filiform corrosion resistance test on aluminium alloys	Corrosion resistance test on aluminium alloys
AMS03-2C[(e)]	Cleaning and Preparation of Metal Surfaces	Cleaning of metal surfaces to remove any extraneous or undesirable material
ASTM F2111[(f)]	Standard Practice for Measuring Intergranular Attack or End Grain Pitting on Metals Caused by Aircraft Chemical Processes	Etching solutions/Deoxidisers Intergranular attack (IGA) and end grain pitting on aircraft metals and alloys caused by maintenance or production chemicals
ASTM D3359-22[(g)]	Standard Test Methods for Rating Adhesion by Tape Test	Adhesion

(a) Standard Practice for Operating Salt Spray (Fog) Apparatus (astm.org)
(b) ISO - ISO 9227:2017 - Corrosion tests in artificial atmospheres — Salt spray tests
(c) DIN EN 3665:1997-08 | ASD-STAN
(d) AMS03 2C: Cleaning and Preparation of Metal Surfaces - SAE International
(e) SAE Standards Works
(f) Standard Practice for Measuring Intergranular Attack or End Grain Pitting on Metals Caused by Aircraft Chemical Processes (astm.org)
(g) Standard Test Methods for Rating Adhesion by Tape Test (astm.org)

9 Annex 2: European Aerospace Cluster Partnerships

Table 9-1: European Aerospace Clusters

Cluster Name	Country	City	Number of Companies	Employees	Sales/turnover
ACSTYRIA MOBILITÄTSCLUSTER GMBH	Austria	Styria	80	3000	650 million Euros
Aeriades	France	Grand Est	65	3100	500 million Euros 7% of total French GDP
Aerospace Cluster Sweden	Sweden	Älvängen	50		
AEROSPACE LOMBARDIA	Italy		220	16000	5.4 billion Euros
AEROSPACE VALLEY	France	Toulouse	600	147000	
Aerospace Wales Forum Limited	UK	Wales	180	23000	£6.5 billion
Andalucía Aerospace Cluster	Spain	Andalusia	37	15931	2.5 billion Euros
Aragonian Aerospace Cluster	Spain	Zaragoza	28	1000	
ASTech Paris Region	France	Paris		100000	
Auvergne-Rhône-Alpes Aerospace	France	Rhône-Alpes	350	30000	3.3 billion Euros
AVIASPACE BREMEN e.V.	Germany	Bremen	140	12000	
Aviation Valley	Poland	Rzeszow	177	32000	3 billion Euros
bavAIRia e.V.	Germany	Bavaria	550	61000	
Berlin-Brandenburg Aerospace Allianz e.V.	Germany	Berlin	100	17000	3.5 billion Euros
Czech Aerospace Cluster	Czech Republic	Moravia	53`	6000	400 million Euros
DAC Campania Aerospace District	Italy	Campania	159	12000	1.6 billion Euros
DTA Distretto Tecnologico Aerospaziale s.c.a.r.l	Italy	Apulia	13	6000	78 million Euros
Estonian Aviation Cluster (EAC)	Estonia	Tallinn	19	25000	3% of GDP
Flemish Aerospace Group	Belgium	Flanders	67	3300	1.2 billion Euros
Hamburg Aviation e.V	Germany	Hamburg	300	40000	5.18 billion Euros
HEGAN Basque Aerospace Cluster	Spain	Basque Country	56	4819	954 million Euros
Innovation & Research for Industry	Italy	Emilia Romagna	30	2000	500 million Euros

Table 9-1: European Aerospace Clusters

Cluster Name	Country	City	Number of Companies	Employees	Sales/turnover
International Aviation Services Centre (IASC)Ireland	Ireland	Shannon	60	46000	3.6bn GVA
Invest Northern Ireland	Northern Ireland	Belfast	100	10000	£6.7 billion
LR BW Forum Luft- und Raumfahrt Baden-Württemberg e.V.	Germany	Baden-Wuerttemberg	93	15000	4.8 billion Euros
LRT Kompetenzzentrum Luft- und Raumfahrttechnik Sachsen/Thüringen e.V.	Germany	Dresden	160	12000	1.5 billion Euros
Madrid Cluster Aeroespacial	Spain	Madrid		32000	8 billion Euros
Midlands Aerospace Alliance	UK	Midlands	400	45000	
Netherlands Aerospace Group	Netherlands		89	17000	4.3 billion Euros
Niedercachsen Aviation	Germany	Hanover	250	30000	
Normandie AeroEspace	France	Normandy	100	20000	3 billion Euros
Northwest Aerospace Alliance	UK	Preston	220	14000	£7 billion
OPAIR	Romania			5000	150 million Euros
Portuguese Cluster for Aeronautics, Space and Defence Industries	Portugal	Évora	61	18500	172 million Euros
Safe Cluster	France		450		
Silesian Aviation Cluster	Poland	Silesian	83	20000	
Skywinn - Aerospace Cluster of Wallonia	Belgium	Wallonia	118	7000	1.65 billion euros
Swiss Aerospace Cluster	Switzerland	Zurich	150	190000	16.6 billion CHF 2.5 % of GDP
Torino Piemonte Aerospace	Italy	Turin	85	47274	14 billion euros

10 Annex 3: UK Aerospace sector

10.1 Aerospace

The annual ADS Industry Facts and Figures guide provides an indication of the UK aerospace, defence, security and space sectors' contribution to the economy in 2021, as shown in Figure 10-1. The Aerospace, Defence, Security and Space Group (ADS) notes that it has over 1,100+ member companies (including over 1,000 SMEs), supporting around 1,000,000 jobs (direct and indirect) across the country.

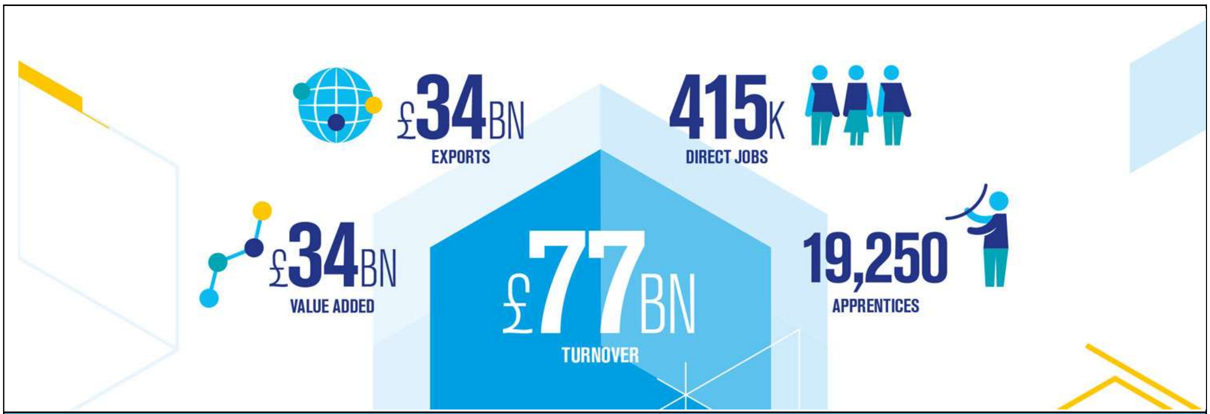

Figure 10-1: Contribution of UK aerospace, defence, security and space sectors to the economy in 2021[106]

The UK aerospace sector is considered by the government to be "hugely important to the UK economy"[107], providing direct employment of over 120,000 highly skilled jobs that pay about 40% above the national average. The sector has an annual turnover of around £77bn, half of which comes from exports to the rest of the world. It is a driver of economic growth and prosperity across the UK, given that most of the jobs (92%) are located outside London and the South East – see Figure 10-1 .

Given the economic importance of the sector, it has been the focus of an Aerospace Sector Deal launched on 6 December 2018) under the UK Industrial Strategy. The deal is aimed at helping industry move towards greater electrification, accelerating progress towards reduced environmental impacts, and has involved significant levels of co-funding by the government (e.g., a co-funded £3.9 billion for strategic research and development activities over the period up to 2026)[108]. 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.

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

[107] BEIS, Aerospace Sector Report, undated.

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

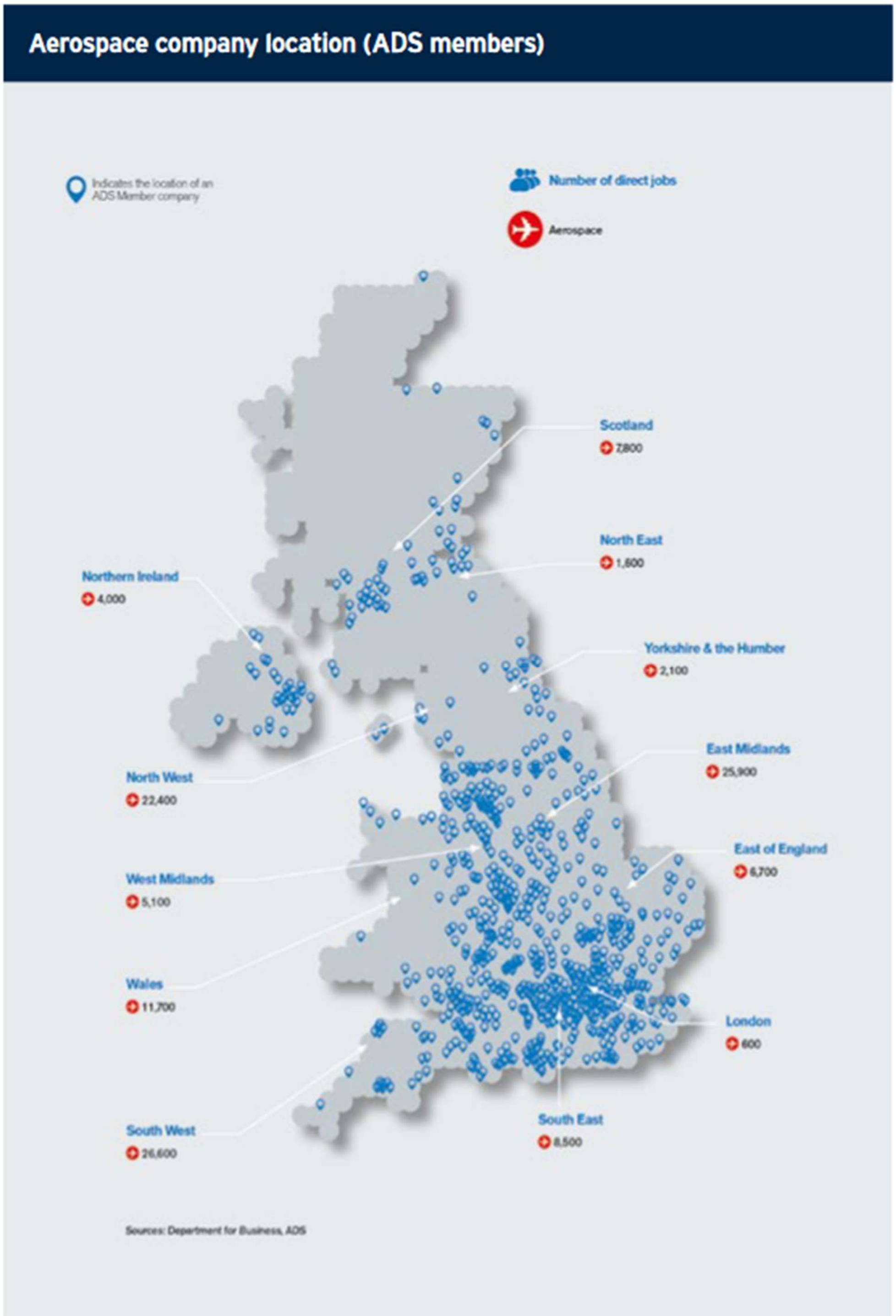

Figure 10-2: Location of aerospace manufacturing sites and associated jobs in the UK[109]

[109] 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 spill overs. These include automotive, marine, oil and gas, nuclear, electronics, composites, metals and other UK industrial sectors. In total, the return on government investment in the sector is estimated as delivering an additional £57 billion of gross value added for the UK aerospace sector and a further £57 billion to the wider UK economy between 2015 and 2035.

10.2 Defence

With respect to defence, the UK is the second largest defence exporter in the world, with its contribution to employment, turnover, and exports illustrated in Figure 10-3[110]. Again, the importance of the sector to UK exports and value added, as well as employment is clear from the figure below.

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

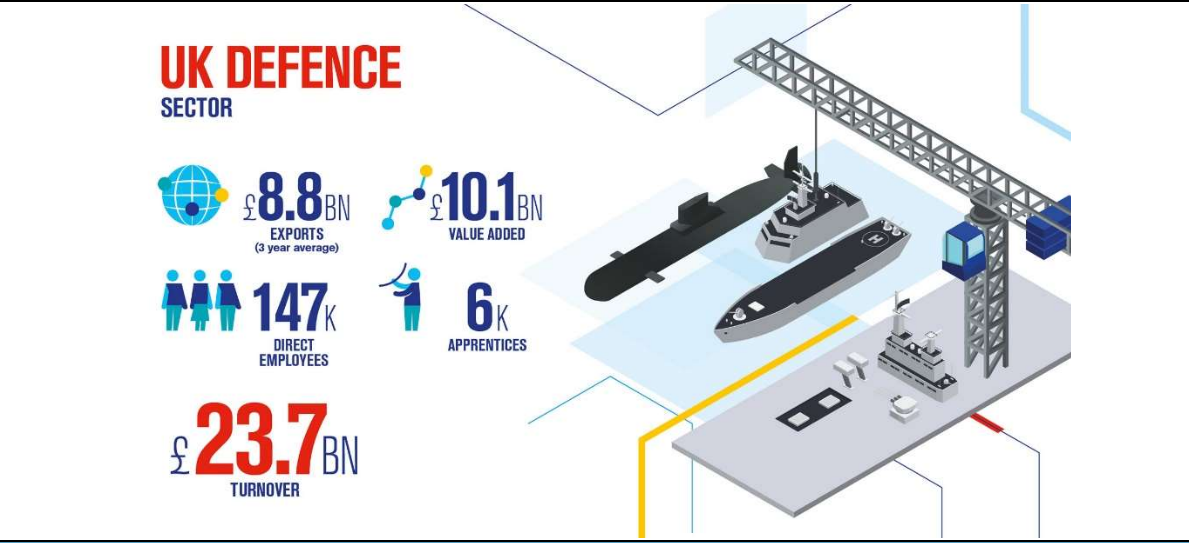

Figure 10-3: UK defence sector contribution to the economy in 2021