ANALYSIS OF ALTERNATIVES

and

SOCIO-ECONOMIC ANALYSIS

Complete version

Legal name of applicant(s):	Boeing Distribution (UK) Inc. MacDermid Performance Solutions UK Ltd
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Note

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

Table of contents

List of tables

List of figures

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 amortisation

ECHA – European Chemicals Agency

EEA – European Economic Area

ESA – European Space Agency

GCCA – Global Chromates Consortium for Authorisation

GDP – Gross domestic product

GOS – Gross operating surplus

GVA – Gross value added

HvE – Human via the Environment

ICAO – International Civil Aviation Organisation

MoD – Ministry of Defence

MRL – Manufacturing readiness level

MRO – Maintenance, Repair, and Overhaul

NADCAP – National Aerospace and Defence Contractors Accreditation Program

NATO – North Atlantic Treaty Organisation

NUS – Non-use scenario

OELV – Occupational Exposure Limit Value

OEM – Original Equipment Manufacturer

RAC – Risk Assessment Committee

REACH – Registration, Evaluation, Authorisation and restriction of Chemicals

RR – Review Report

SC – Sodium chromate

SD – Sodium dichromate

SEA – Socio Economic Analysis

SEAC – Socio Economic Analysis Committee

SME – Small and medium-sized enterprises

SVHC – Substance of Very High Concern

T&E – Testing and Evaluation

TRL – Technology Readiness Level

UK – United Kingdom

WCS – Worker contributing scenario

Glossary

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

Term	Description
Coefficient of friction	Friction is the force resisting the relative motion of solid surfaces sliding against each other. The coefficient of friction is the ratio of the resisting force to the force pressing the surfaces together.
Complex object	Any object made up of more than one article.
Component	Any article regardless of size that is uniquely identified and qualified and is either included in a complex object (e.g., frames, brackets, fasteners and panels), or is a complex object itself (e.g., an assembly or sub-system)
Compound annual growth rate	The mean annual growth rate of an investment over a specified period of time, longer than one year.
Corrosion protection	Means applied to the metal surface to prevent or interrupt chemical reactions (e.g., oxidation) on the surface of the metal component 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 localised permanent deformation, typically by indentation. Hardness may also be used to describe a material’s resistance to deformation due to other actions, such as cutting, abrasion, penetration and scratching.
Heat resilience	The ability of a coating or substrate to withstand repeated cycles of heating and cooling 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.

Term	Description
Layer thickness	The thickness of a layer or coating on a substrate.
Legacy parts	Any part that is already designed, validated, and certified by Airworthiness Authorities or for defence and space, or any part with an approved design in accordance with a defence or space development contract. This includes any part in service.
Material	The lowest level in the system hierarchy. Includes such items as metals, chemicals, and formulations (e.g., paints).
Maintenance, Repair, and Overhaul (MRO)	The service of civilian and/or military in-service products. Term may be used to describe both the activities themselves and the organisation that performs them.
NACE	The Statistical Classification of Economic Activities in the European Community. It is part of the international integrated system of economic classifications, based on classifications of the UN Statistical Commission (UNSTAT), Eurostat as well as national classifications.
NADCAP	National Aerospace and Defence Contractors Accreditation Program, which qualifies suppliers and undertakes ISO audits of their processes.
Net Present Value	Valuation method to value stocks of natural resources. It is obtained by discounting future flows of economic benefits to the present period.
Original Equipment Manufacturer (OEM)	Generally large companies which design, manufacture, assemble and sell engines, aircraft, space, and defence equipment (including spare parts) to the final customer. In addition, an OEM may perform MRO activities.
Part	Any article or complex object.
Pickling	The removal of surface oxides and small amounts of substrate surface by chemical or electrochemical action.
Present Value	The discounted sum of all future debt service at a given rate of interest. If the rate of interest is the contractual rate of the debt, by construction, the present value equals the nominal value, whereas if the rate of interest is the market interest rate, then the present value equals the market value of the debt.
Pre-treatment	Pre-treatment processes are used, prior to a subsequent finishing treatment (e.g., chemical conversion coating, anodising), to remove contaminants (e.g., oil, grease, dust), oxides, scale, and previously applied coatings. The pre-treatment process must also provide chemically active surfaces for the subsequent treatment. Pre-treatment of metallic substrates typically consists of cleaning and/or surface preparation processes.
Producer surplus	Represents the gain to trade a producer receives from the supply of goods or services less the cost of producing the output (i.e., the margin on additional sales).
Proposed candidate	A formulation in development or developed by a formulator as a part of the substitution process for which testing by the design owner is yet to be determined. In the parent applications for authorisation, this was referred to as a ‘potential alternative’.
Qualification	1. Part of the substitution process following Development and preceding Validation to perform screening tests of test candidate(s) before determining if further validation testing is warranted 2. The term qualification is also used during the industrialisation phase to describe the approval of suppliers to carry out suitable processes.
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).

Term	Description
Specification	Document stating formal set of requirements for activities (e.g., procedure document, process specification and test specification), components, or products (e.g., product specification, performance specification and drawing).
Standard	A document issued by an organisation or 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, 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 numerous successes and levels of use have decreased significantly, the specific use of hexavalent chromium compounds in inorganic finish stripping[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 – inorganic finish stripping – 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. 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.

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

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

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

1) *Inorganic finish stripping using chromium trioxide or sodium dichromate in Aerospace and Defence industry and its supply chains.*

The "applied-for-use" of inorganic finish stripping involves the continued use of chromium trioxide or sodium dichromate across the EEA and the UK for a further 12-year review period.

These two chromates were included into Annex XIV of Regulation (EC) No 1907/2006 due to their intrinsic properties (mutagenic, carcinogenic, toxic for reproduction; depending on the chromate). According to Article 62 (4)(d) of this Regulation, the chemical safety report (CSR) supporting an Application for Authorisation (AfA) needs to cover only those risks arising from the intrinsic properties specified in Annex XIV. The carcinogenicity, mutagenicity and reproductive toxicities of CT, its acids, 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 or final product's certification requirements.

Grouping is also appropriate to the analysis of alternatives. The key determinant of functionality is the presence of the Cr(VI) component delivered by the chromate substance. As a result, the 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 inorganic finish stripping due to the fact that different chromates may be used within the same facility.

The potential for double counting is significant given that approximately 90 sites in the EEA and 20 sites in the UK are anticipated as undertaking inorganic finish stripping. This includes sites involved in the production of components and end products, as well as maintenance, repair and overhaul (MRO) services for both civil aviation and military bodies, as well as aeroderivative uses.

It is estimated that these sites consume the following maximum quantities of each of the two chromates of relevance shown in **Table 1-1**, with some sites using more than one chromate in inorganic finish stripping activities. These figures are based on the maximum consumption per site identified from the CSR, Article 66 notifications and the percentage of sites using each of the chromates as identified in responses to the SEA questionnaire and from discussions with formulators and distributors.

Table 1-1: Estimated maximum tonnages used in inorganic finish stripping

	Chromium trioxide	Sodium dichromate
EEA	Up to 50 t/y	Up to 1 t/y
UK	Up to 20 t/y	Up to 1 t/y

1.2 Availability and suitability of alternatives

For the past several decades, ADCR members who are "design owners" [including Original Equipment Manufacturers (OEMs) and Design-to-Build manufacturers (DtBs)] selling products used in civil aviation and military aircraft, ground and sea-based defence systems, and aeroderivatives have been searching for alternatives to the use of the two chromates in inorganic finish stripping as a specific use. At the current time, the remaining use of chromium trioxide and sodium dichromate in inorganic finish stripping is to ensure negligible or no effect on the underlying substrate whilst supporting the efficient removal of the inorganic finish (see also Section 3.1.1). Inorganic finish stripping forms part of an overall system of processes (or "uses"), described by the other AoA-SEA submitted by ADCR.

Inorganic finish stripping is a key use of the chromates by the A&D industry. It is applied to substrates such as aluminium and magnesium alloys to remove anodic and conversion coatings where these are non-conforming or need to be removed as part of MRO work or quality testing. Inorganic finish stripping is also used for the removal of metal coatings, such as copper or cadmium, from steel alloys as part of the main treatment process.

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

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

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

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

As a result of the different requirements outlined above, at the sectoral level, there will be an on-going progression of substitution over the requested 12-year review period, refer to **Figure 1-1**. The potential need for more than 12 years has been identified by multiple OEMs due to the lack of available 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.

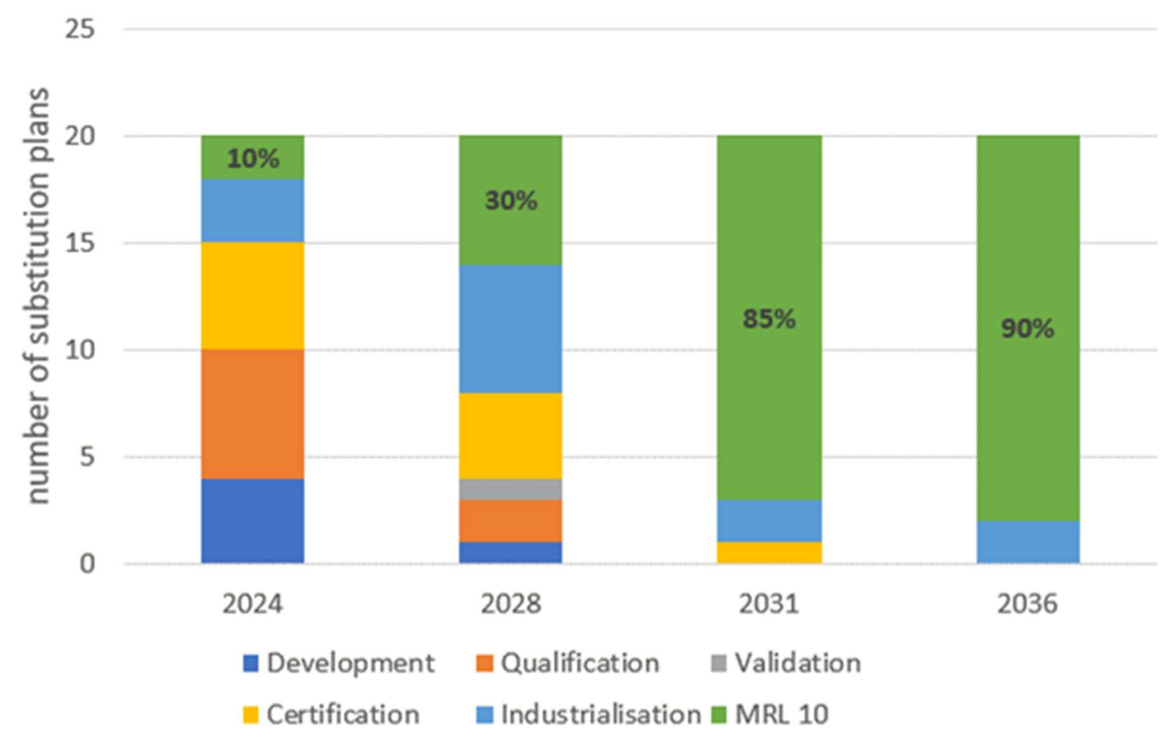

Figure 1-1: Expected progression of substitution plans for the use of Cr(VI) in inorganic finish stripping, by year.

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

***Source:* RPA analysis, ADCR members**

1.3 Socio-economic benefits from continued use

The continued use of the two chromates in inorganic finish stripping 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 aerospace and defence supply chains in the EEA and UK, conferring the wider economic growth and employment benefits that come with this.

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

- Importers of the chromates used in inorganic finish stripping 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 €630 – 4,600 million for the EEA and €80 – 750 million for the UK, over a 2-year period (starting in 2025, PV discounted at 4%). These figures exclude the potential profits that could be gained under the continued use scenario from the global increase in demand for air transport;

- Build-to-Print (BtP) and Design-to-Build (DtB) suppliers would be able to continue their production activities in the EEA/UK and meet the performance requirements of the OEMs. The associated profit losses that would be avoided under the non-use scenario for these companies are calculated at €220 – 370 million for the EEA and €120 – 210 million for the UK over a 2-year period (starting in 2025, PV discounted at 4%);

- MRO companies which provide maintenance and repair services to both civil aviation and/or military forces, would not be forced to move some operations outside the EEA/UK, with the consequent profit losses equating to between €130 – 210 million for the EEA and €17 – 23 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 inorganic finish stripping and linked treatment, manufacturing and assembly activities are estimated at €2.38 billion in the EEA and €0.6 billion in the UK. These benefits are associated with the protection of around 21,400 jobs in the EEA and 7,200 jobs in the UK;

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

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

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

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

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

1.4 Residual risk to human health from continued use

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

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

Risks to workers have been estimated based on the use of exposure monitoring data, supplemented by modelling data as appropriate. Across the 90 EEA sites where chromate-based inorganic finish stripping is anticipated as taking place, an estimated total of 1,890 workers (including 540 incidentally exposed workers) may be exposed to Cr(VI); for the 20 UK sites where inorganic finish stripping takes place, approximately 420 workers may be exposed (including 120 incidentally exposed workers).

Exposures for humans via the environment have been calculated for the local level only. Based on the population density of the different countries within which inorganic finish stripping is considered to take place, an estimated 39,400 people in the EEA and 26,600 people in the UK[4] are calculated as potentially being exposed to Cr(VI) due to chromate-based inorganic finish stripping activities. Again, these figures are conservative due to the on-going substitution of inorganic finish stripping with alternatives.

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

- EEA: 0.31 fatal cancers and 0.08 non-fatal cancers over the 12-year review period, at a total social cost of €457,740

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

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

- UK: 0.08 fatal cancers and 0.02 non-fatal cancers over the 12-year review period at a total social cost of €109,870.

1.5 Comparison of socio-economic benefits and residual risks

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

- EEA: 7,498 to 1 for the lower bound of profit losses and unemployment costs or 16,319 to 1 for the upper bound profit losses and unemployment costs, where economic impacts are assessed over two years and residual risks over 12 years;

- UK: 8,216 to 1 for the lower bound of profit losses and unemployment costs or 12,234 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 inorganic finish stripping, as it only encompasses benefits that could be readily quantified and monetised. The true benefit-cost ratios must be assumed to also encompass:

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

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

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

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

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

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

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

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

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

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

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

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

- **The applicants' downstream users face investment cycles that are demonstrably very long**, with this recognised in various European Commission reports. Final products in the A&D sector can have lives of over 50 years (especially military equipment), with there being examples of contracts to produce components for out-of-production final products extending as long as 35 years. MROs and MoDs 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 a shift away from the need for chromates in inorganic finish stripping, there will remain a stock of in-service aircraft and equipment that will require its use as part of repairs, maintenance and overhaul activities.

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

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

- **The A&D industry has been undertaking R&D into alternatives for the past 30 years**. This includes participation in research initiatives partially funded by the European Commission and national governments. Considerable technical progress has been made in developing, validating, qualifying and certifying components for the use of alternatives, however, it is not technically nor economically feasible for the sector as a whole to have achieved full substitution within a four or seven year period. Although some companies have been able to qualify and certify alternatives for some of their components, others are still in the early phases of testing and development work due to alternatives not providing the same level of performance as Cr(VI). They will not be able to qualify and certify a proposed or a test candidate for some components within a four or seven year time frame. It is also of note that inorganic finish stripping 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 inorganic finish stripping due to mandatory maintenance, repair and overhaul requirements**. MROs must wait for OEMs or MoDs to update Maintenance Manuals with an appropriate approval for each treatment step related to the corresponding components or military hardware. The corresponding timescale for carrying out such updates varies and there can be significant delays while OEMs/MoDs ensure that substitution has been successful in practice. In this respect, **it is important to note that the use of the chromates in inorganic finish stripping is required (and may be required beyond 12 years) to ensure the operational capabilities of the military and the ability to comply with international obligations as partner nations at the EU level and in a wider field, e.g., with NATO.**

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

- As highlighted above and demonstrated in Section 5, **the socio-economic benefits from the continued use of chromium trioxide and sodium dichromate in inorganic finish stripping 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

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

products which it can only serve if it retains its current strong industrial and supply chain base in the EEA and UK. It will not be able to respond to this increased market demand if the continued use of the two chromates in inorganic finish stripping is not authorised while work developing, qualifying, and certifying alternatives continues.

- 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 Aerospace and Defence Chromates Reauthorisation Consortium

This combined AoA/SEA is based on a grouping approach and covers all the soluble chromates relevant for use in inorganic finish stripping by the ADCR consortium members and companies in their supply chains. The primary function of inorganic finish stripping is removal of surface finishing from a substrate, whilst the key function of Cr(VI) is to ensure negligible or no effect on the underlying substrate whilst supporting efficient removal of the inorganic finish. This is required as part of maintenance, repair, and overhaul (MRO) activities, processes to rework new components where the quality of the surface treatment is deemed inadequate, as well as removal of metallic coatings as part of a main treatment.

The use of the chromates in inorganic finish stripping is limited to those situations where it plays a critical (and currently irreplaceable) role in meeting product performance, reliability, and safety standards, particularly those relating to airworthiness set by European Aviation Safety Agency (EASA). This is also true with respect to the use of inorganic finish stripping 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 must comply with numerous comparable requirements, including those of the European Space Agency (ESA) and of national MoDs.

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

As a result, the analysis presented here is based on an extensive programme of work; funded and carried out by the 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 38 of those sites known to use Cr(VI) for inorganic finish stripping 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. Where important, information is separated out for the EEA and UK, so that authorities in both jurisdictions have a clear view of impacts.

2.1.2 Aims of the combined AoA and SEA document

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

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

- The technical and economic feasibility, availability, and airworthiness (i.e., safety) challenges in identifying an acceptable alternative to the use of the chromates, which does not compromise the functionality and reliability of the components treated with inorganic finish stripping and which could be validated by OEMs and gain certification/approval by the relevant aviation and military authorities across the globe.
- The R&D that has been carried out by the OEMs, DtBs and their suppliers towards the identification of feasible and suitable alternatives for the chromates in inorganic finish stripping. These research efforts include EU funded projects and initiatives carried out at a more global level, given the need for global solutions to be implemented within the major OEMs supply chains.
- The efforts currently in place to progress proposed candidate alternatives through Technology Readiness Levels (TRLs), Manufacturing Readiness Levels (MRLs) and final validation/certification of suppliers to enable final implementation. This includes treatment of components for civilian and military aircraft and defence equipment that continue to be produced, as well as for maintenance, repair and overhaul of those products and out-of-production civilian and military aircraft and other defence systems.
- The socio-economic impacts that would arise for ADCR downstream users and their suppliers, their upstream and downstream supply chains and, crucially, for the EEA and UK more generally, if the applicants were not granted re-authorisations for the continued use of the chromates over an appropriately long review period.
- The overall balance of the benefits of continued use of the chromates and risks to human health from the carcinogenic and reprotoxic effects that may result from exposures to the chromates.

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

2.2 The parent applications for authorisation

This combined AoA and SEA covers the use of the following Cr(VI) compounds for inorganic finish stripping:

• 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) was included in Annex XIV of REACH (Entry No. 16) due to its carcinogenic (Cat. 1A) and mutagenic (Cat. 1B) properties. As CT is mainly used as an aqueous solution in inorganic finish stripping, 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 a reproductive toxicant (Cat. 1B).

These two chromates were previously granted authorisations for use in inorganic finish stripping 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	Use name
0032-04 REACH/20/18/14, REACH/20/18/16, REACH/20/18/18	Chromium trioxide	1333-82-0	215-607-8	Various applicants (CTAC consortium)	Surface treatment for applications in the aeronautics and aerospace industries, unrelated to functional chrome plating or functional chrome plating with decorative character
0032-05 REACH/20/18/21, REACH/20/18/23, REACH/20/18/25	Chromium trioxide	1333-82-0	215-607-8	Various applicants (CTAC consortium)	Surface treatment (except passivation of tin-plated steel (ETP)) for applications in various industry sectors namely architectural, automotive, metal manufacturing and finishing, and general engineering (unrelated to Functional chrome plating or Functional chrome plating with decorative character)
0043-2 REACH/20/5/3, REACH/20/5/4, REACH/20/5/5 24UKREACH/20/5/3	Sodium dichromate	10588-01-9	234-190-3	Various applicants (CCST consortium)	Use of Sodium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites and sealings of anodic films

2.3 Scope of the analysis

2.3.1 Brief overview of uses

2.3.1.1 Process description

Stripping is the removal of a surface finishing from a substrate. Inorganic finish stripping with CT or SD is required to remove the finish as part of maintenance, repair and overhaul (MRO) work, or for rework, when surface finishes are nonconforming or were removed for quality testing. Further, it can be used as part of a main treatment to remove plating (copper) used to mask new components in the carburising process.

The surface layers produced by anodising (aluminium substrate), chemical conversion coating (e.g., aluminium, magnesium, or brass substrate), and passivation of non-aluminium metallic coatings (steel or stainless steel substrate with e.g., cadmium or copper coating), according to ADCR definition, can be removed by inorganic finish stripping with Cr(VI). During this process, the main treatment layer (together with the post-treatment layer, if present, or, in case of passivation of non-aluminium metallic coatings, in combination with the metallic coating below the passivation layer) is removed by inorganic finish stripping. In case a Cr(VI) primer is applied as a post-treatment to components treated with passivation of non-aluminium metallic coatings, the primer is typically first removed by blasting before the underlying layers are removed by inorganic finish stripping.

The composition and therefore also the Cr(VI) concentration of the stripping solution may be different depending on the finish and the substrate or coating to be stripped. The required process temperature of the stripping bath and the immersion duration may also depend on the prevailing surface treatment.

During chemical stripping, the inorganic finish is removed, with negligible or no effect on the underlying substrate. Where the finish is stripped for MRO work, for rework or when surface finishes are nonconforming, the finish is reapplied to the component, together with all relevant pre- or post-treatments.

Inorganic finish stripping is a chemical, non-electrolytic process that is carried out by immersion of components in treatment baths (see **Figure 2-1**). Typically, the treatment baths for inorganic finish stripping are positioned in a large hall where baths for other immersion processes are also present; some of these other baths can also contain Cr(VI) although their use may be unrelated to inorganic finish stripping. The immersion tanks can be placed individually or within a line of several immersion tanks. Usually, at least one drag-out and/or rinsing tank with water is positioned after an immersion tank, for washing off the stripping solution from the component(s).

Figure 2-1: Treatment baths for inorganic finish stripping

Substrate(s)

A variety of surface finishes (e.g., anodising on aluminium substrate, chemical conversion coating on aluminium or magnesium substrates. and passivated cadmium or copper coatings on steel or stainless steel substrates) can be removed by inorganic finish stripping. Also, metallic coatings (e.g., cadmium, copper) can be stripped off by inorganic finish stripping.

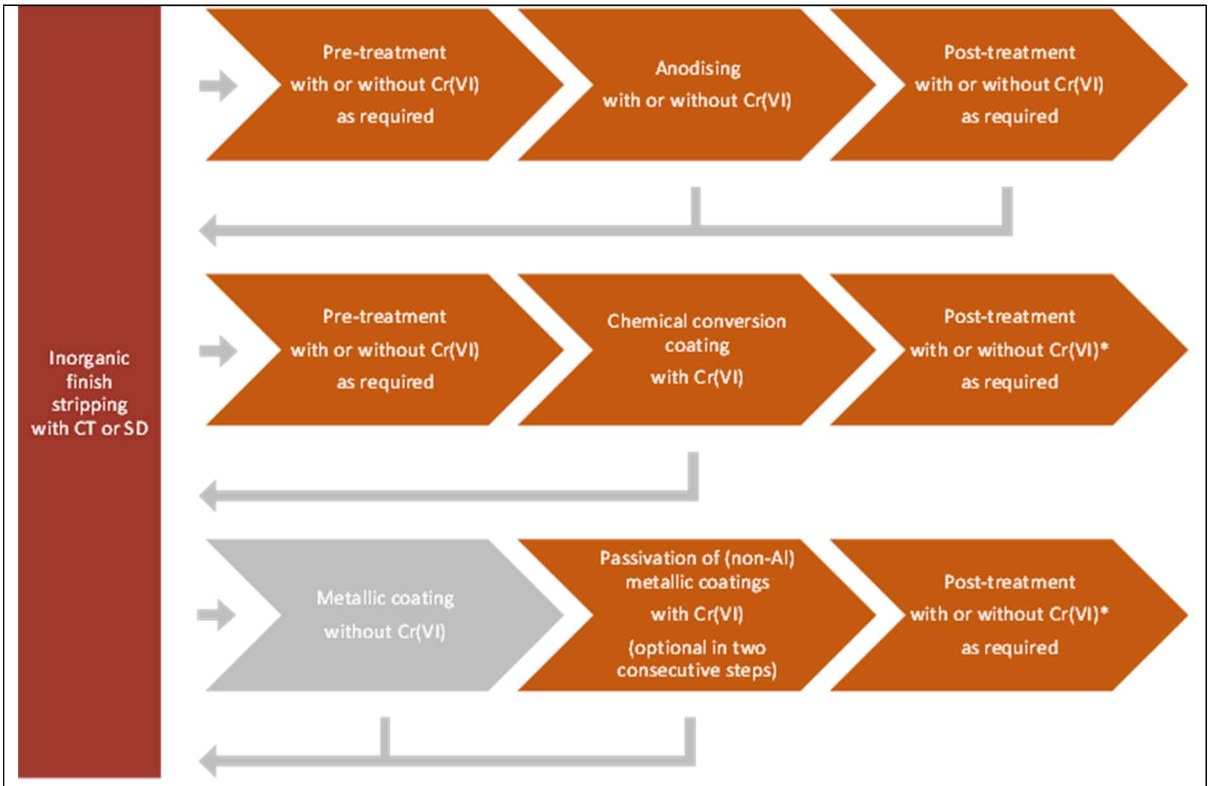
Differences between chromates

Either chromium trioxide (CT) or sodium dichromate (SD) can be used for inorganic finish stripping in the aerospace and defence industry and its supply chains. The two chromates do not differ in terms of functionality for this use. The reason either one or the other is used is, in most cases, due to that particular chromate being defined in the customer specifications for a particular component and/or application; such a customer specification often has a historical or empirical background.

When no specification is given by a client, the choice of the chromate 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 two products is preferred.

Relationship to other uses

Inorganic finish stripping with CT or SD is used to remove a surface finishing from a substrate. The surface layers produced by anodising, chemical conversion coating, and passivation of non-aluminium metallic coatings according to ADCR definition can be removed with inorganic finish stripping. For the combination with chemical conversion coating, anodising or passivation of non-aluminium metallic coatings all details on these processes are described in the combined AoA/SEA for chemical conversion coating (see ADCR dossier "Chemical conversion coating"), anodising (see ADCR dossier "Anodising"), and passivation of non-aluminium metallic coatings (see ADCR dossier "Passivation of non-aluminium metallic coatings") respectively.



* May include primer application with Cr(VI), which is not concerned by this Review Report

Figure 2-2: Schematic presentation of treatment steps

2.3.2 Temporal scope

Due to the lack of qualified and viable alternatives for the use of the chromates in inorganic finish stripping for A&D components, it is anticipated that it will take a further 12 years or more to develop, qualify, certify, and industrialise alternatives across all 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	12 years	Based on the length of requested review period
	Impacts on growth and GDP	12 years	Based on the length of requested review period
	Disruption to EU society due to impacts on civil, emergency and military aviation, as well as defence equipment	12 years	Based on the length of requested review period
	Loss of employment	1 to over 3 years	Average period of unemployment in the EEA (Dubourg, 2016)

2.3.3 The supply chain and its geographic scope

2.3.3.1 The ADCR Consortium

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

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

With respect to finish stripping:

- Of the 24 larger ADCR members, 13 support the use of chromium trioxide and sodium dichromate for inorganic finish stripping in the EU; this includes for their own use as well as for use by their suppliers; and

- Of the 24 larger ADCR members, six support the UK use of chromium trioxide and sodium dichromate for inorganic finish stripping; including the use by their suppliers.

2.3.3.2 Suppliers of chromate substances and mixtures

For inorganic finish stripping, two generic chromate products have been identified, as listed in **Table 2–3**. As can be seen, the chromates are purchased as pure substances in solid form.

Table 2–3: Products used in inorganic finish stripping

Product Type A	Solid chromium trioxide (flakes), pure substance (100%)
Product Type B	Solid sodium dichromate (powder), pure substance (100%)

The chromates are not manufactured within the EEA or UK, with all uses reliant on imports of the substance. Following import, CT and SD products are delivered to downstream users either directly or via distributors. Some distributors operate across many EEA countries while others operate nationally.

2.3.3.3 Downstream users of chromates for inorganic finish stripping

Inorganic finish stripping within the aerospace sector is performed exclusively in industrial settings and is carried out by actors across all levels in the supply chain:

- Original equipment manufacturer (OEM) – generally large companies which design, manufacture, assemble and sell engines, aircraft, space, and defence equipment to the final customer;
- Design-to-Build[7] (DtB) manufacturers – companies which design and build components;
- Build-to-Print (BtP) manufacturers – companies that undertake specific processes, dictated by their customers, involving use of chromates on components; and
- Maintenance, Repair and Overhaul (MRO) – companies or military sites that service civilian and military in-service products.

Commercial aircraft, helicopter, spacecraft, satellite, and defence manufacturers are some of the actors involved in the supply chain, and in the use of the chromates for inorganic finish stripping of critical components essential to the manufacturing of their final products.

It is also important to note that companies may fit into more than one of the above categories, acting as an OEM, DtB, and MRO,[8] where they service the components they designed and manufactured, and which are already in use. Similarly, a company may fall into different categories depending on the customer and the component/final product.

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.

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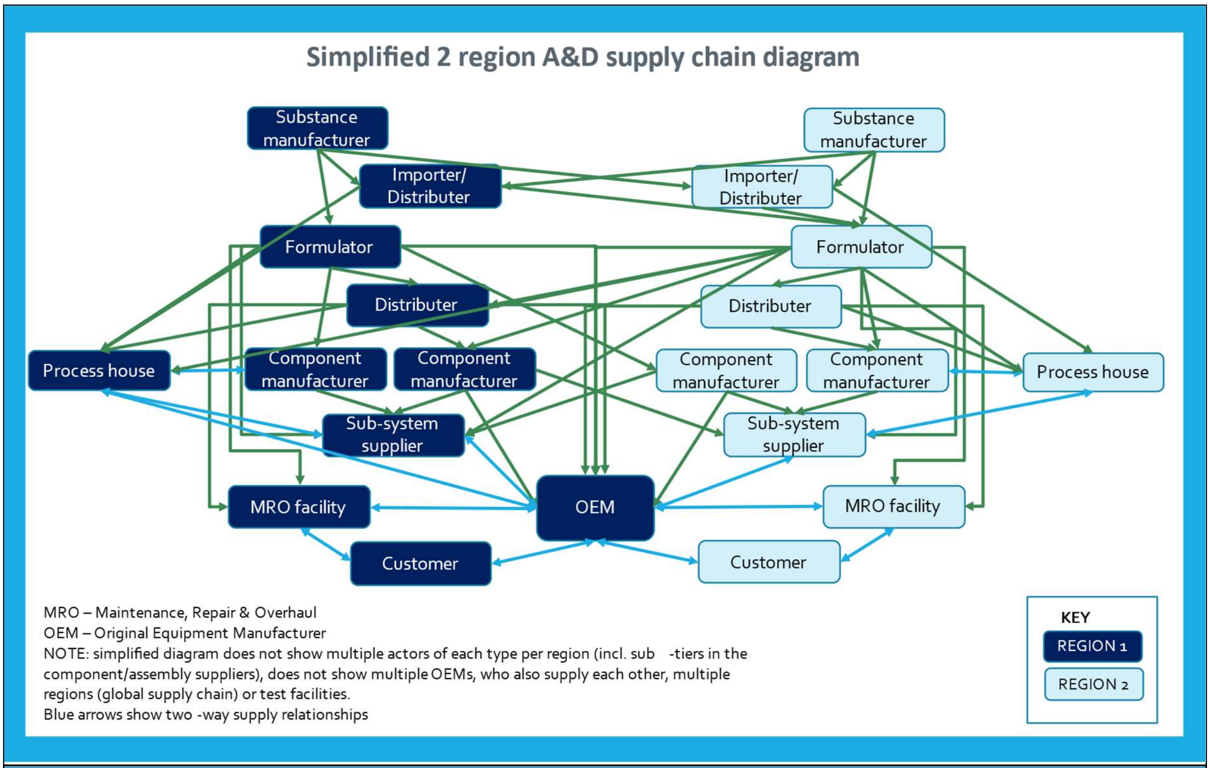
[7] Also referred to as “design and make” or “design responsible” suppliers.

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



MRO – Maintenance, Repair & Overhaul
OEM – Original Equipment Manufacturer
NOTE: simplified diagram does not show multiple actors of each type per region (incl. sub -tiers in the component/assembly suppliers), does not show multiple OEMs, who also supply each other, multiple regions (global supply chain) or test facilities.
Blue arrows show two -way supply relationships

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

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

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

Table 2-4: Numbers of companies providing SEA information on inorganic finish stripping

Role	Number of companies	Number of sites
OEMs	5	11
Design-to-Build	5	5
Build-to-Print	9	11
MRO mainly (civilian and/or military)	6	11
Total	**25**	**38**

2.3.3.4 OEMs, DtB and BtP Manufacturers

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

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

DtB manufacturers develop in-house designs to meet the performance requirements of their customers, and therefore will also act as design owners. These suppliers may have more control over the substances that they use in manufacturing their components but must still ensure that they achieve the strict performance requirements set by OEMs or their customers. They may carry out research into alternatives and/or 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 substances to be used in inorganic finish stripping to meet the requirements set by their customers. The components are then used by DtBs or OEMs in the final production of A&D equipment. These suppliers have no choice in the substances and formulations that they are required to use within their processes. They therefore carry out no research into alternatives (although they may act as test facilities for their customers).

Both DtB and BtP suppliers may undertake inorganic finish stripping using dip/immersion methods. Both types of suppliers tend to be located relatively close to their customers, which sometimes results in the development of clusters across the EEA and within the UK.

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

2.3.3.5 Maintenance, repair and overhaul (MRO)

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. These activities include chromate-based inorganic finish stripping.

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

Figure 2-5 provides an overview of the life cycle of weapon systems, which are usually used for 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.

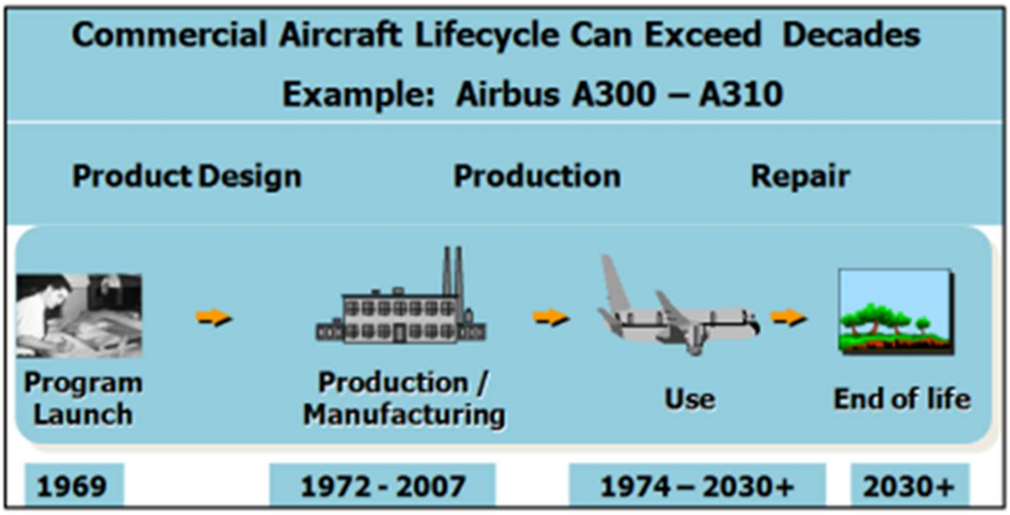


Figure 2-4: Commercial aircraft service life, from ECHA & EASA (2014)[9]

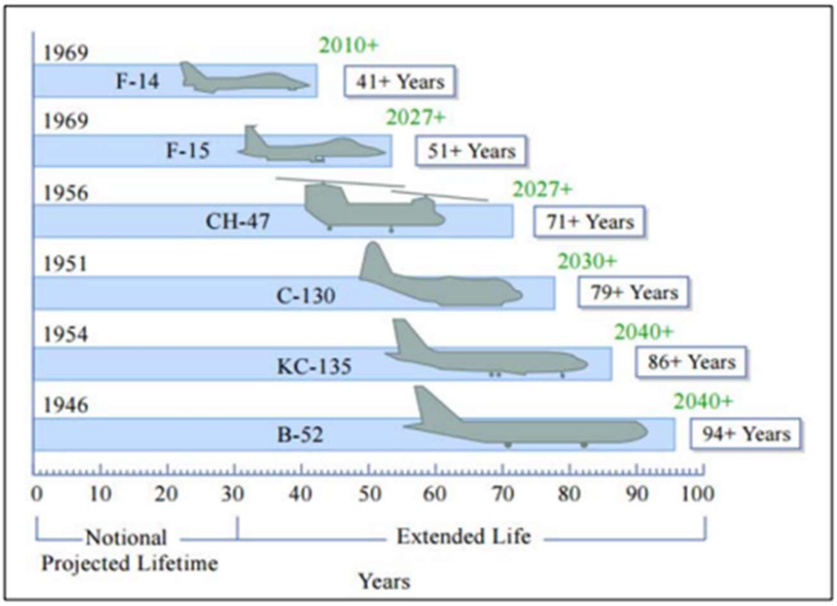


Figure 2-5: Life cycles of defence aircraft, from A Haggerty (2004)[10]

Even if new designs/components – coming onto the market in the short to medium term – might succeed in dispensing with the use of Cr(VI)-based inorganic finish stripping, products already placed on the market still need to be maintained and repaired using Cr(VI)-based inorganic finish stripping

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

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

until suitable alternatives are validated and certified for use in MRO for those existing products. Maintenance manuals for such existing products (which the user is legally obliged to comply with) detail, amongst other information, the processes and materials initially qualified (sometimes decades ago) and required to be used, which form a substantial portion of the type certification or defence approval.

As a result, MROs (and MoDs) face on-going requirements to undertake inorganic finish stripping, using dip/immersion methods in strict adherence to the requirements of qualified repair and maintenance schemes to ensure continued safe operation of the A&D final products.

It is important to note that there will be an overlap between those companies undertaking work exclusively as MROs and those 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 OEMs, each of these companies has, on average, around 10 approved suppliers and/or their own sites involved in the provision of inorganic finish stripping. However, one of these OEMs is UK focused and has therefore been excluded. This would suggest that there could be up to 100 (= 10 x 10) sites involved in inorganic finish stripping across the EU.

Given that some sites will provide services to more than one OEM, the estimated number of EU sites has been taken as 90.

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 382 notifications relating to the REACH Authorisations listed above covering 508 sites across the EU-27 (and Norway). The distribution of notifications by substance and authorisation is summarised in **Table 2-5**.

There are more sites than notifications, reflecting the fact that some notifications cover more than one site[11]. However, several of the authorisations cover 'surface treatment', which covers more treatments than just inorganic finish stripping. As such, the number of sites undertaking inorganic finish stripping will be far fewer than indicated by Article 66 data. Furthermore, some sites will have notified ECHA that they use both chromates for inorganic finish stripping, reducing the figure even further.

With these points in mind, the estimated 90 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. This number of sites reflects the fact not all the original CTAC applicants are supporting the ADCR, with this expected to lead to some changes in the number of customers being supplied the chromates by ADCR applicants. In addition, the figure of 90 sites takes into account the fact that some of the A&D sector will be covered by the non-ADCR applicants. Use of sodium dichromate by the aerospace and defence industry under parent Authorisations which are not being renewed may shift to those covered by this RR, and figures associated with them are included here for completeness.

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[11] Article 66 reporting is by legal entity, which can have multiple sites using a chromate for inorganic finish stripping. 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.

Note that Authorisations 20/18/21-25 relate to aeroderivative uses of chromium trioxide for surface treatment, but these uses will occur at the same sites as notifying for A&D uses and would therefore result in double-counting.

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

Table 2-5: 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	20/18/14-20	Surface Treatment for aerospace	263	357
Sodium dichromate	20/5/3-5	Surface Treatment for aerospace	61	84
	20/4/1	Surface Treatment for aerospace	58	67
		Totals	**382**	**508**

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
Use of sodium dichromate by the aerospace and defence industry under parent Authorisations, which are not being renewed may shift to those covered by this RR, and figures associated with them are included here for completeness.

2.3.3.7 Geographic distribution

The distribution of the sites notified to ECHA is summarised in **Table 2-6**. This percentage distribution is adopted for the later analysis carried out as part of the SEA. There is no comparable publicly available data for the UK.

Table 2-6: Number of authorised sites using chromium trioxide or sodium dichromate notified to ECHA as of 31 December 2021

Country	**% Total**
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	

Number of sites relates to specific authorisations listed in the previous table.

2.3.3.8 Customers

The final actors within this value chain are customers of A&D final products that have had coatings removed with inorganic finish stripping.

With respect to civil aviation, the global air transport sector employs over 10 million people to deliver some 120,000 flights and 12 million passengers a day, in a normal year. In 2017, airlines worldwide carried around 4.1 billion passengers. They transported 56 million tonnes of freight on 37 million commercial flights. Every day, aeroplanes transport over 10 million passengers and around US$ 18 billion (€16 billion, £14 billion) worth of goods. Across the wider supply chain, assessments of subsequent impacts and jobs in tourism made possible by air transport, show that at least 65.5 million jobs and 3.6% of global economic activity are supported by the industry[12]. More specifically to Europe, in 2019 over one billion passengers travelled by air in the European Union, with net profits of over US$ 6.5 billion (€5.8 billion, £5.1 billion).[13] 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.[14] 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 inorganic finish stripping, including naval systems, ground based radars, ground vehicles etc.

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

2.4 Consultation

2.4.1 Overview

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

- Consultation with the applicants to gather Article 66 downstream user notification data, and information on volumes placed on the market and numbers of customers.
- 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.

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

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

[14] *Source:* Eurostat (gov_10a_exp)

2.4.2 Consultation with applicants

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

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

2.4.3 Consultation with downstream users

2.4.3.1 ADCR Consortium members

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

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

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

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

4) Phase 4 collected information for the SEA component of this document, with this including:
    a. Base data on the economic characteristics of different companies
    b. Additional information on volumes used of the chromates and for what processes, and trends in this usage over the past 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. Separate questionnaires were provided for BtP and DtB suppliers given their different roles within the supply chain and the potentially greater flexibility for DtB suppliers to move to alternatives certified for the manufacture of their components and products as part of their own design activities.

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

As a final count, data for 38 sites operated by the OEMs and their BtP and DtB suppliers provided responses to these questionnaires. The information provided by the companies forms the basis for the SEA components of this document.

2.4.3.3 Maintenance, repair, and overhaul suppliers and MoDs

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

3 Analysis of Alternatives

3.1 SVHC use applied for

3.1.1 Substance ID and overview of the key functions and usage

The definition of inorganic finish stripping, as agreed by ADCR members, is:

> *“The removal of inorganic coatings from the surface of a substrate”*

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

3.1.1.1 Process steps and overview of key functions

To protect, or improve the performance of, the metallic substrate, there are a number of different inorganic coatings that may be applied to the surface of a component. Examples include anodic layers, conversion coatings, enamelling, and metallic coatings. These coatings are produced by a chemical reaction that transforms the surface layer of the substrate into a metallic oxide film or compound, or by electrochemical plating processes in which a metallic deposit is left on the surface of the substrate. The inorganic coating has a wide range of potential functions, such as: corrosion resistance, adhesion promotion, improved wear resistance, and increased hardness. Inorganic coatings can also be used as a maskant to protect sensitive substrates, or areas of a component which are to remain untreated. For example, before undergoing thermo-chemical treatments such as carburising, nitriding and nitrocarburising[15], copper plate is used as a diffusion barrier to mask areas of the substrate where the thermal treatment should not be applied.

Though inorganic coatings are applied for specific purposes, it is essential that the finish can also be removed. The removal of a coating or surface finish from a substrate is known as stripping. The stripping of anodised layers, conversion coatings or hard chrome plating with chromium trioxide or sodium dichromate-based solutions may be used as a surface pre-treatment step to remove the finish as part of MRO work, or for rework, when surface finishes are non-confirming or must be removed for quality testing. Stripping using chromium trioxide can also be used as the main treatment to remove copper plating after the thermo-chemical treatment process, as described above. For any of the stripping processes described to be successful, the surface of the underlying substrate must not be adversely affected or degraded by the agent removing the inorganic coating.

Cr(VI)-based stripping solutions are used on a wide variety of substrates and coatings without any change in the stripping process, whereas any alternative stripping solution identified requires process

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[15] If required, additional information relating to these processes is available at the following source: Principles of Nitriding and Nitrocarburising tcm410-114390.pdf (boconline.co.uk).

adaptation to the substrate and type of coating being removed. Among the substrate-coating combinations identified are:

- Anodised layers on alloys of aluminium or magnesium;
- Copper or cadmium plating on steel;
- Conversion coatings on alloys of aluminium, magnesium or steel; and
- Hard chrome plating on aluminium alloys.

The key function of the chromates in inorganic finish stripping is:

- To ensure negligible or no effect on the underlying substrate whilst supporting the efficient removal of the inorganic finish.

In the stripping solutions currently used, the chromate is combined with an inorganic acid, and in the removal of anodic layers or conversion coatings it is this acid that plays the principal role in removing the inorganic finish. Whilst the chromate can also contribute to this function, the key reason for its inclusion is to mitigate excessive attack on the substrate by the co-formulants, and to provide some level of protection to the surface of the substrate after the coating has been removed and prior to application of subsequent layers. In the removal of metallic coatings, such as copper, cadmium or hard chrome plating, the Cr(VI) plays a key role in dissolving the inorganic finish, as well as in protecting the surface of the substrate. Cr(VI) is unique in being able to contribute to both of these functions, as it creates an oxidising acidic solution that can remove the metal coating whilst also passivating the substrate and protecting its surface during the process.

In the case of stripping anodic layers and conversion coatings from aluminium alloys, a mixture of chromic acid and phosphoric acid is used to dissolve the aluminium oxide layer. The principal function of the chromate is to rapidly passivate the exposed substrate surface. This passivation process creates a new thin layer of aluminium oxide on the substrate to discourage further dissolution inhibiting material loss, preventing corrosion prior to reprocessing, and preserving residual stress, surface roughness, and fatigue properties of the substrate. Whilst the aluminium is being oxidised, the Cr(VI) is simultaneously reduced to Cr(III) creating a protective layer of chromate anions, absorbed in the pores of the aluminium oxide layer. This reaction is shown in the equations below (adapted from CTAC, 2015):

(1) $2\ Al \rightarrow 2\ Al^{3+} + 6e^-$
(2) $2\ Al^{3+} + 3\ H_2O \rightarrow Al_2O_3 + 6\ H+$
(3) $Cr_2O_7^{2-} + 14\ H^+ + 6e^- \rightarrow 2\ Cr^{3+} + 7\ H_2O$

In the stripping of copper, hexavalent chromium ions in solution with sulphuric acid oxidise copper into a water-soluble cation. As a result of this oxidation, Cr(VI) is reduced to Cr(III). Sludge produced by the process contains Cr^{6+} and copper hydroxide waste that needs to be treated.

$$3Cu + Cr_2O_7^{2-} + 14H^+ \rightarrow 3Cu^{2+} + 2Cr^{3+} + 7H_2O$$

$$3Cu^0 + 2Cr^{6+} \rightarrow 3Cu^{2+} + 2Cr^{3+}$$

By oxidising the Cu(0) of the electrodeposited layer to Cu(II), which can be removed by the inorganic acid present in the mixture, Cr(VI) plays a key role in the stripping function. Additionally, Cr(VI) performs a protective role, reducing to Cr(III) and protecting the surface of the substrate to stop excessive base material corrosion and substrate etching.

Cr(VI) solutions efficiently remove copper plating from steel without harming the underlying metal or nearby areas of carburised steel. Carburised steel components are susceptible to hydrogen embrittlement but stripping with a Cr(VI)-solution, and the protection of the metal surface described above, minimises this risk, limiting hydrogen formation arising from the reaction between the mineral acid and base metal.

3.1.1.2 Usage

Components that may be treated with the Annex XIV substance

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

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

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

Source: (GCCA, 2017)

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

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

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

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

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

Service life and maintenance intervals of components

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

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

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

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

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

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

3.1.2.1 Introduction

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

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

- High utilisation rate (around 16 hours per day for commercial aircraft, whilst critical defence systems must operate continuously for extended periods);
- Environmental and service temperatures ranging from below minus 55°C at cruising altitude to in excess of plus 200°C (Depending on substrate and location on final product);
- Wide ranging and varying humidity and pressure;
- High and varying loads;
- Fatigue resistance under varying modes of stress;

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

- Corrosive and abrasive environments (e.g., salt water and vapour, sand and grit, and exposure to harsh fluids such as cleaning solutions, de-icer, fuels, lubricants, and hydraulic fluids at in-service temperatures); and
- Maintained performance in the possible case of a lightning, bird, or other foreign object strike.

Successful, reliable, and safe performance against these parameters is the result of decades of experience and research, and a high level of confidence in the systems currently employed to provide corrosion and wear resistance. Years of performance data, as well as thorough reviews following any incidents, have resulted in improvements to the designs, manufacturing or maintenance processes employed in the industry. Such a level of confidence in the performance of Cr(VI) is essential as the treatments on some A&D components cannot be inspected, repaired, or replaced during the life of the A&D system. An inadequately performing surface treatment allows corrosion pits to form. These can turn into fatigue cracks, which potentially endanger the final product.

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

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

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

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

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

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

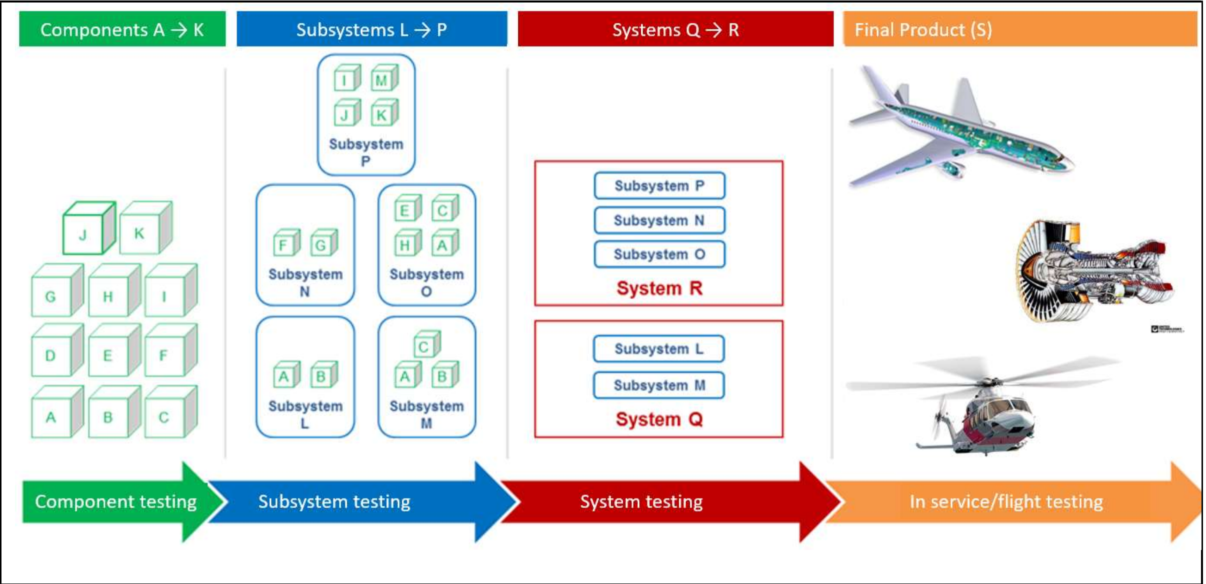


Figure 3-1: Assessment requirements in the implementation of alternatives
Source: Adapted from GCCA white paper

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

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

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

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

TRL	Definition	Description

Source: U.S. Department of Defence, April 2011, https://www.ncbi.nlm.nih.gov/books/NBK201356/

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

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

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

MRL	Definition	Description
1	Basic Manufacturing Implications Identified	Basic research expands scientific principles that may have manufacturing implications. The focus is on a high-level assessment of manufacturing opportunities. The research is unfettered.
2	Manufacturing Concepts Identified	This level is characterized by describing the application of new manufacturing concepts. Applied research translates basic research into solutions for broadly defined military needs.
3	Manufacturing Proof of Concept Developed	This level begins the validation of the manufacturing concepts through analytical or laboratory experiments. Experimental hardware models have been developed in a laboratory environment that may possess limited functionality.
4	Capability to produce the technology in a laboratory environment	This level of readiness acts as an exit criterion for the MSA Phase approaching a Milestone A decision. Technologies should have matured to at least TRL 4. This level indicates that the technologies are ready for the Technology Development Phase of acquisition. Producibility assessments of design concepts have been completed. Key design performance parameters have been identified as well as any special tooling, facilities, material handling and skills required.
5	Capability to produce prototype components in a production relevant environment	Mfg. strategy refined and integrated with Risk Management Plan. Identification of enabling/critical technologies and components is complete. Prototype materials, tooling, and test equipment, as well as personnel skills have been demonstrated on components in a production-relevant environment, but many manufacturing processes and procedures are still in development.

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

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

Source: *Manufacturing Readiness Level (MRL) - AcqNotes*

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

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

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

3.1.2.2 Process, requirements and timeframe

Identification & Assessment of need for substitution

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

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

<u>Definition of requirements</u>

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.

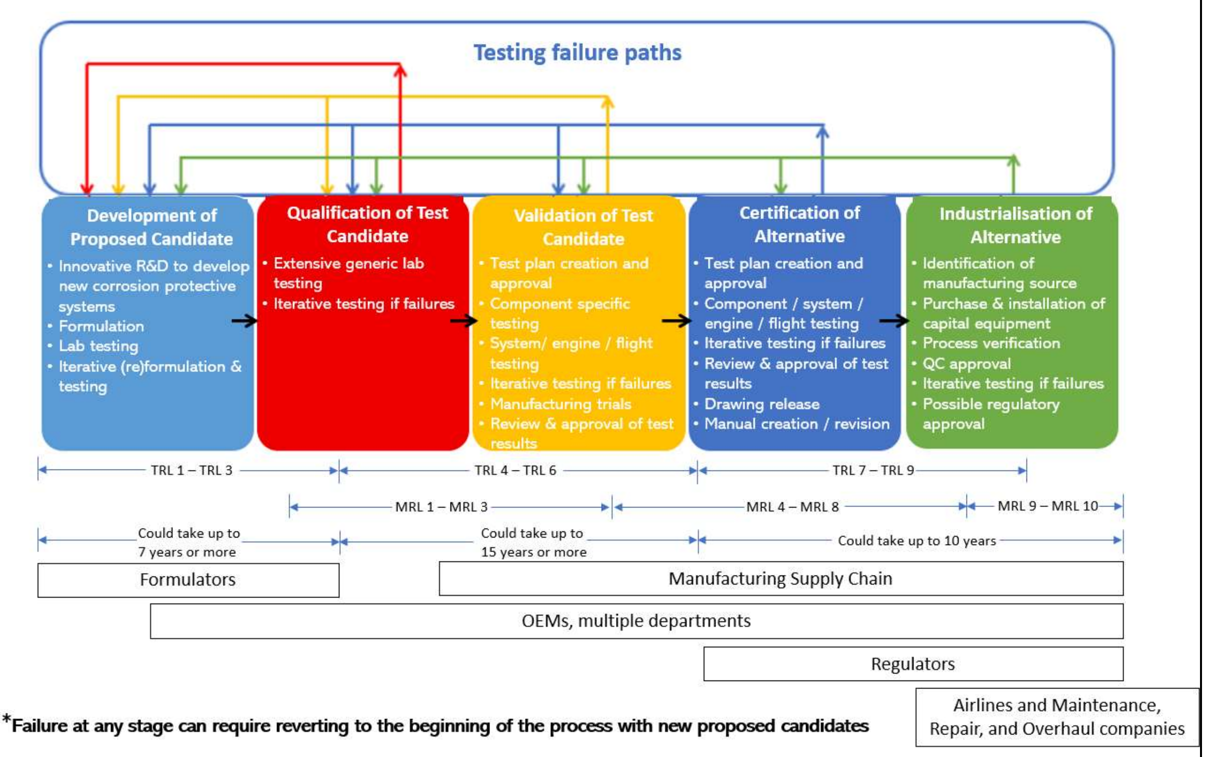
Development of initial requirements can take at least six months, although requirements may be added and continue to be refined during the different levels of maturity, based on learnings from the various testing/qualification stages.

<u>Key phases of the substitution process</u>

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

Each stage in the process comprises various steps including extensive laboratory testing programmes and, in some situations, in service/flight testing. Each step therefore requires flexibility in the time to be completed, typically taking years overall. It should be noted that there can be **failures at any stage**

in this process, and failures may not reveal themselves until a large amount of testing, taking considerable time and incurring significant expense, has already been carried out. Such failures result in the need to return to earlier steps in the process and repeat the extensive testing and associated activities leading to industrialisation. The later in the process these failures occur, the greater the impact will be on schedule and cost.



*Failure at any stage can require reverting to the beginning of the process with new proposed candidates

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

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

Development of proposed candidates

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

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

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

Formulators 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 candidates. It is important to note that many iterations of these formulas are rejected in the formulator's laboratory and do not proceed to evaluation by the design owner. Formulators estimate that it typically takes two to five years of testing potential formulations before a proposed candidate is identified for submittal to the design owner[18].

Qualification of test candidate

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

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

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

Once proposed candidates are developed by the formulator, the design owner evaluates the formulations by first performing their own screening tests. If the test candidate fails, formulators may choose to reformulate. It is common to iterate multiple times before a test candidate passes the

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[18] GCCA

design owners' screening, potentially adding several years to the substitution process (see **Figure 3-2** above).

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

Validation of test candidate

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

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

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

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

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

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

Certification of alternative

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

Steps in the Certification stage include:

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

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

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

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

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

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

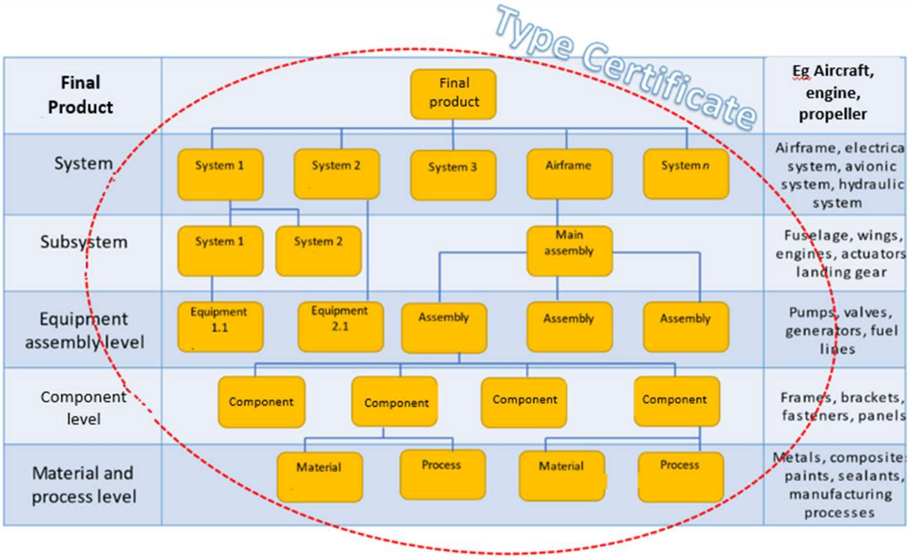

Figure 3-3: System hierarchy of a final product, showing the interconnection of each level in the system hierarchy, and how changes at a lower level have impacts on higher levels
Source: ADCR member

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

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

During initial manufacture, all the components of the system are in a pristine and relatively clean condition, whereas during repair and maintenance, the components are likely to be contaminated and suffering from some degree of (acceptable) degradation. Furthermore, certain cleaning and surface

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

preparation techniques that are readily applicable during initial manufacture may not be available or practical during repair and maintenance. Carrying out MRO activities on in-service products is further complicated due to restricted access to some components, which are much more readily accessible during initial manufacture and assembly. These factors are significant with respect to surface treatments, as their performance is strongly dependent upon the condition of the surfaces to which they are applied. As such, all these conditions must be addressed in the repair approval process.

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

Industrialisation of alternative

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

Elements of the Industrialisation of alternative process include:

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

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

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

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

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

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

Using the example of a commercial aircraft, a simplified example of the process, described above and leading to industrialisation of the alternative, is illustrated in **Figure 3-4** below.

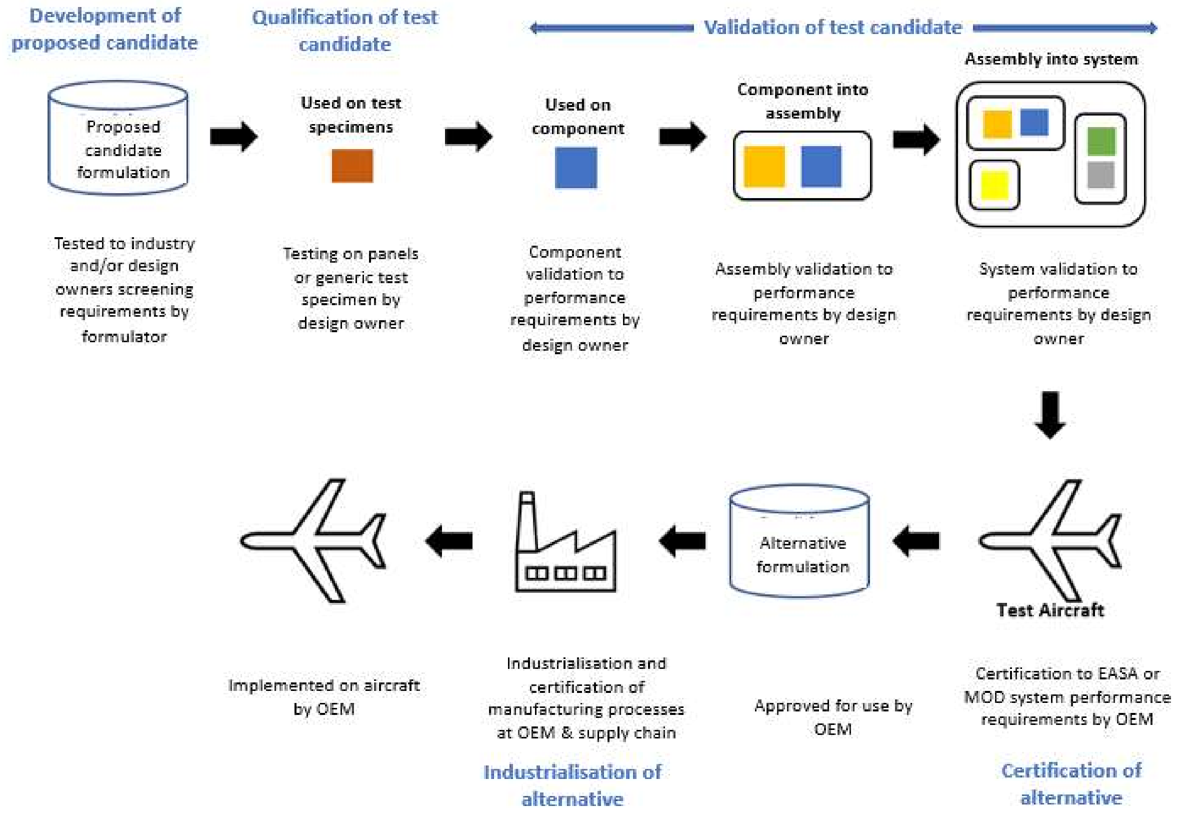

Figure 3-4: Process to Certify a Formulation for use on Aircraft
Formulations used in production have completed this process. New or reformulations must follow same process for use in production.
Source: ADCR member

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

3.2.1 Technical feasibility criteria for the role of the chromates in inorganic finish stripping

3.2.1.1 Introduction

As noted above, this combined AoA/SEA covers the use of multiple chromates for inorganic finish stripping (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 the key function of ensuring negligible or no effect on the underlying substrate clearly describes the benefit as coming from the Cr(VI) species. Therefore, by extension, any donor substance that delivers Cr(VI) is also responsible for delivering the functions attributed to Cr(VI) within the over-arching use. When considering prevention of damage to the substrate, the mode of action of Cr(VI) makes use of the chemical process by which the Cr(VI) is reduced to Cr(III) to form a physical chromium oxide barrier layer. 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.

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

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

In parallel, scientific literature describing specificities of inorganic finish stripping and the assessment of the technical feasibility of specific alternatives was collected, reviewed (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 proposed candidates are as follows:

- Complete removal of surface finish;
- Does not induce hydrogen embrittlement;
- Mitigation of end grain pitting and intergranular attack;
- Compliance with component drawing post treatment; and
- No impact upon residual stress, surface roughness and fatigue properties.

The discussion below explains the relevance and importance of each of the technical feasibility criteria in more detail, and presents in more detail the key performance requirements that are used in the assessment of proposed candidates discussed in section 3.4.

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

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

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

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

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

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

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

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

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

As previously noted in this combined AoA/SEA, chromium trioxide is the main treatment to remove the copper plating after the thermo-chemical treatment process to unmask the non-carburised steel surface of the thermally treated components. An additional step in this treatment process (not within scope of this dossier) involves the use of potassium dichromate to brighten the copper plating, allowing proper quality inspection of the masking coverage prior to thermal treatment. Modification of the copper stripping line cannot be undertaken in parallel with the current process taking place, and therefore the substitution timeline is dependent on the deployment of a Cr(VI)-free copper brightening and stripping process at the same time.

3.2.1.3 Technical feasibility criteria 1: Complete removal of surface finish

Whilst the key function of the chromate is to ensure negligible or no effect on the underlying substrate as the inorganic finish is removed, the key function of the stripping solution remains complete removal of the coating or surface finish, regardless of thickness. For any proposed candidate to progress in the substitution process, it must therefore be capable of meeting this requirement.

In the stripping of electrodeposited metallic coatings (e.g., copper), the high oxidation potential of Cr(VI) means it plays an important role in the removal of the inorganic finish and allows the process to take place at a much faster rate than it would without the Cr(VI) being present.

3.2.1.4 Technical feasibility criteria 2: Does not induce hydrogen embrittlement

Since a key function of inorganic finish stripping is that it does not adversely impact the substrate, it is necessary that the process should not induce damaging hydrogen embrittlement of the treated substrate. Hydrogen embrittlement is a phenomenon caused by atomic hydrogen generated in an aqueous environment. This nascent hydrogen diffuses into the lattice of the steel substrate where it combines to form the much larger molecular hydrogen. The trapped molecular hydrogen causes internal stress within the steel manifested as embrittlement. Cr(VI) has a twin benefit in reducing the risk of hydrogen embrittlement. It firstly acts in suppressing the excess hydrogen generation from unwanted metal oxidation, but further the reduction of Cr(VI) to Cr(III) serves as an alternative, non-hydrogen generating, reaction in place of hydrogen ion reduction.

Heat treatment can be used to purge hydrogen before damage can occur, however this is dependent upon the component fabricated from the steel alloy not being sensitive to heat. If heat treatment is required to purge hydrogen from the substrate, an important consideration when shortlisting proposed candidates is also to ensure compatibility with the heat treatment process.

High strength steels are particularly susceptible to hydrogen embrittlement.

3.2.1.5 Technical feasibility criteria 3: Mitigation of end grain pitting and intergranular attack

Following removal of the inorganic finish, the substrate is susceptible to end grain pitting and intergranular attack[21], which can cause residual stress and cracks. Cr(VI)-containing stripping solutions prevent such attack by passivating the substrate after removal of the coating and providing limited corrosion protection for a short period of time prior to re-processing with the new protective treatment.

3.2.1.6 Technical feasibility criteria 4: Compliance with component drawing post treatment

Inorganic finish stripping is used for coating repairs or if tolerances were not met during the previous anodising or conversion coating process. The aim of the process is therefore to replace the non-conforming coatings to allow the component to be re-treated in a way that complies with the component drawing. For MRO activities, it is important that the inorganic finish stripping solution does not etch the base metal to such an extent that the dimensional tolerances of the stripped component are exceeded.

3.2.1.7 Technical feasibility criteria 5: No impact upon residual stress, surface roughness and fatigue properties

Following MRO activities, it has been reported that these parameters must not exceed the values attained by the original coating. Any etching of the surface of a substrate can lead to residual stress, surface roughness or, as described earlier, intergranular attack – which can affect the fatigue

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[21] Intergranular attack is a form of corrosion where the boundaries of crystallites of the material are more susceptible to corrosion than their insides. Pitting corrosion, or pitting, is a form of extremely localised corrosion that leads to the random creation of small holes in metal extending from the metals surface. End Grain Pitting is specific to corrosion emanating from exposed end grain.

properties of the design. A short immersion time for the component to be stripped is vital to avoid this.

3.3 Market analysis of downstream uses

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

3.4 Efforts made to identify alternatives

3.4.1 Research and Development

3.4.1.1 Past Research

Even though 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), in considering the replacement of Cr(VI), this should be set against the diversity of applications of metallic substrates 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 3-6**. 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 3-6: Examples of finished products in A&D sector
Rheinmetall – Systems & Products, n.d.; Royal Navy, 2021

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

In the parent AfAs relating to this combined AoA/SEA for the use "inorganic finish stripping", there were only two alternatives identified. The first was a mixture of sulphuric acid, nitric acid, and ferric ions ("sulfonitroferric acid") which was a proposed candidate for the removal of anodic and conversion coatings on aluminium and aluminium alloys (excluding hard anodic and thermal spray coatings); and the second was a tartaric-nitric acid-based solution, assessed for its potential to strip conversion coatings from magnesium alloys.

Within the period since the parent authorisations were granted, members did not report any progression of the tartaric-nitric acid-based solution, however further R&D has been conducted on "sulfonitroferric acid" and other proposed candidates within the group inorganic acids including nitric acid, sulphuric acid, and phosphoric acid-based solutions. The "sulfonitroferric acid" has been progressed beyond TRL 3 to test candidate status for hard anodic coating by one member, however the other inorganic acids assessed as proposed candidates for the removal of anodic coatings or conversion coatings from aluminium alloys did not progress beyond laboratory scale investigations (TRL 3) as without a suitable co-formulant, the acid caused excessive etching of the substrate or was inefficient in the removal of sealed coatings. One proposed candidate, containing phosphoric acid in combination with sodium molybdate, caused limited etching of the substrate, however showed no evidence of intergranular attack or pitting. It has therefore been progressed beyond TRL 3 to test candidate status for one member. See section 3.5 for further information on these test candidates.

As with the inorganic acids discussed above, sodium hydroxide has also been demonstrated to be effective in removing the anodic layer from aluminium, however following removal of the coating, an excessive rate of material etching was again observed and maintaining control of the process was not considered feasible.

For the stripping of copper plate, a number of alkaline or basic solutions are currently being investigated as Cr(VI)-free proposed candidates. Within this group, an ammonia-based solution is showing some potential, and although the R&D remains at laboratory scale, it has not yet shown regression against any of the technical feasibility criteria. Further chemical solutions containing either sodium chlorite or sodium nitrite have also been tested at laboratory scale as proposed candidates for the stripping of copper plate. With these proposed candidates, the copper was removed from the substrate, leaving no corrosion pits and avoiding hydrogen embrittlement on the treated material, whilst also only minimally altering the weight and coupon dimensions. Progression to TRL 4 was therefore possible. See section 3.5 for further information.

A further option for the removal of copper plate is an electrochemical process, and members have presented two proposed candidates which have been tested in such a process. The first is a cyanide-based solution which is reported to be at TRL 3, and a potassium phosphate-based solution which is at TRL 4. Electrochemical processes are discussed further in section 3.5.

To further highlight the significant efforts being made by the aerospace and defence sector to substitute chromates, an example of an ongoing R&D collaboration is identified below. It is noted that multiple collaborations are mentioned within the parent AfAs associated with the ADCR consortium

Review Reports, however not all include research into the development of alternatives for inorganic finish stripping.

Please note that for this project only limited information is publicly available due in part to maintaining intellectual property rights and potentially patentable technologies.

- **Clean Sky Joint Technology Initiative (JTI) –** Launched in 2008 as a collaboration between the European Aerospace and Defence Industry and the European Commission. The project was established beforehand by industry members in 2006. Since the launch of Clean Sky, two Clean Sky Joint Undertakings have taken place, known as Clean Sky 1 and Clean Sky 2. Since December 2021, Clean Aviation began, running alongside Clean Sky 2 which will end in 2024 (Clean Aviation, 2022).

  Cr Free REAL "Development and testing of innovative Cr Free solution for Removal of Anodic Layers", ran under Clean Sky 2 under the Systems programme. The project ran between April 2019 and September 2021, receiving the total budget of €499,062.50 from the EU. Cest Kompetenzzentrum Fur Elektrochemische Oberflachentechnologie GmbH led the project, with participation from Mecaprotec Industries. Non-toxic stripping methods were considered particularly for aluminium oxide. The alternative was required to be Cr(VI)-free and be suitable for use in the aeronautics industry, although would also be suitable for automotive and railway sectors (European Commission, n.d.). The process would be used to remove non-Cr(VI) coatings such as SAA, Cr(III), chemical conversion, CAA or Alodine (Vladu, 2020). The process would be used by CEST and Metaprotec when it is fully developed. Results are kept confidential between the consortium members (CEST and Metaprotec) and the topic manager Liebherr-Aerospace Toulouse SAS (Vladu, 2019).

  As of 1 December 2021, the Clean Sky project has become Clean Aviation[22] aiming to provide climate-neutral aviation. The project appears to consider hydrogen powered fully electric and hybrid-electric aircraft technologies within its scope. No mention is made of chromates within the new joint undertaking (Clean Aviation project).

3.4.2 Consultations with customers and suppliers of alternatives

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

3.4.3 Data Searches

3.4.3.1 High level patent review

A non-exhaustive patent search was performed with the aim of identifying patents related to the stripping of anodic film. The search was performed using Espacenet[23], the European Patent Office (EPO) open access search portal. Espacenet contains over 120 million patent documents held by patent offices around the world, including North America and Asia (EPO, 2020).

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[22] https://clean-aviation.eu/media/news/clean-aviation-takes-flight

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

Periodic review of the patent landscape serves to highlight the depth of activity within the field, principal drivers for innovation, such as REACH Authorisation, as well as new developments that could feed into wider research activities within the aerospace and defence sector.

The search terms: “anodic film stripping without chromic acid”[1]; “anodic film stripping without potassium dichromate”[2]; “anodic film stripping without sodium dichromate”[3] were used and filtered via the Cooperative Patent Classification (CPC) filter. This is an extension of the International Patent Classification system used to group patents into specialised categories (EPO, 2020).

The three searches returned 95, 23 and 27 results respectively. These were screened by reading of the abstracts, and discussion with ADCR members, and those identified as potentially relevant to this AoA are presented in **Table 3-4** below:

Table 3-4: Patent search technology summary

Title	Patent publication reference	Summary
Peeling liquid for anodised film and peeling method of anodised film	JP2008190033	This patent aims to solve the problem of selectively removing an anodised film on an aluminium or aluminium alloy member anodised by immersion. The solution proposed in the patent is to use a peeling liquid containing phosphoric acid and a molybdic acid salt to selectively remove the anodised film on the aluminium or aluminium alloy member without practically dissolving the base of the aluminium or aluminium alloy.
Aluminium alloy anodic oxide film removal agent and film removal method	CN108950644A	The object of the present invention is to provide an aluminium alloy anodised film stripping agent -which is particularly suitable for removing an anodised film of a 7-series aluminium product of high luminance aluminium alloy to solve the problem caused by the alkali etching method. The method involves an agent consisting of potassium hydroxide and/or sodium hydroxide, present with a polyol or polyol ether and water. The application method is immersion.
Aluminium alloy anodising film removing agent and preparation method and using method thereof	CN106591857A	This invention describes an aluminium alloy anodising film removing agent comprising sulphuric acid, glacial acetic acid, and a corrosion inhibitor in an aqueous solution. As a preferred solution, the corrosion inhibitor is thiourea. The invention describes the preparation of the anodising film removing agent. Sulphuric acid is dissolved in a certain amount of water to form a sulphuric acid solution. Glacial acetic acid is then dissolved in the sulphuric acid solution to form a mixed solution. The corrosion inhibitor is added to the mixed solution. Anodised aluminium is immersed in the removing agent, which is claimed to not corrode the workpiece.

The patents identified describe the use of inorganic acids or hydroxides for the replacement of Cr(VI) in the stripping of anodic coatings. These represent proposed candidates that have already been considered by members and are discussed above.

As indicated, the search summarised above focussed on the removal of anodic coatings. For the stripping of copper, patent description No. 4,443,268 was identified. This describes a process in which, to remove copper coatings from metal surfaces, aqueous alkaline solutions containing iron chelates of polycarboxylic alkenopolyamide acids (e.g., iron chelate with EDTA - also called iron edetate) were used. The etching process is improved by adding aqueous hydrogen peroxide solution to the solution used in the process. Hydrogen peroxide removes the copper layer and copper oxide from metal surfaces faster. Due to the availability of other test candidates, this has not been further investigated by members, however an initial review of the process identified health, safety and environmental concerns with handling high concentration hydrogen peroxide as well as the treatment of a large amount of excess water. Chelating agents such as EDTA can interfere with the industrial wastewater treatment process and their use in metal surface treatment has therefore been prohibited by some facilities.

As with all patents, those listed above introduce concepts and developments that may be advantageous within a given field in the fullness of time. However, it should be remembered that patents are granted for their novelty. Novelty does not necessarily translate to feasibility or applicability. Patented technologies are still bound to the requirements of the substitution process which will determine if a novel concept can be transformed into a feasible test candidate. Patents can also introduce limitations on the availability of a particular technology, for example through the requirements for licencing. Where this is the case, a third party may obtain access to the technology if a licensing or some other commercial arrangement is available and meets the requirements of both parties.

3.4.3.2 High level literature review

A non-exhaustive technical literature review was carried out using Science Direct (Journals and Books)[24] on-line service using the keyword search terms: ‘Anodic film stripping without chromic acid’; ‘anodic film stripping without potassium dichromate’; and ‘anodic film stripping without sodium dichromate’[25]. The purpose of this search was to identify examples of alternatives to Cr(VI) for removing anodic layers that have been investigated in the academic field or within other industry sectors. Of the four results returned in the literature search of the above terms, no relevant open access articles were identified.

3.4.4 Identification of alternatives

As noted above in section 3.2.1, the technical feasibility criteria for inorganic finish stripping are:

- Complete removal of inorganic finish;
- Does not induce hydrogen embrittlement;
- Mitigation of end grain pitting and intergranular attack;
- Compliance with component drawing post treatment; and
- No impact upon residual stress, surface roughness and fatigue properties

In support of initial screening, testing, also referred to as Critical to Quality (CTQ) tests, is conducted to assess performance of proposed candidates in the laboratory environment for each of the criteria.

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

[25] Literature search conducted September 2021

Hydrogen embrittlement can be tested according to ASTM F 519, or using the tensile test (EN2832), the slow bending test (EN2831), or other procedures. End grain pitting and intergranular attack have a negative influence on the substrate quality, so the ratio of (surface) pit size to pit depth can be tested according to ASTM F 2111. The conformance of the component to the drawing after stripping is tested by post processing inspection measurements, whilst the stress corrosion cracking of the substrate can be tested according to ASTM G-41. Under this method, test specimens are placed in a molten salt bath for 4.0 ±0.5 h. The specimens are rejected if the material shows pitting, cracking or rough etching.

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

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

Proposed candidates for the replacement of Cr(VI) in the stripping of inorganic finishes are shown in **Table 3-5** below. This list comprises the alternatives that were reported in the parent AfAs, as well as any novel processes identified during consultation or following review of the data searches undertaken and presented above. These are assessed against the technical feasibility criteria identified above.

Table 3-5: Proposed candidates for the replacement of Cr(VI) in inorganic finish stripping

Proposed candidate	Coating/ substrate	Complete removal of inorganic finish	Does not induce hydrogen embrittlement	Mitigation of end grain pitting and intergranular attack	Compliance with component drawing post treatment	No impact upon residual stress, surface roughness and fatigue properties
Sulfonitroferric acid	Anodic layers and conversion coatings on aluminium alloys	🟨	N/R	🟨	N/R	🟨
Tartaric-nitric acid	Conversion coatings on magnesium alloys	🟨	N/R	N/R	N/R	🟨
Phosphoric acid/sodium molybdate	Anodic layers on aluminium alloys	🟨	N/R	🟨	N/R	🟨
Other inorganic acids	Anodic layers or conversion coatings on aluminium alloys	🟨	N/R	🟥	N/R	N/R
Potassium/sodium hydroxide	Anodic layers on aluminium alloys	🟨	N/R	N/R	N/R	🟥
Ammonia-based	Copper plating on steel	🟨	N/R	🟨	N/R	N/R
Electrochemical processes	Copper plating on steel	🟨	🟨	🟨	N/R	N/R
Sodium nitrite-based	Copper plating on steel	🟨	🟨	🟨	N/R	N/R
Sodium chlorite-based	Copper plating on steel	🟨	🟨	🟨	N/R	N/R

Green = Meets performance requirements for all relevant components; Yellow = Meets performance requirements for some relevant components; Red = Does not meet performance requirements for any relevant components; N/R = Not reported

3.4.5 Shortlist of alternatives

Focusing on the overriding need to maintain performance requirements critical to airworthiness, safety, and reliability, proposed candidates must demonstrate performance as good as, or better than, the incumbent Cr(VI)-based 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[26] level testing.

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

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

Based on an assessment of technical feasibility and potential to be suitable alternatives to Cr(VI), the following proposed candidates can be/have been progressed to test candidate status:

For the removal of anodic layers from aluminium alloys:

- Sulfonitroferric acid; and
- Phosphoric acid/sodium molybdate.

For the removal of copper plating from steel:

- Ammonia-based solutions;
- Cyanide-based solutions;
- Sodium nitrite-based solutions; and
- Sodium chlorite-based solutions.

Note that, although electrochemical processes using both a potassium phosphate-based solution and a cyanide-based solution have been considered in **Table 3-5**, only the cyanide-based solution is discussed further in section 3.5. Although the electrochemical process using a potassium phosphate-based solution met the technical feasibility criteria, as an electrochemical process, rather than a chemical process, this test candidate would require significant changes to equipment to achieve complete stripping of components. It therefore remains at TRL 4 for the stripping of copper plating

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[26] 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

from steel substrates but has not been shortlisted for the components on which it has been tested in favour of the equally promising chemical solutions also described.

3.5 Assessment of shortlisted alternatives

3.5.1 Introduction

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

Approval of the test candidate must include a complete understanding of the influence of the adjacent treatments to inorganic finish stripping within the process flow. Evaluation of the technical feasibility of the test candidate for inorganic finish stripping should consider its behaviour in combination with other supporting treatments within the surface treatment 'system'. Any change in these system variables may lead to irregular or unacceptable performance of the test candidate used to strip the inorganic finish and consequently impact or delay approval of the alternative for different component designs. This scenario is a leading reason for the graduated implementation of test candidates in combination with different component/design families. Different designs exhibiting varying degrees of complexity have the potential to interact with elements of the treatment system differently and thus affect the performance of the test candidate.

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

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

When assessing the suitability of an alternative, reference is made to the European Commission note dated 27 May 2020 which clearly defines the criteria by which an alternative may be judged as suitable[27] 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 considering 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?

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

To be available, a test candidate should meet the regulatory requirements of placing it on the market. Until the technical feasibility criteria and associated performance requirements of the use and wider treatment system are fulfilled, including all certification obligations as stipulated in the Airworthiness Directives[28], the test candidate cannot be deemed 'available'.

All civil aircraft operating in the EU are subject to Airworthiness Directives issued by EASA on behalf of the EU and its Member States, and European third countries participating in the activities of EASA. Changes to design of a product are subject to certification (EU, 2018), and can only be made following approval from the Regulator and compliance with the requirements of the appropriate Airworthiness Regulation, such as (EU) 2018/1139[29]. 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

3.5.2.1 Introduction

In the parent AfA, a variety of inorganic acids were reported as being under evaluation as alternatives to Cr(VI) in surface pre-treatment processes, with none having progressed beyond TRL4. R&D studies were reported to have found that a mineral acid-based solution of sulphuric acid nitric acid, and ferric ions from iron sulphate (named "sulfonitroferric acid") could be a potential alternative for the stripping of conversion coatings and anodic coatings from aluminium and aluminium alloys. Preliminary assessment of this chemistry had been carried out on sulphuric acid anodic coatings, but further studies were reported to be required to determine the suitability over a wider range of anodic coatings and substrates. This alternative was stated to meet some requirements, however as it is not possible on assembled components to differentiate between aluminium and other substrates, the alternative process has severe limitations where differing substrates are in close proximity and compatibility with the alternative is unproven.

There were no generally accepted non-chromate alternatives reported for the stripping of hard anodic coating from aluminium alloys and for the stripping of thermal spray coatings from aluminium alloys. Even though R&D started in the 1990s, no alternative was reported to have been found which meets the necessary performance criteria related to parameters such as hydrogen embrittlement, residual stress, surface roughness, fatigue, intergranular attack and end grain pitting. During the consultation exercise however, it was reported that the sulfonitroferric acid described in the parent AfA was now being tested for the removal of hard anodic coatings from aluminium alloys.

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

[29] 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)

3.5.2.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of sulfonitroferric acid

Testing, reported by one member, has included: surface analysis to determine coating removal, depth of attack, surface profile (roughness); reapplication of anodise coating and examination of microstructure; and compatibility with other metals (e.g., titanium) that may come into contact with the solution during stripping. While this test candidate progressed to TRL 5 for stripping hard coat anodise from the aluminium alloys commonly used in testing, for other anodic layers it has not yet progressed beyond TRL 2, and for certain 2000 series aluminium alloys, used on a key component, substrate attack was seen. With further optimisation of process conditions, it is hoped that the proposed candidate could pass screening tests for stripping of all relevant sealed anodic layers, and TRL 6 could be achieved by 2030.

Economic feasibility of sulfonitroferric acid

As there would be little change in equipment, it is unlikely that the sulfonitroferric acid would present a significantly different cost to the existing process.

Health and safety considerations related to the use of sulfonitroferric acid

For the purposes of understanding the risks associated with this test candidate the key identifiers and summary of hazard properties for the formulation identified are given in **Table 3-6** below.

Table 3-6: Summary of composition and hazard properties of sufonitroferric acid

Substance	EC Number	CAS number	CLP classification
Sulphuric acid[a]	231-639-5	7664-93-9	Skin Corr. 1A; H314
Nitric acid[a]	231-714-2	7697-37-2	Ox. Liq. 3; H272 Skin Corr. 1A; H314 Acute Tox. 3; H331 EUH071
Ferric sulphate [b]	233-072-9	10028-22-5	Acute Tox, 4;H302 Skin Irrit.2; H315 Eye Dam.1; H318 Skin Sens.1; H317

[a] Classified in accordance with Annex VI of Regulation 1272/2008 (CLP)
[b] Classified in accordance with REACH registration dossier

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

Availability of sulfonitroferric acid

The sulfonitroferric acid formulation that has been progressed to test candidate status is commercially available globally. Although it comes from a single manufacturing source it is thought that it is produced in sufficient quantities to meet the demands of the A&D sector.

The biggest issue impacting availability is qualification of the test candidate for use on all relevant A&D components, and qualification of the supply chain required to support the process. This ultimately prevents the test candidate from being an alternative generally available to the A&D sector.

Suitability of sulfonitroferric acid

The use of sulfonitroferric acid represents a reduction in risk when compared to the use of the current Cr(VI)-based solution for the stripping of anodic coatings from aluminium alloys and relies on a commercially available alternative. There are also no significant increases in costs when compared to the current process.

Despite this, sulfonitroferric acid has so far only reached test candidate status for a limited number of substrate-coating combinations. To date there has been no progression of the proposed candidate for the removal of conversion coatings and certain types of anodic films, or for alloys other than aluminium. Given the low technical maturity of this test candidate and the technical feasibility issues that have been encountered, sulfonitroferric acid cannot yet be considered a generally available and suitable alternative to Cr(VI) inorganic finish stripping.

3.5.3 Test candidate 2: Phosphoric acid/sodium molybdate

3.5.3.1 Introduction

This solution, not described in the parent AfA, is proposed in patent JP2008190033, described above. It involves the use of a peeling liquid containing phosphoric acid and a molybdic acid salt to selectively remove the anodised film without dissolving the base of the aluminium or aluminium alloy. In the process the phosphoric acid acts to strip the coating, whilst the sodium molybdate acts to form a molybdenum film, coating the aluminium surface and inhibiting exposure. To remove the molybdenum film from the surface of the substrate, an additional rinsing step using nitric acid is required after the stripping. It is also recommended that a complexing agent is added to stabilise the phosphoric acid and molybdenum concentrations.

3.5.3.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of Phosphoric acid/sodium molybdate

One member reported that this test candidate has progressed to TRL 6 for the stripping of anodic layers from aluminium alloys, although unlike the current process using Cr(VI), there was some etching of the substrate in the case of some alloys. For this test candidate to be progressed further, optimisation of the bath conditions, and monitoring of the solution life and stability is required.

Economic feasibility of Phosphoric acid/sodium molybdate

The long-term stability study currently being undertaken will also inform the economic feasibility of this test candidate. If the solution needs to be regularly replaced, this will bring significant additional costs when compared to the current process.

Health and safety considerations relating to the use of phosphoric acid/sodium molybdate

For the purposes of understanding the risks associated with the test candidate based on phosphoric acid/sodium molybdate, the key identifiers and summary of hazard properties for the formulation are given in **Table 3-7** below.

Table 3-7: Summary of composition and hazard properties of phosphoric acid/sodium molybdate

Substance	EC Number	CAS number	CLP classification
Phosphoric acid[(a)]	231-633-2	7664-38-2	Skin Corr. 1B; H314
Sodium molybdate[(b)]	231-765-0	7722-84-1	Data conclusive but not sufficient for classification
Nitric acid[(a)]	231-714-2	7697-37-2	Ox. Liq. 3; H272 Skin Corr. 1A; H314 Acute Tox. 3; H331
[(a)]Classified in accordance with Annex VI of Regulation 1272/2008 (CLP) [(b)]Classified in accordance with REACH registration dossier			

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

Availability of phosphoric acid/sodium molybdate

The metal salt used in the process, sodium molybdate, is widely available on the market in both hydrous and anhydrous forms. Although an additional tank will be required for the nitric acid rinsing step, the equipment is not specialised and again readily available.

The biggest issue impacting availability is qualification of the test candidate for use on all relevant A&D components, and qualification of the supply chain required to support the process. This ultimately prevents the test candidate from being an alternative generally available to the A&D sector.

Suitability of Phosphoric acid/sodium molybdate

Although this test candidate represents an economically feasible solution which has progressed to TRL 6 for the stripping of anodic layers from certain aluminium alloys, there are still questions about long-term solution life and bath stability.

As with sulfonitroferric acid, there has so far been no progression of the proposed candidate for the removal of conversion coatings and certain types of anodic films, or for alloys other than aluminium.

3.5.4 Test candidate 3: Ammonia-based solutions

3.5.4.1 Introduction

Test candidates for the replacement of Cr(VI) in finish stripping as part of a main treatment were not reported in the parent AfA, therefore information on this test candidate is only available through research and consultation conducted in the preparation of this combined AoA/SEA.

This solution involves a process in which an aerated bath of ammonia is used to solubilise copper ions such that they can be removed from the substrate surface. Compared to the incumbent treatment, pH maintenance is critical in this process due to the evaporation of ammonia during processing.

3.5.4.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of ammonia-based solutions

Processes based on this technology have been reported to be at TRL 3 for the stripping of copper mask from steel alloys, and whilst it has not yet failed any screening tests, a reduction in process efficiency has been seen.

Economic feasibility of ammonia-based solutions

The direct challenge for the substitution of inorganic stripping using ammonia-based solutions is the overall increase in the infrastructural cost and operating costs. In order to implement this test candidate, and the associated changes to other parts of the process, all parts of the process line would need to be modified. Only a qualitative assessment of economic feasibility can be provided here since it's early in the project, which makes extracting quantitative data for general indicators difficult.

The costs will increase due to the following impacts:

- **New Equipment:** The process requires significant investment in equipment, including new dedicated extraction and treatment equipment to remove the ammonia fumes generated.
- **Raw Material costs:** In general, the price of raw materials for the test candidate is higher than the price of the Cr(VI)-based formulations currently in use.
- **Waste disposal cost:** Potential increases in the volume of waste and therefore disposal costs compared to current levels.

Health and safety considerations related to the use of ammonia-based solutions

During processing with the ammonia-based solution, ammonia is evaporated, and ammonia fumes are generated. For the purposes of understanding the risks associated with the test candidate, the key identifiers and summary of hazard properties of anhydrous ammonia are given in **Table 3-8** below:

Table 3-8: Summary of hazard properties of ammonia

Substance	EC Number	CAS number	CLP classification
Ammonia[(a)]	231-635-3	7664-41-7	Flam. Gas 2; H221, Skin Corr. 1B; H314, Acute Tox. 3; H331; Aquatic Acute 1; H400

[(a)]Classified in accordance with Annex VI of Regulation (EC) No 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, however there is still a significant risk associated with using a process which generates an acutely toxic flammable gas.

Availability of ammonia-based solutions

This test candidate relies on the use of readily available chemicals, however the process requires unique equipment for chemical regeneration that is both costly to implement and not proven on a production system yet.

As with the previous test candidates, the biggest issue impacting availability is qualification of the test candidate for use on all relevant A&D components, and qualification of the supply chain required to support the process. This ultimately prevents the test candidate from being an alternative generally available to the A&D sector.

Suitability of ammonia-based solutions

Whilst ammonia-based solutions have shown some promise for the stripping of copper from steel alloys, there is no indication that this process could be applied to the other coating/substrate combinations described in this combined AoA/SEA. The solution significantly increases the costs associated with the process and there are also serious health and safety concerns relating to the use of ammonia-based solutions which may prevent their implementation at some sites.

Given the low technical maturity of this test candidate and the technical feasibility issues that have been encountered, ammonia-based solutions cannot yet be considered a generally available and suitable alternative for Cr(VI) inorganic finish stripping.

3.5.5 Test candidate 4: Cyanide-based solutions

3.5.5.1 Introduction

Test candidates for the replacement of Cr(VI) in finish stripping as part of a main treatment were not reported in the parent AfA, therefore information on this test candidate is only available through research and consultation conducted in the preparation of this combined AoA/SEA.

This test candidate uses an electrochemical method in which the typical copper plating process is reversed (with the components used as anodes and the steel as the cathode) and a sodium cyanide solution is used in the bath. Recovery of copper from copper-bonded steel objects without corrosive damage to the steel substrate by electrolytic method is possible with the use of cyanide solutions because copper cyanides do not have a corrosive effect on steel.

3.5.5.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of cyanide-based solutions

A cyanide-based solution has been reported to be at TRL 3 for the stripping of copper mask from steel alloys, and whilst it has not yet failed any screening tests, a reduction in process efficiency has been seen.

Economic feasibility of cyanide-based solutions

In order to implement this test candidate, and the associated changes to other parts of the process, all parts of the process line would need to be modified.

As discussed earlier, the implementation of an electrochemical process has a significant financial impact, which has led other test candidates requiring such a process to be rejected in favour of chemical processes. For the cyanide-based solution the processing time is longer than the current treatment involving Cr(VI), therefore energy costs are increased. The process also requires additional baths as well as other equipment to improve process efficiency.

Additionally, cyanide solutions require segregation from any nearby acid solutions to prevent the risk of generating hydrogen cyanide gas. Cyanide-bearing wastewater streams also require segregation and specific pre-treatment processes. The implementation of such measures would come at significant cost, and potentially require additional space, which may not currently be available.

Health and safety considerations related to the use of cyanide-based solutions

For the purposes of understanding the risks associated with the test candidate, the key identifiers and summary of hazard properties are given in **Table 3-9** below:

Table 3-9: Summary of hazard properties of test candidate for cyanide-based solution

Substance	EC Number	CAS number	CLP classification
Sodium cyanide[(a)]	205-599-4	143-33-9	Met. Corr. 1; H290, Acute Tox. 1; H300, Acute Tox. 1; H310, Acute Tox. 1; H330, STOT RE 1; H372, Aquatic Acute 1; H400, Aquatic Chronic 1; H410
Sodium hydroxide[(b)]	215-185-5	1310-73-2	Skin Corr. 1A; H314

[(a)] Classified in accordance with REACH registration dossier
[(b)] Classified in accordance with Annex VI of Regulation (EC) No 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, however there is still a significant risk associated with using a process which uses an acutely toxic substance, or which could generate hydrogen cyanide following contact with acid solutions. For many member companies this risk would be deemed unacceptable to their EHS departments, and some companies prohibit the use of cyanide-based processes on site.

Availability of cyanide-based solutions

This test candidate relies on the use of readily available chemicals, and although the process would need to be modified, there is no equipment required which is not also readily available.

As with the previous test candidate, the biggest issue impacting availability is qualification of the test candidate for use on all relevant A&D components, and qualification of the supply chain required to support the process. This ultimately prevents the test candidate from being an alternative generally available to the A&D sector.

Suitability of cyanide-based solutions

Whilst cyanide-based solutions have shown some promise for the stripping of copper from steel alloys, there is no indication that this process could be applied to the other coating/substrate combinations described in this combined AoA/SEA. The solution significantly increases the costs associated with the process and there are also serious health and safety concerns relating to the use of cyanide-based solutions which may prevent their implementation at some sites.

Given the low technical maturity of this test candidate and the technical feasibility issues that have been encountered, cyanide-based solutions cannot yet be considered a generally available and suitable alternative for Cr(VI)-based inorganic finish stripping.

3.5.6 Test candidate 5: Sodium nitrite-based solutions

3.5.6.1 Introduction

Test candidates for the replacement of Cr(VI) in finish stripping as part of a main treatment were not reported in the parent AfA, therefore information on this test candidate is only available through research and consultation conducted in the preparation of this combined AoA/SEA.

One member reported the progression of a commercially available formulation containing sodium nitrite and sodium acetate.

3.5.6.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of sodium nitrite-based solutions

This test candidate removed copper plating without causing any corrosion pits. It also avoided hydrogen embrittlement of the treated substrate, made no significant changes to coupon dimensions or weight and didn't significantly increase surface roughness. The test candidate is currently at TRL 4.

Economic feasibility of sodium nitrite-based solutions

Product price is expected to be higher than for the incumbent substances, due to patents and relatively small-scale production of the formulation tested. Since the test candidate involves a chemical process similar to the existing process using Cr(VI) however, costs related to equipment adaptation and operator training are expected to be limited.

Health and safety considerations related to the use of sodium nitrite-based solutions

For the purposes of understanding the risks associated with the test candidate, the key identifiers and summary of hazard properties are given in **Table 3-10** below:

Table 3-10: Summary of hazard properties of sodium nitrite-based solution

Substance	EC Number	CAS number	CLP classification
Sodium nitrite[a]	231-555-9	7632-00-0	Ox. Sol. 3; H272 Acute Tox. 3; H301 Aquatic Acute 1; H400
Sodium acetate[b]	204-823-8	127-09-3	Data conclusive but not sufficient for classification

[a] Classified in accordance with Annex VI of Regulation (EC) No 1272/2008 (CLP)
[b] Classified in accordance with REACH registration dossier

Based on the above, the test candidate would represent a less hazardous alternative to the current process using Cr(VI), a non-threshold carcinogen, however when the bath for this process was prepared on a pilot line, the formation of hazardous nitrite vapour was seen, creating an unacceptable safety risk which could not be easily removed.

Availability of sodium nitrite-based solutions

This test candidate relies on a commercial solution which only has limited availability in Europe.

As with the previous test candidate, the biggest issue impacting availability is qualification of the test candidate for use on all relevant A&D components, and qualification of the supply chain required to support the process. This ultimately prevents the test candidate from being an alternative generally available to the A&D sector.

Suitability of sodium nitrite-based solutions

Whilst this solution has met all the technical feasibility criteria against which it has been tested for the removal of copper plating from steel, the issues associated with safety and availability means that members are no longer progressing this alternative.

3.5.7 Test candidate 6: Sodium chlorite based solutions

3.5.7.1 Introduction

Test candidates for the replacement of Cr(VI) in finish stripping as part of a main treatment were not reported in the parent AfA, therefore information on this test candidate is only available through research and consultation conducted in the preparation of this combined AoA/SEA.

Two weakly alkaline chemical formulations containing sodium chlorite have been developed by formulators and are being progressed by members as test candidates for the replacement of chromium trioxide solutions in the stripping of copper plating from steel components.

3.5.7.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of sodium chlorite based solutions

For one member both solutions are currently in TRL 3. It is anticipated that for the small number of steel components from which copper plating needs to be removed, TRL 6 will be reached by the end of 2024, with industrialisation by 2028.

Two further members have progressed the solutions to TRL 4, with TRL 6 again planned to start in 2024. For one of these members TRL 4 is focussing on the components to which the process is most commonly applied, however at TRL 6 tests will be performed on critical production components.

Economic feasibility of sodium chlorite-based solutions

Since the test candidates are chemical processes similar to the current copper stripping process using Cr(VI), costs related to equipment adaptation and operator training are expected to be limited. Investments are necessary to identify and implement effective analytical methods to monitor bath composition, however.

Thanks to the similarity with the current process, no significant impact on energy usage is expected. Longer process times could impact the overall process cost, however further tests are required for a more precise evaluation. Cost for waste disposal and risk management measures (including sanitary expenses for operators) are expected to significantly decrease.

Despite this, additional costs are likely with this process due to the risk of fire/explosion when sodium chlorite solutions dry in contact with organic materials. Additional control measures may therefore need to be purchased to ensure suitable segregation of the raw material during storage and transport.

Health and safety considerations related to the use of sodium chlorite-based solutions

For the purposes of understanding the risks associated with the test candidate, the key identifiers and summary of hazard properties of the two formulations are given in **Table 3-11** and **Table 3-12** below:

Table 3-11: Summary of hazard properties of sodium chlorite-based solutions (formulation 1)

Substance	EC Number	CAS number	CLP classification
Tetraethylenepentamine[(a)]	203-986-2	112-57-2	Acute Tox. 4; H302 Acute Tox. 4; H312 Skin Corr. 1B; H314 Skin Sens. 1; H317 Aquatic Chronic 2; H411
Sodium chlorite[(b)]	231-836-6	7758-19-2	Oxi Sol. 1; H271 Acute Tox. 3; H301 Acute Tox. 2; H310 Skin Corr. 1B; H314 STOT RE 2; H373 Aquatic Acute 1; H400 Aquatic Chronic 3; H412
Sodium carbonate[(a)]	207-838-8	497-19-8	Eye Irrit. 2; H319

[(a)] Classified in accordance with Annex VI of Regulation (EC) No 1272/2008 (CLP)
[(b)] Classified in accordance with REACH registration dossier

Table 3-12: Summary of hazard properties of sodium chlorite-based solutions (formulation 2)

Substance	EC Number	CAS number	CLP classification
Ammonium hydroxide[(a)]	215-647-6	1336-21-6	Skin. Corr. 1B; H314 Aquatic Acute 1; H400
Ammonium carbonate[(b)]	213-911-5	1066-33-7	Acute Tox. 4; H302
Sodium chlorite[(b)]	231-836-6	7758-19-2	Oxi Sol. 1; H271 Acute Tox. 3; H301 Acute Tox. 2; H310 Skin Corr. 1B; H314 STOT RE 2; H373 Aquatic Acute 1; H400 Aquatic Chronic 3; H412

[(a)] Classified in accordance with Annex VI of Regulation (EC) No 1272/2008 (CLP)
[(b)] Classified in accordance with REACH registration dossier

Based on the above, the test candidates would represent a less hazardous alternative to the current process using Cr(VI), a non-threshold carcinogen, however there is still a significant risk associated with using a process which uses an acutely toxic substance. This, and the fire/explosion risk associated with incorrect storage, would be deemed unacceptable to the EHS departments of many members.

Availability of sodium chlorite-based solutions

Of the two solutions, one is already widely used throughout Europe for other processes, and supply issues are not anticipated. The other solution, although only recently developed, contains substances which are widely used, and therefore the expectation is that demand would be met.

As with the previous test candidate, the biggest issue impacting availability is qualification of the test candidate for use on all relevant A&D components, and qualification of the supply chain required to support the process. This ultimately prevents the test candidate from being an alternative generally available to the A&D sector.

Suitability of sodium chlorite-based solutions

Sodium chlorite-based solutions represent an economically feasible, and commercially available test candidate for the stripping of copper plating from steel components, which reduces the risks associated with the incumbent process. Despite this, there application is limited and, even if progression through the substitution process exceeds expectations, there is insufficient time to implement the process and communicate the change to the number of impacted customers prior to the expiry of the existing authorisation in 2024. This test candidate can therefore not be considered a generally available and suitable alternative for Cr(VI) inorganic finish stripping.

3.6 Conclusions on shortlisted alternatives

Table 3-13 summarises the current development status of the test candidates to replace Cr(VI) for inorganic finish stripping. A qualitative assessment (low, moderate, or high) has been provided for each of the criteria: technical feasibility, economic feasibility, risk reduction, availability, and suitability. The qualitative assessment is provided as a high-level summary and is based on the detailed discussions in the preceding sections.

Table 3-13: Current development status of test candidates

Alternative	Coating/substrate	Technical feasibility	Economic feasibility	Risk reduction	Availability	Suitability
Sulfonitroferric acid	Anodic layers on aluminium alloys	Moderate	High	Moderate	Moderate	Moderate
Phophoric acid/sodium molybdate	Anodic layers on aluminium alloys	Moderate	Moderate	Moderate	Moderate	Moderate
Ammonia-based solutions	Copper plating on steel	Low	Low	Low	Moderate	Low
Cyanide-based solutions	Copper plating on steel	Low	Low	Low	Moderate	Low
Sodium nitrite-based solutions	Copper plating on steel	Moderate	Moderate	Low	Low	Low
Sodium chlorite-based solutions	Copper plating on steel	Moderate	High	Low	Moderate	Moderate

For the stripping of non-conforming coatings, or the removal of inorganic finishes for MRO work, solutions based on inorganic acids with additives represent the only two identified test candidates. These have demonstrated technical feasibility for the stripping of some anodic layers from certain aluminium alloys, but further research and additional progress is required before these can be considered a solution which could be applied to all substrate-coating combinations which may need to be stripped for this type of restorative work. For the stripping of copper from steel alloys a number of different test candidate solutions have passed initial screening, however there are reasons linked to economic feasibility and risk that progression of these may not be possible for all components.

Each of these test candidates is represented in members' substitution plans, however due to the current level of development, the technical obstacles, and the complexity of the substitution process described in section 3.1.2, none can be implemented for all components and final products prior to the end of the existing review period.

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 inorganic finish stripping. 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 with individual members

Each ADCR member has a substitution plan to remove Cr(VI) in inorganic finish stripping that is uniquely reflective of their individual situation. Additionally, an individual member often has multiple substitution plans for inorganic finish stripping, running in parallel work streams. The reason for different substitution plans within one member company is that they are segmented by factors such as type of inorganic finish, 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 main treatments

As discussed earlier, modification of the copper stripping line to remove Cr(VI) cannot be undertaken in parallel with the current process taking place, and therefore the copper plate substitution timeline is dependent on the deployment of a Cr(VI)-free copper brightening and passivation process at the same time.

There is also a strong interrelationship between the substitution of the Cr(VI)-containing stripping solutions used for the removal of anodic layers and conversion coatings, and the replacement of Cr(VI) in these main treatments. A number of members have expressed that the substitution of Cr(VI) in the stripping process should align with the removal of Cr(VI) from these main treatments. Any unexpected delay in the substitution plan for one of these processes could therefore adversely impact the progression of the substitution plan for inorganic finish stripping.

3.7.2 Substitution plan for ADCR in inorganic finish stripping

3.7.2.1 Substitution plans

Multiple test candidates to replace Cr(VI) in both the stripping of anodic layers, and the stripping of copper plating, have been investigated by members, and have been progressed to various stages, with variation arising from different types of components and substrates.

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

The data in **Figure 3-7** shows the expected progress of 20 distinct substitution plans for Cr(VI) in inorganic finish stripping, 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 inorganic finish stripping for the ADCR consortium as a whole.

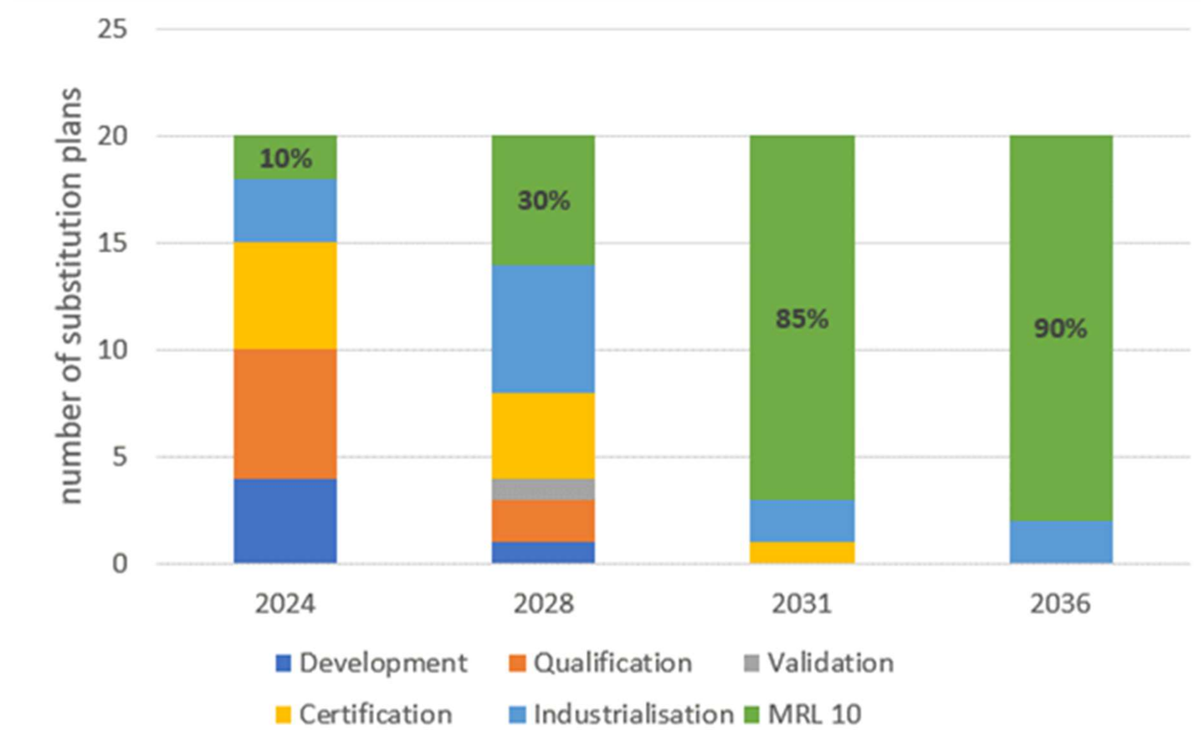


Figure 3-7: Expected progression of substitution plans for the use of Cr(VI) in inorganic finish stripping, by year

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

Source: **RPA analysis, ADCR members**

The above summary shows:

- Variation in the status of different substitution plans in each of the years (this variation is due to issues such as technical difficulty, type of substrate, type of coating); 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, and presented in **Figure 3-7**. The actual status of the substitution plans 12 or more years from now could be different to our expectations today.

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

There are many issues that limit members' progression of the substitution plans beyond the stages indicted in **Figure 3-7.** Technical issues include, for example, technical failures on some types of coating or substrate (induction of hydrogen embrittlement, evidence of intergranular attack or other forms of substrate damage), and inability to meet performance requirements set out in customer specifications.

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. These members are represented by the substitution plans at the development phase in 2024. For proposed candidates which have not yet progressed beyond TRL 3, predicting the length of time until industrialisation will be completed can be a particularly difficult task because iterative re-formulations of a proposed candidate are not uncommon. Each of these re-formulations results in the timeline for this substitution plan being reset. A proportion of those substitution plans which are not anticipated to progress to MRL 10 until 2036 or beyond are also impacted by the needs of MROs and MoDs for continued use in the maintenance and repair of in-service (legacy) final A&D products.

The timeframes associated with the activities presented in **Figure 3-7** 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 3-7** that despite ongoing and concerted efforts of the members to develop alternatives to Cr(VI) in inorganic finish stripping, 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 authorisations), while many substitution plans are expected to have successfully progressed to MRL 10 and the consortium is expected to have reduced its Cr(VI) use, an equally significant proportion (15% of the total substitution plans) are not expected to have achieved MRL 10 and are expected to be predominantly at the certification or industrialisation stages. For these substitution plans (which are from several member companies), there is still expected to be a need for the use of Cr(VI).

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

4 Continued Use Scenario

4.1 Introduction

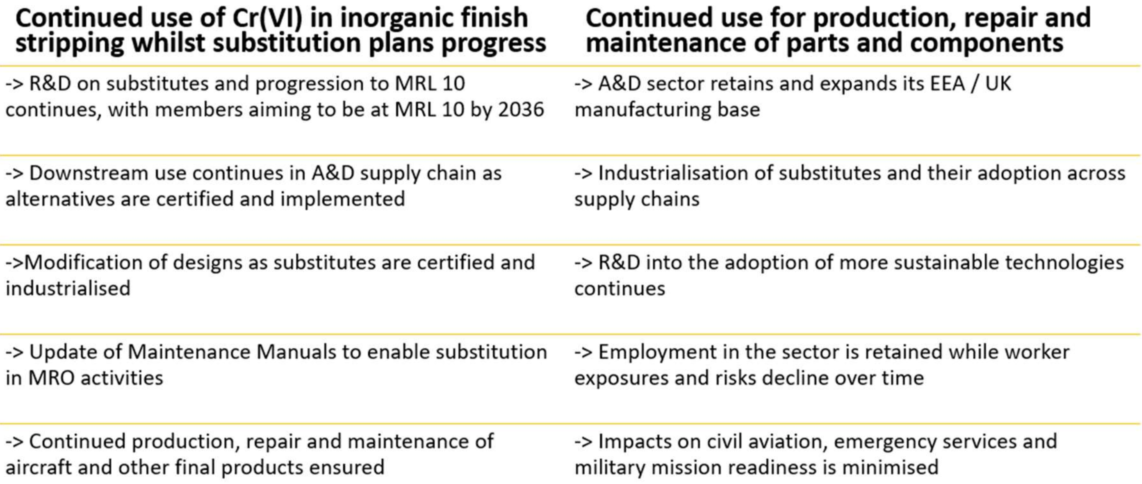
Section 3 provided an analysis with respect to the technical feasibility, economic feasibility, availability, risk reduction, and suitability of alternatives. The assessment highlights the importance of Cr(VI) for inorganic finish stripping, in its application to substrates including (but not limited to) aluminium (and it alloys), magnesium (and its alloys) and steel. Although some of the companies supporting this use have industrialised alternatives for some components, this is not feasible across all components or products given varying coatings, operational performance requirements and substrates.

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

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

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

The continued use scenario can be summarised below:



Continued use of Cr(VI) in inorganic finish stripping 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 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 inorganic finish stripping, including projected tonnages over the requested review period based on design owners' substitution plans; and
- The risks associated with the continued use of the chromates.

4.2 Market analysis of downstream uses

4.2.1 Introduction

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

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

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

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

4.2.2 Overview of the European aerospace sector

In 2020, the European A&D industry comprised of over 3,000 companies of all sizes and employed over 880,000 highly skilled employees (with these figures including the UK[30]). 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".[31] **Figure 4-1** provides details of turnover and employment for the industry in 2020, based

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

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

on the AeroSpace, Security and Defence Industries Association of Europe (ASD) publication "2021 Facts & Figures".[32]

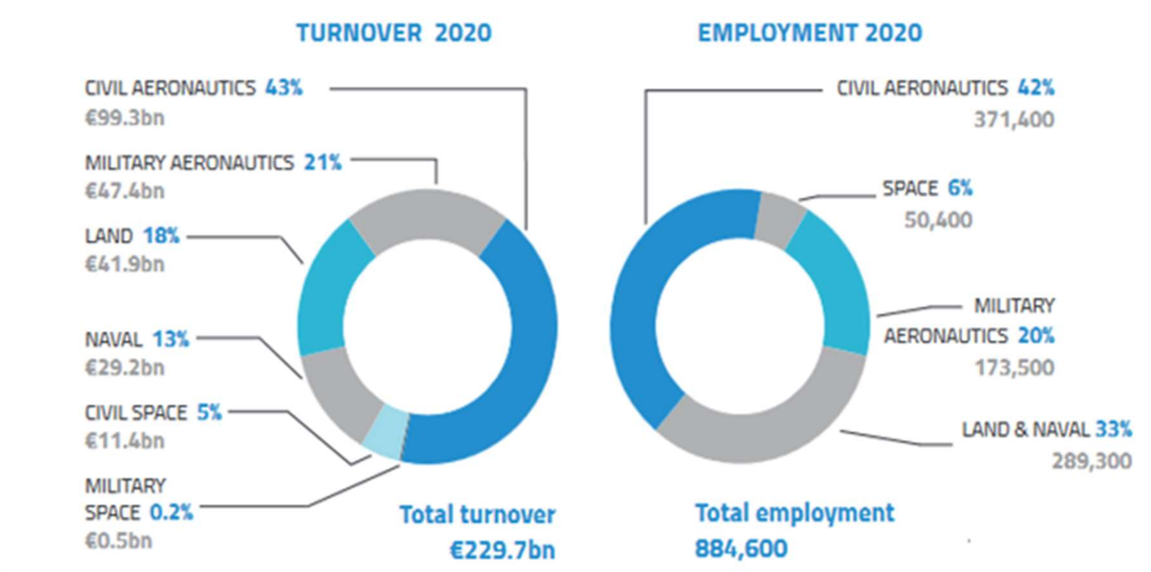

Figure 4-1: Turnover and employment for the European aerospace and defence industry in 2020

Source: 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 for the sector in 2020.

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

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

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

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

- Aircraft and other A&D products remain in service over long time periods. For example, the Boeing 747 first entered service in 1970, and continues to be flown and produced in 2022 (although it will now go out of production but remain in service). Given the need to ensure on-going airworthiness, and due to certification requirements, there will continue to be a "legacy" demand for the use of chromates in the production of components for maintenance, repair and overhaul of existing aircraft and equipment, as well as for models that are still in production for long periods after the first aircraft or military products were placed on the market.

- A&D technologies take many years to mature. Product development is a five to ten-year process, and it can take 15 years (or more) before the results of research projects are applied in the market. As part of the development and roll-out of new A&D products, OEMs must be ready to demonstrate fully developed technologies, or they risk losing contracts that may have a lasting effect on business.[33]

- The long product development process applies not only to the introduction of new technologies, but also to 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 inorganic finish stripping processes proving one of the most difficult tasks, in part due to its process flow (see **Figure 2-2**) and relationship with other surface treatments.

- There are over 20,000 commercial aircraft and 15,000 business jets currently in operation globally. Given the global nature of civil aviation, it is important that global solutions are found for inorganic finish stripping, with respect to maintenance, repair and overhaul (MRO) operations. 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 inorganic finish stripping

4.2.3.1 Overview of use and downstream users

As noted in section 2, inorganic finish stripping is a common use of chromium trioxide (CT) and sodium dichromate (SD) within the aerospace sector. This includes in-house use by the major OEMs and DtB companies, as well as use by BtP suppliers and both military and civilian MROs.

It is relevant to production, repair, maintenance, and overhaul of a range of different components, with examples identified through consultation being as follows:

- Landing gear
- Gear systems
- Propellers
- Airframe fasteners
- Engine bolts
- Rotor assemblies.

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

SEA questionnaire responses were provided by 25 A&D companies undertaking inorganic finish stripping (28 when considering the EEA and UK separately), with these companies operating across 25 EEA sites and 13 UK sites.

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

Table 4–1: Numbers of SEA respondents undertaking inorganic finish stripping

Role (and total number of companies)	Number of companies/sites undertaking inorganic finish stripping				Company Size[34]	
	EEA		UK		EEA	UK
	Companies	Sites	Companies	Sites	Companies	Companies
Build-to-Print	3	3	7	8	1 small 1 medium 1 large	5 small 1 medium 1 large
Design-to-Build	2	2	3	3	1 medium 1 large	1 medium 2 large
MRO only	6	10	1	1	2 medium 4 large	1 large
OEM	5	10	1	1	5 large	1 large
Total *	16	25	12	13		

*Some of the OEMs members have sites in both the EU and UK. In total, 25 companies provided a response, but some reported for the purposes of both EU and UK REACH. There is therefore overlap in the number of companies but there is no overlap in the figures given for the number of sites.

4.2.3.2 Economic characteristics

Table 4–2 provides a summary of the number of companies identifying their activities against different NACE codes, which are used here to develop the economic characteristics of the “typical” OEM, DtB, BtP or MRO company. Companies may have indicated more than one NACE code as being relevant to their activities, such that the number of relevant NACE code counts is higher than the number of SEA responses relevant to inorganic finish stripping alone. It is notable that most companies identified “treatment and coating of metals” as a relevant NACE code, while at the same time identifying other relevant codes.

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

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

Table 4–2: Economic characteristics of "typical" companies by NACE in sectors involved in inorganic finish stripping (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	20	20.88	54,000	35,500	15.5%
C2540 - Manufacture of weapons and ammunition	1	306.44	70,000	42,500	12.3%
C2594 - Manufacture of fasteners and screw machine products	3	57.20	65,000	43,200	9.7%
C2599 - Manufacture of other fabricated metal products n.e.c.	7	57.20	65,000	43,200	9.7%
C265 - Manufacture of instruments and appliances for measuring, testing and navigation;	0	159.30	84,000	57,500	11.1%
C2815 - Manufacture of bearings, gears, gearing and driving elements	3	284.64	72,000	44,500	4.8%
C3030 - Manufacture of air and spacecraft and related machinery	6	1,214.65	98,000	76,400	7.9%
C3040 - Manufacture of military fighting vehicles	2	1,214.65	99,000	64,800	11.2%
C3316 - Repair and maintenance of aircraft and spacecraft	10	71.33	85,000	56,400	9.8%
Other	2	NA	NA	NA	8.4%
Total count	54				
Note: The count total is by number of NACE code identifications by company and not by sites, with 25 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 the UK) linked to inorganic finish stripping and taking into account the size distribution of the companies[35] 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, therefore 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[36] as a percentage of turnover (the GOS rate) is also used here to provide an indication of the profits associated with the turnover generated by these sites. This is based on a figure of 10.5% which is the average across the various NACE codes weighted by the number of companies declaring each NACE code.

As can be seen from **Table 4–3**, the 38 sites for which data were collected via the SEA questionnaire represent an estimated €15 billion in turnover and €2 billion in GOS as a proxy for profits. Across all 110 sites expected to be undertaking inorganic finish stripping in the EEA and UK, these figures rise to around €46 billion in turnover and €5 billion in GOS.

Table 4–3: Key turnover and profit data for market undertaking inorganic finish stripping (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
25 EEA Sites	13,176	1,449
13 UK sites	1,982	218
Extrapolation to all sites involved in chromate-based inorganic finish stripping in the EU or UK		
90 EEA sites	40,355	4,439
20 UK sites	5,886	648

Source: Based on SEA questionnaire responses, combined with Eurostat data

4.2.3.3 Economic importance of inorganic finish stripping to revenues

Inorganic finish stripping will only account for a percentage of the calculated revenues, GVA and jobs associated with the figures given in **Table 4–2**. To understand its importance to the activities of individual companies, a series of questions were asked regarding other processes carried out,

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

[36] 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).

production costs, and the share of revenues generated from the use of chromates in inorganic finish stripping.

As the supply chains covered by this SEA vary from manufacturers of small components to producers of much larger components (e.g., components for landing gear versus doors and/or skirts), the responses vary significantly across companies. For the design owners, inorganic finish stripping continues to be a critical surface treatment step, the loss of which would result in loss of a significant level of turnover. The inability to continue inorganic finish stripping would jeopardise the ability to perform the rest of the processes in the surface treatment system due to the inability to meet airworthiness requirements, even though as a process it accounts for only a very small percentage of production costs.

In addition, responses to the SEA questionnaire highlight that inorganic finish stripping is an important component of process flows for conversion coating, anodising, and passivation of non-aluminium metallic coatings. **Table 4–4** sets out the number of companies that indicated that they also carry out conversion coating, anodising and/or passivation of non-aluminium metallic coatings. This includes both Cr(VI)-based and non-Cr(VI) based surface treatments as part of a certified system.

Table 4–4: Number of companies undertaking surface treatments relevant to inorganic finish stripping

Role	Number of companies also undertaking conversion coating		Number of companies undertaking anodising		Number of companies also undertaking passivation of non-aluminium metallic coatings	
	Cr(VI) based	**Non-Cr(VI) based**	**Cr(VI) based**	**Non-Cr(VI) based**	**Cr(VI) based**	**Non-Cr(VI) based**
Build-to-Print	9	5	7	7	8	3
Design-to-Build	5	1	3	3	3	2
MRO only	6	0	5	1	4	0
OEMs	3	2	5	2	3	3
Total	**23**	**8**	**20**	**13**	**18**	**8**

Given the importance of inorganic finish stripping for removal of surface treatments, there is no direct linkage between the share of production costs linked to inorganic finish stripping and revenues; the loss of inorganic finish stripping would have a far greater impact on revenues and the financial viability of the companies involved than suggested by its share of production costs. Inorganic finish stripping is used as part of a process, and therefore the revenue generated will not just consider inorganic finish stripping but also subsequent treatments such as conversion coating.

Nevertheless, it is relevant to consider the extent to which the production costs at different companies/sites relate to these activities. Based on responses from all 25 companies, 65% state that inorganic finish stripping makes up less than 5% of all production costs. More generally, 60% of all companies stated that Cr(VI)-based activities make up more than 75% of their revenue.

Table 4–5 provides a summary of responses on the revenues generated by inorganic finish stripping. As can be seen from this table, 72% of responders indicated that over 50% of their revenues were linked to Cr(VI)-based processes. Of note is the fact that five of these were OEMs, whose main sources of revenues will be the sale of large assemblies or of finished aircraft/hardware.

Table 4–5: Number of companies reporting proportion of revenues generated by or linked to the set of Cr(VI)-using processes

	<10%	10% - 25%	25% - 50%	50% - 75%	>75%
Build-to-Print	0	0	1	2	6
Design-to-Build	1	0	0	0	4
MROs	2	2	1	1	0
OEMs	0	0	0	0	5

These responses cover multiple sites and only reflect those companies carrying out the activities
*NOTE – 3 companies did not respond this question

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

4.2.3.4 Past investments

OEMs

OEMs have carried out R&D into the substitution of Cr(VI) for over 30 years, but as detailed in Section 3 technical difficulties remain in substituting the use of chromium trioxide and sodium dichromate in inorganic finish stripping. Although some have developed, validated, qualified, and are currently certifying, alternatives for use in the manufacture of their final products, others are still in the testing and development phase. These differences are driven by differences in operating performance requirements, coatings, and substrates across final products.

Examples of R&D expenditure outside of the larger joint programmes include new test lines costing €58,400, and general research costs up to €128,160. Both investments were made after 2020.

Another company spent almost €8,000 on improvement of water treatment processes in 2021. This is expected to have a lifetime of 20 years.

Certification costs for one company from 2018 until November 2021 were quoted at almost €6 million.

Design-to-Build suppliers

DtB companies have carried out R&D into alternatives for inorganic finish stripping either themselves or in cooperation with their customers or suppliers (i.e., OEMs). This investment has included repurposing a plant to enable pilot trial activities, as well as participation in the research initiative described in Section 3.

One company stated that they had invested €80,000 on the purchase of new baths in 2019. Another stated expenditure of €800,000 on NADCAP required equipment in 2018, with a lifetime of 10 years. This company additionally spent €400,000 on NADCAP certification.

Build-to-Print suppliers

BtP suppliers rely on their customers (OEMs and/or DtBs) to mandate the requirements of the products they manufacture, including the use of chromates in inorganic finish stripping. 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 BtP company quotes expenditure of £750,000 (around €872,000) on equipment including rectifiers, tanks, inductors, and process area development from 2007 to date. Another has spent £50,000 (around €58,000) in 2019 on modifications to workplace LEV.

MROs

As would be expected given their role in the value chain, MROs have not been involved in R&D regarding substitution of Cr(VI) in inorganic finish stripping.

One MRO had invested €3.3 million on construction of a hall for chemical processes, treatment plant, and laboratory in 2017. Another has spent €4 million across improving their Cr(VI)-based process and €1 million on research and development.

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 if they expected potential future benefits to using alternatives under the continued use scenario 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, and companies were 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, the majority of 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 Cr(VI)-based inorganic finish stripping prepares metal substrates for further surface treatment. These treatments provide multiple properties including corrosion prevention to civil aviation and other aerospace products, that must operate safely and reliably, across different geographies. The extreme service conditions require a high level of performance, while the potentially severe consequences of failure require a high level of certainty of that performance.

Because Cr(VI)-based inorganic finish stripping cannot be fully substituted at present, it plays a critical role in ensuring the reliability of aircraft and adherence to safety standards. Thus, although the economic importance of the chromates in inorganic finish stripping is indirect in nature, its significance is clear with respect to:

- The ability of MRO companies to undertake their activities within the EEA, including the ability to carry out repairs with short turn-around times;

- The importance of timely MRO services to airlines and military fleets, given the costs associated with aircraft being grounded and out of service for increased periods of time;

- The impacts that increased groundings 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 but globally; and

- Impacts on defence operations, including the potential unavailability of critical equipment and impaired operations during military missions.

The economic importance of ensuring that aircraft retain their airworthiness is illustrated by the figures quoted in section 2.3.3.8 for the number of air passengers transported in the European Union in 2019 (over 1 billion), as well as the net profits of the airlines in 2019 at US$ 6.5 billion. The military importance cannot be quantified in the same manner; however, the involvement of MoDs in supporting this combined AoA/SEA through the provision of information demonstrates the critical nature of Cr(VI)-based inorganic finish stripping to on-going mission readiness.

The economic importance of ensuring the continued use of Cr(VI)-based inorganic finish stripping until alternatives are certified is also demonstrated by the expected future growth of the A&D sector.

4.2.4.2 Expected growth in the EEA and UK aerospace and defence sectors

Demand for new civilian aircraft is expected to grow into the future. Projected global compound annual growth rates for different aircraft classes for the period 2020-2031 are given in **Figure 4–2** below[37], with this suggesting an overall Compound Annual Growth Rate (CAGR) from 2020 to 2031 of around 2.5%.

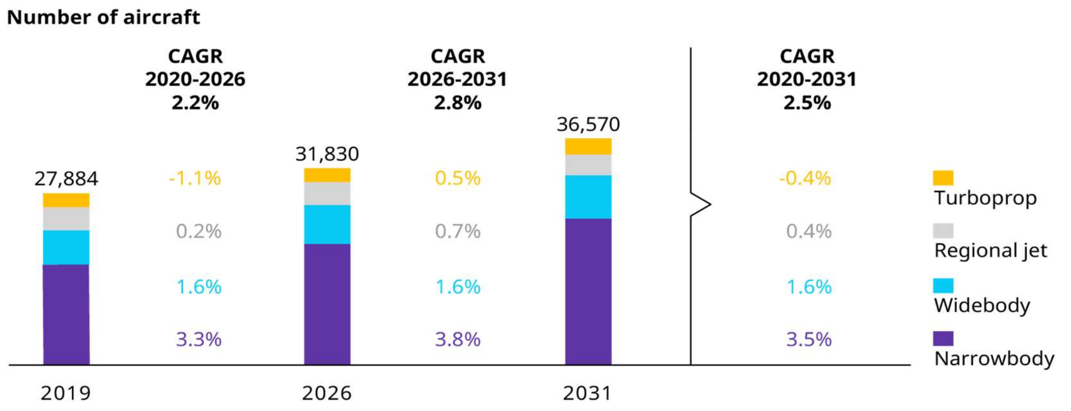

Figure 4–2: Global fleet forecast by aircraft class, 2020-2031
***Source:* Oliver Wyman analysis**

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

Market reports issued by Airbus and Boeing indicate that future growth is expected to extend beyond 2031. Airbus' Global Market Forecast for 2022-2041 predicts that passenger air traffic will grow at 3.6% CAGR and freight traffic will grow at 3.2% CAGR globally. By 2041, there will be some 46,900 aircraft in service, with this including an estimated 39,500 new passenger and freighter aircraft and the retirement of some of the older aircraft. This includes delivery of new aircraft for the European market, as well as the Asian and Chinese markets in particular[38].

Boeing's 2022 Commercial Market Outlook[39] indicates a similar level of increase, noting that the global fleet will increase by around 80% through to 2041, forecasting the value of new aeroplane deliveries at around US $7.2 trillion (based on a slightly higher growth in traffic at around 3.8% CAGR).

Based on public figures available on Airbus' website, the demand for new aircraft will progressively shift from fleet growth to accelerated replacement of older, less fuel-efficient aircraft. This will mean a need for over 39,000 new passenger and freighter aircraft, delivered over the next 20 years - around 15,250 of these will be for replacement of older less fuel efficient models. By 2040, the vast majority of commercial aircraft in operation will be of the latest generation[40]. Projections based on generic neutral seating categories (100 plus seater passenger aircraft and 10 tonnes plus freighters) are given in **Table 4-6** below.

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

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

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

When considering these figures, it is important to recognise that the European aerospace sector is a global exporter of aircraft. However, unless operations in the EEA and UK can remain financially viable in the short to medium term, it is unlikely to be feasible for EEA/UK based OEMs to carry out

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

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

[40] https://aircraft.airbus.com/sites/g/files/jlcbta126/files/2021-11/Airbus%20Global%20Market%20Forecast%202021-2040.pdf

manufacturing at the levels implied by these compound annual growth rates. As a result, manufacture of these newer generations of aircraft and military products may shift to locations outside the EU with a consequent loss in Gross Value Added (GVA) to the EU and UK economies, with impacts also on employment.

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 parts market encompasses the market for both new and used rotable[41] parts available as spares for aircraft and components. This market was projected to grow with a CAGR of over 4% over the period from 2022-2027, although this rate may now be lower due to COVID-19. Growth is due to the increase in the commercial aircraft fleet as well as the need for timely MRO services to keep the aircraft fleet fuel-efficient and to reduce aircraft emissions. In addition, the anticipated replacement of older craft will result in an on-going reduction in the need for the use of chromates in the manufacture of spare parts and as part of MRO activities. However, in the short to medium term, demand for their use will continue.

The MRO market was significantly affected by COVID-19 in 2020 but saw a gradual increase in demand as travel restrictions were lifted in 2021 and is expected to see positive growth over the next 5 to 10 years. Globally, the market is expected to have a CAGR of over 3% over the period from 2022-2027, as illustrated in **Figure 4–3**.[42, 43]

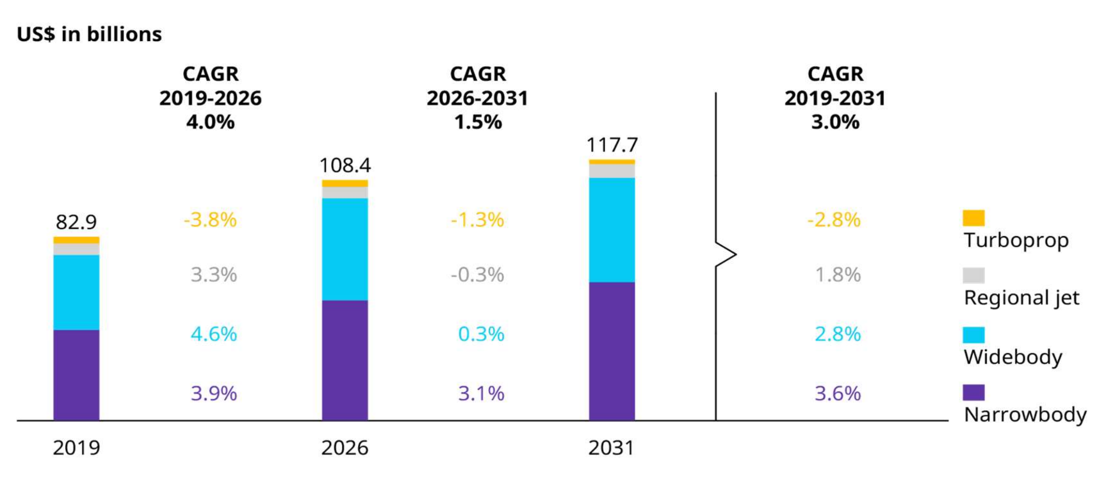

Figure 4–3: MRO market forecast by aircraft class, 2019-2031
Source: Oliver Wyman analysis

This growth is due to two 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 on revenues and profit margins, more airlines

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[41] 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.

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

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

are expected to resort to MROs to maintain fleet efficiency; 2) Increases in fleet sizes over the next five years will also lead to a continued growth in demand for maintenance and repair activities.

In addition to the above, EEA/UK exports would be impacted given the important role that aerospace and defence products play in the overall balance of trade. For example, France and Germany alone had export markets totalling over US$ 57 billion in 2020, while the UK export market was around US$ 13.2 billion in 2020[44].

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 4,700 kg Cr(VI) per year per site using multiple chromates, with tonnages for each chromate at individual sites as follows:

- 0 to 9 000 kg CT used per year, thereof up to 4 700 kg Cr(VI)
- 0 to 10 kg SD used per year, thereof up to 4 kg Cr(VI)

At most sites, CT is used for inorganic finish stripping.

4.3.2 Consultation for the SEA

Most SEA respondents (not included in the CSR work) identifying inorganic finish stripping as important to their turnover indicated total chromate use levels in the region of tens of kg per annum to around 1000kg per annum. 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 upper bound figures quoted in the SEA responses and extrapolating to the 90 EEA and 20 UK sites, and also taking into account the maximums found in the CSR work, the maximum tonnages of the chromates used in inorganic finish stripping have been calculated. The maximum tonnes per annum (t/a) are as follows for 2024 (assuming no decline from 2022 levels):

- EEA tonnage for 90 sites in ADCR supply chain: 50 t/a CT and 1 t/a SD
- UK tonnage for 20 sites in ADCR supply chain: 11 t/a of CT and 0.2 t/a SD

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

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

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 382 notifications relating to the REACH Authorisations listed above covering 508 sites across the EU-27 (and Norway).

The distribution of notifications by substance and authorisation is summarised in **Table 4-7**[45]. Use of sodium dichromate by the aerospace and defence industry under parent Authorisations which are not being renewed may shift to those covered by this RR, and figures associated with them are included here for completeness. Note that Authorisations 20/18/21-25 relate to aeroderivative uses of chromium trioxide for surface treatment, but these uses will occur at the same sites as notifying for A&D uses and would therefore result in double-counting.

Table 4-7: Article 66 Notifications to ECHA

Substance	Authorisation	Authorised Use	Notifications	EU Sites
Chromium trioxide	20/18/14-20	Surface Treatment for aerospace	263	357
Sodium dichromate	20/5/3-5	Surface Treatment for aerospace	61	84
	20/4/1	Surface Treatment for aerospace	58	67
Totals			**382**	**508**

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

Use of sodium dichromate by the aerospace and defence industry under parent Authorisations, which are not being renewed may shift to those covered by this RR, and figures associated with them are included here for completeness.

Since there are more sites than notifications, it is assumed that some notifications cover more than one site[46]. Some sites may, of course, use both chromium trioxide and sodium dichromate.

It is important to stress that these notifications relate to 'surface treatment', which covers many more processes than inorganic finish stripping. Indeed, only eight of the notifications received by ECHA include specific reference to 'stripping'. The associated quantities are low – less than 1 t/yr.

With these points in mind, the estimated 90 sites is consistent with the ECHA data on downstream user notifications of REACH authorised uses of chromates with an associated consumption of about 60 tonnes per annum (mostly chromium trioxide – estimated 50 tonnes per annum).

4.3.4 Projected future use of the chromates

The aerospace sector is actively working to phase out the use of Cr(VI). However, as indicated by the substitution plans, it will take further time to qualify, validate, certify, and implement alternatives within the supply chain across all components and products for A&D industry. Individual companies

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

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

are at different points along this path, although there are also variations based on specific aircraft/defence application and across different types of components/final products.

OEM responses to the SEA questionnaire indicate a downward future trend in the use of Cr(VI) over the review period, despite the increase in demand for new aircraft and defence final products (although these responses were also provided prior to the war in Ukraine). However, it is also clear that almost half of the respondents will require a further 12 years to finalise R&D, development, testing, qualification, validation, certification, and industrialisation of alternatives at an industrial level. This also involves making changes to specifications, drawings, and maintenance manuals. A key reason cited for requiring a 12-year period relates to complexity of what needs to be achieved. As noted by respondents:

- *"It is tied with anodising. We will need the same period for replacement of both processes."*
- *"We are uncertain whether there are technical alternatives available on the market. Therefore, we assume to need 5 years for technical tests; followed by 3 years of qualification with the customer, and another 2-3 years for changing of the drawings/technical specifications of the customer."*
- *"We are advanced in alternative testing, but the process creates new and different EHS and wastewater concerns due to the presence of ammonia. Alternative cannot be implemented until an environmentally compliant closed loop system is funded, installed and tested."*
- *"Stripping of anodize without removing additional base metal is a major problem with tightly controlled parts; dimensions less the 0.001 inches tolerance. We do not have a non-chromate alternate for those applications."*

Companies repeatedly mentioned the co-dependency of uses, particularly the requirement for inorganic finish stripping of surfaces which have been anodised. Therefore, companies state that they cannot fully substitute chromates in inorganic finish stripping until use of Cr(VI) in anodising has also been substituted.

It is important to note that this planned reduction in usage by the OEMs will also impact on their BtP and DtB suppliers, as well as MROs, given that OEM specifications are the key driver for all suppliers/MROs. All BtP respondents indicated that use of chromates was required by their customers', or due to OEMs' requirements for MRO activities, as they rely on their design owners' specifications. This is not surprising given their role in the A&D value chain, and their reliance on design owners certifying alternatives for use in the production of different components. Additionally, all DtB companies stated that they use the chromates due to OEM requirements.

As indicated above, MROs had difficulty predicting whether they would be able to move away from the use of chromates by and after 2032. Some expected use to decrease as alternatives are implemented and components/final products are certified, others for use to increase, while the majority expected it to either remain steady or were uncertain.

It is clear though, that continued use of the chromates will be required for a further 12 years (and potentially longer for some military products) as substitution efforts progress, and to allow sufficient time for implementation (including a contingency period for setbacks). In particular, MROs, who are dependent on design owners' certifying alternatives, will require the use of chromates for inorganic finish stripping for a full 12 years, given the time periods required by the design owners to finish certification activities.

The responses also made clear that MROs and some companies producing spare components would require chromate use beyond the 12 years requested. The long service life of aircraft and military products combined with the infeasibility of gaining new certifications for products that have already been in service for long periods, makes this a small, but essential use for up to 20 years.

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

4.4 Risks associated with continued use

4.4.1 Classifications and exposure scenarios

4.4.1.1 Human health classifications

The chromates were included into Annex XIV of Regulation (EC) No 1907/2006 due to their intrinsic properties (mutagenic, carcinogenic, and 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 (ECHA, 2015)[47]:

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

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[47] 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

4.4.1.2 Overview of exposure scenarios

All sites that perform inorganic finish stripping within the ADCR supply chains are specialised industrial sites being active in the EEA or the UK. They have rigorous internal health, safety, and environment (HSE) organisational plans. A mix of technical, organisational and personal protection-based measures are in place to reduce workplace exposures. The sites adhere to best practices to reduce workplace exposures and environmental emissions to as low as technically and practically feasible and use automated processes to the 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 inorganic finish stripping activities. See the CSR for further details of measures in place.

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

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

Table 4-8: Overview of exposure scenarios and their contributing scenarios

ES number	ES Title	Environmental release category (ERC)/Process category (PROC)
ES1-IW1	Inorganic finish stripping – use at industrial site	
Environmental contributing scenario(s)		
ECS 1	Inorganic finish stripping – 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 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 inorganic finish stripping. The calculated exposure levels and associated excess cancer risks are presented below. For further information on their derivation see the CSR.

4.4.2.1 Worker assessment

Excess lifetime cancer risks

The findings of the CSR with respect to worker exposures are summarised in **Table 4-9** below, which presents the excess lung cancer risks to workers involved in inorganic finish stripping related activities. The risks are calculated using a combination of measured inhalation data and modelling for different SEGs (Similar Exposure Groups). The SEGs include:

- WCS1: Line operators who may be involved in a range of activities including immersion of parts into a treatment bath and sampling of the treatment baths;
- WCS2: Storage area workers who decant liquids and measure solids, clean containers, handle solid wastes, undertake bath make-up and cleaning of baths as part of bath renewal;
- WCS3: Laboratory technicians who may be involved in sampling of treatment baths and laboratory analysis of treatment bath solutions;
- WCS4: Maintenance and/or cleaning workers who carry out maintenance and cleaning of equipment and handling of solid wastes; and
- WCS6: Incidentally exposed workers, who include those workers spending part of their time in the work area where treatment baths are located but do not carry out the tasks with direct exposure themselves.

Table 4-9 sets out the excess lifetime cancer risk for workers involved in each of the above tasks. **Table 4-9** also indicates the number of workers on average that may be exposed per typical site, with this figure taken into account in estimating the total number of workers exposed across all 90 EEA sites and 20 UK sites that would continue to carry out inorganic finish stripping.

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

#	SEG	Average number of workers per site	Excess lifetime lung cancer risk [1/υg/m^3]
WCS1	Line operators	5	1.31E-03
WCS2	Storage area workers	4	1.07E-04
WCS3	Laboratory technicians	3	NA
WCS4	Maintenance and/or cleaning workers	3	3.84E-04
WCS5	Incidentally exposed workers	6	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[48]. The approach to not perform a regional assessment for human Cr(VI) exposure via the environment as part of AfAs for chromate uses was also supported in compiled RAC and SEAC (Socio-economic Analysis Committee) opinions, as described for example in the *Opinion on an Application for Authorisation for Use of Sodium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites and sealings of anodic films* (ID 0043-02). This reference states that regional exposure of the general population is not considered relevant by RAC[49].

The assessment presented in the CSR is based on measured data for emission to air and wastewater. For this assessment, combined exposure of humans via the inhalation (air) and the oral (uptake of water and fish) route is considered. Data were available from 8 sites undertaking inorganic finish stripping to act as the basis for estimating exposure concentrations and associated risks. Air emissions from site 3 and consequently the local PEC in air is much higher than from all other sites. This is due to the total tonnage of CT used at the site and the high percentage used for inorganic finish stripping (the total tonnage deployed at the site is used almost exclusively for inorganic finish stripping). This is a special situation not encountered at any other site. Therefore, the CSR considers this site separately for the risk evaluation. The resulting maximum figures (discounting site 3) are provided in **Table 4-10** below.

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

Inhalation		Oral		Combined
Local Cr(VI) PEC in air [µg/m3]	**Inhalation risk**	**Oral exposure [µg Cr(VI)/kg x d]**	**Oral risk**	**Combined risk**
7.92E-05	2.30E-06	4.83E-04	3.87E-07	2.30E-06

a) RAC dose-response relationship based on excess lifetime lung cancer risk (ECHA, 2013): Exposure to 1 µg/m3 Cr(VI) relates to an excess risk of 2.9x10-2 for the general population, based on 70 years of exposure; 24h/day.

b) RAC dose-response relationship based on excess cancer risk for tumours of the small intestine (ECHA, 2013): Exposure to 1 µg/kg bw/day Cr(VI) relates to an excess risk of 8x10-4 for the general population, based on 70 years of exposure; daily exposure.

4.4.3 Populations at risk

4.4.3.1 Worker assessment

Numbers of workers exposed based on Article 66 data

The Article 66 data on numbers of staff (workers) exposed to chromium trioxide and sodium dichromate is summarised in **Table 4-11**, below, for those Authorisations relevant to the continued

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[48] European Chemicals Bureau, 2005 "European Union Risk Assessment Report" for chromate https://echa.europa.eu/documents/10162/3be377f2-cb05-455f-b620-af3cbe2d570b

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

use in inorganic finish stripping. Included in this table are Authorisations which will expire in 2024 and whose holders will not be seeking re-authorisation for the aerospace supply chain relevant to ADCR. As there is the potential for the applicants of this Review Report to begin supply to downstream users who are not supporting the ADCR, the numbers of exposed staff relevant to the original CTAC parent authorisations is presented here. Use of sodium dichromate by the aerospace and defence industry under parent Authorisations which are not being renewed may shift to those covered by this RR, and figures associated with them are included here for completeness. Note that Authorisations 20/18/21-25 relate to aeroderivative uses of chromium trioxide for surface treatment, but these uses will occur at the same sites as notifying for A&D uses and would therefore result in double-counting.

No similar data are publicly available for the UK.

Table 4-11: Number of workers exposed - Article 66 Notifications data

Substance	Authorisation number	Staff Exposed
Chromium Trioxide	REACH/20/18/14 to REACH/20/18/20	1107
Sodium Dichromate	REACH/20/5/3 to REACH/20/5/5	450
	REACH/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

Note that Authorisations 20/18/21-25 relate to aeroderivative uses of chromium trioxide for passivation, but these uses will occur at the same sites as notifying for A&D uses and would therefore result in double-counting.

Use of sodium dichromate and potassium dichromate by the aerospace and defence industry under parent Authorisations, which are not being renewed may shift to those covered by this RR, and figures associated with them are included here for completeness.

Number of workers based on SEA questionnaire data

Responses to the SEA questionnaire indicate that around 390 workers (FTE) are directly involved in Cr(VI)-based inorganic finish stripping across the 38 sites covered by responses, this is broken down into **Table 4–12** below by role in the supply chain and extrapolated out to the 90 EEA and 20 UK sites.

Table 4–12: Number of employees undertaking inorganic finish stripping across the EEA and UK

Type of company	Number of sites EEA	Number of sites UK	No of employees EEA	No of employees UK	Total
Number of workers 38 sites involved in inorganic finish stripping					
Build-to-Print	3	8	12	12	24
Design-to-Build	2	3	21	42	63
MRO only	10	1	120	10	130
OEM	10	1	156	14	170
Total 38 sites	**25**	**13**	**309**	**78**	**387**
Average per site			**12**	**6**	**10.2**

Table 4–12: Number of employees undertaking inorganic finish stripping across the EEA and UK

Type of company	Number of sites EEA	Number of sites UK	No of employees EEA	No of employees UK	Total
Number of workers at 90 EEA sites and 20 UK sites involved in Inorganic finish stripping					
Build-to-Print	30	10	120	15	135
Design-to-Build	15	4	158	56	214
MRO only	15	2	180	20	200
OEM	30	4	468	56	524
Total 110 sites	**90**	**20**	**926**	**147**	**1073**

In total, this translates to around 930 exposed workers in the EEA and around 150 in the UK, or between 6 and 12 per site. These figures are considered consistent with the CSR assumptions on the number of workers exposed to the chromates, which totals to 15 per site on average excluding machinists and incidentally exposed workers.

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

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

Table 4–13: Number of employees undertaking inorganic finish stripping across the EEA and UK

Worker Contributing Scenarios		Average No. Exposed from CSR	90 EEA sites	20 UK sites
WCS1	Line operators	5	450	100
WCS2	Storage area workers	4	360	80
WCS3*	Laboratory technicians	3	270	60
WCS4	Maintenance and/or cleaning workers	3	270	60
WCS5	Incidentally exposed workers	6	540	120
Total		**21**	**1890**	**420**
Excluding WCS5 & 6		**15**	**1350**	**300**
***Not considered further**				

4.4.3.2 Humans via the Environment

Exposed Local Populations

The relevant local population exposure to humans via the environment (HvE) 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; and
- The relevant distance from sites for the local assessment, taken as the default assumption of a 1000 m radius (or 3.14 km^2).

A 1000 m radius is adopted here to estimate the exposed population as, for most sites, the HvE results are driven by emissions to air. Oral exposure risks are typically much lower and for two of the sites no wastewater is released. As a result, adopting the EUSES default assumption related to the capacity of local sewage treatment plants would over-estimate the number of inhabitants that may be exposed due to emissions from each site.

The resulting estimates of the number of people exposed within the general population are given in **Table 4–14** for both the EEA and UK. The total number of humans exposed via the environment in the EEA is estimated at just over 39,000, with the UK figure being around 26,600 (the UK figure appears disproportionately high due to the UK's high population density).

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

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

Countries with DUs	No. Sites per country	Population density per km^2	Exposed local population within 1000m radius
France	31	118	11344
Germany	13	232	9184
Italy	11	200	6786
Spain	7	92	2081
Poland	8	123	3130
Czech Republic	4	135	1527
Sweden	3	23	195
Finland	2	16	101
Netherlands	1	421	1323
Belgium	1	376	1181
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	**90**		**39417**
UK	**20**	**424**	**26641**

4.4.4 Residual health risks

4.4.4.1 Introduction

Under the Applied-for-Use Scenario, use of chromates in inorganic finish stripping will continue after the end of the review period for a total of 12 years.

In December 2013, the Risk Assessment Committee (RAC) agreed lifetime (i.e., for 40 years and 70 years of exposure) mortality risk estimates associated with carcinogenicity for workers and humans via the environment exposed to Cr(VI) substances[50]. It assumes a linear relationship for both lung and intestinal cancer.

As the excess cancer risk estimates apply to each exposed worker for a total working life of 40 years, they need to be adjusted to reflect exposures over the length of the review period. Exposures are thus treated as separable over time, meaning that annual risk is equivalent to 1/40 of the risk over 40 years of exposure. For members of the general population, excess cancer risk estimates apply for a lifetime of 70 years, meaning that annual risk is equivalent to a 1/70 of the risk of 70 years of exposure.

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[50] ECHA (2013): Application for authorisation: Establishing a reference dose response relationship for carcinogenicity of hexavalent chromium. Helsinki, 04 December 2013. RAC/27/2013/06 Rev. 1 (agreed at RAC-27).

4.4.4.2 Morbidity vs mortality

Excess cancer cases need to be split between fatal and nonfatal cases. To this end, estimates of fatality and survival rates associated with lung and colorectum[51] cancer cases were derived from the Cancer Today database, see **Table 4-15** below.

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

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

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

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

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

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

In a similar fashion, the figures from Cancer Today reported in **Table 4-15** above are applied to the estimates to calculate the total number of additional fatal and non-fatal intestinal cancer cases[52].

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

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

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

Total excess cancer risk cases are calculated per line to reflect differences in activities, task allocation and exposure levels across the different sites. The number of excess cancer cases is calculated by multiplying the number of workers expected to be exposed in each task by the value of the excess cancer risk given above adjusted for the requested review periods, i.e., over 12 years. This value is then multiplied by the number of workers exposed in each WCS to calculate the total excess cancer cases arising from the continued use of Cr(VI) in inorganic finish stripping. **Table 4-16** and **Table 4-17** provide a summary of the results across all WCS for EEA and UK workers.

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

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

Table 4-16: Number of excess lifetime cancer cases to EEA workers

WCS	Number of persons exposed	LUNG CANCER - Excess lifetime cancer risk	Excess number of lifetime cancer cases	LUNG CANCER - Number of excess lifetime fatal cancer cases	LUNG CANCER - Number of excess lifetime non-fatal cancer cases
WCS1	450	1.31E-03	**0.59**	**0.47**	**0.12**
WCS2	360	1.07E-04	**0.04**	**0.03**	**0.01**
WCS4	270	3.84E-04	**0.10**	**0.08**	**0.02**
WCS5	540	1.00E-03	**0.54**	**0.43**	**0.11**
		Years - Lifetime	**40.00**	**1.00**	**0.27**
		Years - Review period	**12.00**	**0.30**	**0.08**
		Years - Annual	**1.00**	**0.03**	**0.01**

Table 4-17: Number of excess lifetime cancer cases to UK workers

WCS	Number of persons exposed	LUNG CANCER - Excess lifetime cancer risk	Excess number of lifetime cancer cases	LUNG CANCER - Number of excess lifetime fatal cancer cases	LUNG CANCER - Number of excess lifetime non-fatal cancer cases
WCS1	100	1.31E-03	**0.13**	**0.10**	**0.03**
WCS2	80	1.07E-04	**0.01**	**0.01**	**0.00**
WCS4	60	3.84E-04	**0.02**	**0.02**	**0.00**
WCS5	120	1.00E-03	**0.12**	**0.09**	**0.03**
		Years - Lifetime	**40.00**	**0.22**	**0.06**
		Years - Review period	**12.00**	**0.07**	**0.02**
		Years - Annual	**1.00**	**0.01**	**0.001**

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

The total number of people exposed via the environment as given in **Table 4–14** is multiplied by the excess cancer risk estimates to calculate the total excess cancer cases arising under the Continued Use scenario. The results are given in **Table 4–18**. The basis for estimating the number of people exposed per country is the percentage of Article 66 notifications made to ECHA per country, as described in Section 4.2, plus some adjustments based on SEA responses and the location of suppliers to the ADCR OEMs and DtB companies (and taking into account military sites).

Table 4–18: Number of excess cases in people exposed via the environment (local assessment) across the EU and UK

Countries with DUs	No. Sites per country	Population Density per km2	Exposed local population	Combined excess lifetime cancer risk	Excess number of lifetime cancer cases	Number of lifetime fata case
France	31	118	11344	**2.30E-06**	**2.61E-02**	**0.02**
Germany	13	232	9184	**2.30E-06**	**2.11E-02**	**0.02**
Italy	11	200	6786	**2.30E-06**	**1.56E-02**	**0.01**
Spain	7	92	2081	**2.30E-06**	**4.79E-03**	**0.00**
Poland	8	123	3130	**2.30E-06**	**7.20E-03**	**0.01**
Czech Republic	4	135	1527	**2.30E-06**	**3.51E-03**	**0.00**
Sweden	3	23	195	**2.30E-06**	**4.49E-04**	**0.00**
Finland	2	16	101	**2.30E-06**	**2.31E-04**	**0.00**
Netherlands	1	421	1323	**2.30E-06**	**3.04E-03**	**0.00**
Belgium	1	376	1181	**2.30E-06**	**2.72E-03**	**0.00**
Denmark	1	135	424	**2.30E-06**	**9.75E-04**	**0.00**
Hungary	1	105	330	**2.30E-06**	**7.59E-04**	**0.00**
Norway	1	14	44	**2.30E-06**	**1.01E-04**	**0.00**
Romania	1	82	258	**2.30E-06**	**5.93E-04**	**0.00**
Bulgaria	1	64	201	**2.30E-06**	**4.62E-04**	**0.00**
Ireland	1	69	217	**2.30E-06**	**4.99E-04**	**0.00**
Greece	1	82	258	**2.30E-06**	**5.93E-04**	**0.00**
Lithuania	1	43	135	**2.30E-06**	**3.11E-04**	**0.00**
Portugal	1	112	352	**2.30E-06**	**8.09E-04**	**0.00**
Slovakia	1	111	349	**2.30E-06**	**8.02E-04**	**0.00**
Total	**90**		**39417**	**2.30E-06**	**0.09**	**0.07**
				Years – Lifetime cases	**70.00**	**7.16E-**
				Years - Review period	**12.00**	**1.23E-**
				Years - Annual	**1.00**	**1.02E-**
UK	**20**	**424**	**26641**	**2.30E-06**	**6.13E-02**	**0.05**
				Years – Lifetime cases	**70.00**	**4.84E-**

			Years - Review period	**12.00**	**8.30E-03**	**2.21E-03**
			Years - Annual	**1.00**	**6.92E-04**	**1.84E-04**

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 2025 (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[53]. 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, although 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.

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[54] 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[55]. 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[56]. This suggests that the aforementioned figures should be multiplied by a factor of 1.12. Thus, the following values are employed in the analysis below:

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

In addition to these valuations, for the purpose of quantifying human health impacts, consideration has also been given to annual medical treatment costs for morbidity. A range of studies were identified that provide estimates of the costs of medical treatment for patients surviving lung and intestinal cancer. These are summarised in **Table 4-19**.

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

[54] 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.

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

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

Table 4-19: Alternative estimates of medical treatment costs

Study	Year for prices	Average direct costs in original units (per annum)	Direct costs in € 2021
Lung cancer			
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)			
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 1 year since diagnosis, 10% after 5 years, and 5% after 10 years[57]. With respect to intestinal cancer morbidity cases, we have taken a percentage survival of 76% after 1 year since diagnosis, 59% after 5 years, and 57% after 10 years[58]. Based on these time periods, the NPV of average future medical costs per lung cancer case is estimated at €30,110 in 2021 prices, using a 4% future discount rate. The NPV of average future medical costs per intestinal cancer case is estimated at €82,620 in 2021 prices. It is noted that a large percentage of people survive intestinal cancer after a period of 10 years and any stream of health care costs incurred after that is not incorporated in our calculations. However, such costs are not likely to be relevant considering that those surviving after such a long period of time can either be considered as definitely cured or probably only in need of a small degree of medical attention.

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

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

$$(4)\quad (\delta \times (€\ 3{,}920{,}000)) + (\eta \times (€\ 460{,}000 + €84{,}790)) = \text{Total intestinal cancer costs}$$

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[57] 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.

[58] These values are based on a study conducted by Cancer Research UK on adults aged 15-99 in England and Wales from 2009-2013. https://www.cancerresearchuk.org/health-professional/cancer-statistics/statistics-by-cancer-type/bowel-cancer/survival#heading-Zero

4.4.5.2 Predicted value of excess cancer cases with continued use: workers

Table 4-20 applies the economic value of the associated health impacts to these additional statistical cases of cancer to generate the total economic damage costs of the excess lung cancer cases. Under the Continued Use scenario, the present value costs are **€440,000 for the EEA and €98,000 for the UK**, based on the assumption that Cr(VI)-based inorganic finish stripping continues at the current level of use over the entire review period (this will lead to an overestimate of the impacts as the sector transitions to the alternatives over the 12-year period).

Table 4-20: Present value and annualised economic value of mortality and morbidity effects to workers (discounted over 12 years @4% per year, 20 year lag)

	EEA Workers		UK Workers	
	Mortality	Morbidity	Mortality	Morbidity
Total number of lung cancer cases	3.01E-01	8.01E-02	6.70E-02	1.78E-02
Annual number of lung cancer cases	2.51E-02	6.68E-03	5.58E-03	1.48E-03
Present Value (PV, 2024)	€ 426,472	€ 13,303	€ 94,772	€ 2,956
Total PV costs	**€ 439,775**		**€ 97,728**	
Total annualised cost	**€ 101,526**		**€ 22,561**	

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

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

Table 4-21 applies the economic value of the associated health impacts to the additional statistical cases of cancer for the general population (humans via the environment) to generate the total economic damage costs of the excess cancer cases. Under the Continued Use scenario, the present value costs are roughly **€18,000 for the EEA and €12,000 for the UK**, based on the assumption that inorganic finish stripping continues over the entire review period at 2024 tonnages; as indicated above, this reflects an overestimate of the levels of exposures as use declines with a transition to the alternatives over the 12-year period.

Table 4-21: Present value and annualised economic value of mortality and morbidity effects to the general population, local assessment (discounted over 12 years @4% per year, 20 year lag)

	EEA General Population		UK General Population	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cancer cases	1.23E-02	2.21E-03	8.30E-03	2.21E-03
Annual number of cancer cases	1.02E-03	2.72E-04	6.92E-04	1.84E-04
Present Value (PV, 2024)	€ 17,373	€ 592	€ 11,742	€ 400
Total PV costs	**€ 17,965**		**€ 12,142**	
Total annualised cost	**€ 4,147**		**€ 2,803**	

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

Since Cr(VI) is only used to remove finishes and as the surfaces treated with inorganic finish stripping are rinsed in water afterwards, no Cr(VI) from the stripping solution remains on the surface. Consequently, subsequent machining activities on treated components are not further included in this assessment.

4.4.7 Environmental impacts

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

Releases of wastewater containing Cr(VI) may occur from cleaning water and wash water from wet scrubbers. At all sites, wastewater is collected and treated by one or more of the following three options:

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

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

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

4.4.8 Summary of human health and environmental impacts from Continued Use

Table 4-22 provides a summary of the economic value of the human health impacts across the worker and local populations.

Table 4-22: Combined assessment of health impacts to workers and general population value of mortality and morbidity effects to workers (discounted over 12 years @4% per year, 20 year lag, figures rounded)

	EEA		UK	
	Mortality	**Morbidity**	**Mortality**	**Morbidity**
Total number of cancer cases	3.14E-01	8.23E-02	7.53E-02	2.00E-02
Annual number of cancer cases	2.61E-02	6.95E-03	6.27E-03	1.67E-03
Present Value (PV, 2024)	€ 443,845	€ 13,895	€ 106,514	€ 3,356
Total PV costs	**€ 457,740**		**€ 109,870**	
Total annualised cost	**€ 105,674**		**€ 25,364**	

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 (NUS)

5.1.1 Summary of consequences of non-use

The inability of companies to undertake inorganic finish stripping across the EEA and in the UK using one or more of the chromates would be severe. This use is critical for stripping previous surface treatments without damaging the substrate, on key components including landing gear and hydraulic flight control. This includes application to newly produced components and for ensuring on-going corrosion protection following maintenance and repair activities.

If inorganic finish stripping was no longer authorised, design owners (i.e., OEMs and DtB companies) would be forced to re-locate some or all their component production, manufacturing, and maintenance activities out of the EEA/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 importers and the critical set of key functions provided by inorganic finish stripping would be lost to A&D downstream users in the EEA and UK

↓

Due to certification and airworthiness requirements, downstream users would be forced to undertake Cr(VI)-based inorganic finish stripping activities outside the EEA or shift to suppliers outside of the EEA/UK

↓

OEMs would shift manufacturing outside the EEA/UK due to the need for inorganic finish stripping 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 inorganic finish stripping only (and especially so for touch-up repairs)

↓

DtB suppliers may have more flexibility and shift their production activities outside the EEA/UK, resulting in the loss of profits and jobs inside the EEA/UK

↓

BtP suppliers in the EEA would be forced to cease Cr(VI)-based inorganic finish stripping treatments, leading to loss of contracts and jobs due to relocation of this and related activities outside the EEA/UK

↓

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

↓

Relocation of MRO activities would cause significant disruption to the A&D sector itself

↓

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

⬇

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

As indicated in the above diagram, because inorganic finish stripping is part of a process flow 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 portions of the entire value chain (production, repair, and maintenance) outside of the EEA/UK, as summarised below.

5.1.2 Identification of plausible non-use scenarios

Consultation was carried out with the applicants, OEMs, MROs, and the BtP and DtB suppliers supporting them.

These discussions acted as the basis for a series of questions in the SEA questionnaire, aimed at gathering information on the role of different types of companies, how this impacts on why they use the two chromates, past investments and R&D, and the most likely impacts of a refused re-authorisation. The first three of these were discussed in Section 4 as part of the description of the continued use scenario.

Moving to a poorer performing alternative was ruled out based on the unacceptability of such an option to the OEMs due to safety and airworthiness requirements, as detailed further below. Producing components overseas, shipping them back to the EEA/UK and then warehousing them was ruled out due to logistic difficulties and economic feasibility.

Table 5-1 below details the choices presented in the SEA questionnaire and a count of the number of companies selecting each.

Respondents were asked to provide further comments to support their responses, and to explain any other possible responses not included in the above list. These comments demonstrate the differences that exist within the aerospace supply chain and hence how the most plausible scenarios will vary by role.

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

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

	OEM/Tier 1	Build-to-Print only	Design-to-Build only	MROs – only
It is unclear at this time/The decision is up to our customer	1	4	1	1
We may have to cease all operations as the company will no longer be viable	1	1		4
We will focus on other aerospace uses or on non-aerospace and defence uses		1	1	
We will shift our work outside the EEA/UK	2			
We will stop undertaking use of the chromate(s) until we have certified alternative	1	2	3	1
Number of responses (companies)	5	8*	5	6
*One response left blank				

5.1.2.1 OEMs

The OEMs all stressed that the aim is replacement of Cr(VI) in inorganic finish stripping to a qualified and certified alternative. In some cases, a qualified alternative has been identified, but more time is required to implement the alternative across suppliers (particularly where a significant number of suppliers may be involved in undertaking inorganic finish stripping of similar components, e.g., structural components). In other cases, the companies have been trying to find a suitable replacement for over 25 years (e.g., in their defence applications) and have been unable to do so.

With respect to the plausibility of the different non-use scenarios identified above, the following are clear from the SEA responses and consultation with members who are representing a broader defence-sector supply chain (including Ministries of Defence):

- **We will shift our work involving Chromates to another Country outside the EEA/UK.** This is the most plausible scenario for two of five OEM companies directly involved in inorganic finish stripping activities. In order to maintain the current business, components would need to be shipped outside of the EEA/UK to be stripped and then shipped back – which would not be economically feasible. Due to the active nature of the stripped surface, it may not be technically feasible to ship the components without surface degradation. Furthermore, given the importance of inorganic finish stripping for preparing surfaces for surface treatments providing corrosion protection, it is also the most likely response for those OEMs who do not perform inorganic finish stripping, but who are supporting the continued use of inorganic finish stripping in their supply chains.

- **We will stop using the chromates until we have certified alternatives:** It is clear that in most cases substitution activities, and especially the industrialisation phase, of moving to alternatives will not be completed for at least 7 years and for a significant number of components/products for 12 years (or even longer). Two of the OEMs indicated that this would be their most plausible scenario. One would cease production in the short term while it developed a case-by-case strategy to enable production to restart. Losses in turnover in the short term, e.g., 1-2 years, would be up to 100%. This company produces components and equipment for both civilian aerospace and defence. For the other OEM identifying this as the most plausible scenario, losses in turnover would be 30 - 50%. For the other companies, the potential duration of such a production stoppage would not be economically feasible.

- **We may have to cease all operations as the company will no longer be viable.** If shifting inorganic finish stripping work outside the EEA/UK is not economically feasible, nor is stopping production on a temporary basis until alternatives are certified, then companies will cease their operations. It is important to note that this includes a cessation of aircraft assembly within the EEA/UK, with consequent reductions in revenues from aircraft assembly operations; the loss of this turnover would result in other operations (R&D, Engineering, Sales, etc.) also becoming non-viable with the final outcome being a shut-down of all activities. This option was identified by two of the large OEMs whose activities include the manufacture and assembly of aircraft, together with repair and maintenance activities, due to the importance of inorganic finish stripping.

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

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

Similarly, none of the companies indicated that they would move to a poorer performing alternative. This scenario is not considered plausible as a less efficacious alternative that risked damaging the underlying substrate would not be acceptable:

- EASA would not accept a downgrade in a product's performance;
- Consequent increased maintenance requirements would lead to an increase in the downtime of civilian aircraft, increased maintenance costs, less flying hours, impacts on airlines and passengers, logistic issues including increased CO_2 emissions, etc;
- Consequent impacts on military equipment and its maintenance requirements may affect the mission readiness of equipment, increased costs, and lead to early redundancy of equipment.

Thus, although moving to a poorer performing alternative may appear plausible, the associated risks would be unacceptable to all the OEMs and their customers. 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 safety risks become too great, in both civilian and military products.

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 (September 2024) on components, then their most plausible response under the non-use scenario would be to relocate all or some of their manufacturing activities outside of the EEA or UK. It may not be realistic given the efforts and expenditure involved in such relocation, in which case, the more likely result is the complete closure of OEMs or divisions within them, with consequent impacts for the EEA/UK economies and the aerospace and defence supply chain.

The extent to which companies would move all or only some of their manufacturing outside the EEA/UK depends on the integrated "system" of activities undertaken at individual sites. Inorganic finish stripping is not undertaken across all sites operated by the larger OEMs companies; however, it may be carried out by suppliers to those sites. Consultation indicates that these companies' sites may each be supported by up to 10 suppliers undertaking inorganic finish stripping regionally (with this figure used in generating the number of sites in total assumed to be carrying out inorganic finish stripping in the EEA in particular).

As discussed above, the impacts on individual companies may be a loss of production and turnover related to anything from around 30% to 100% of current levels, with production expected to stop completely at a significant percentage of sites where inorganic finish stripping is a core activity. These impacts would be experienced by sites involved in civil aviation and defence.

It was also noted that due to the vertical integration of manufacturing activities at these sites, it is not feasible to cease only undertaking inorganic finish stripping using the chromates; all activities related to the manufacture of the relevant components, assemblies, aircraft, and other products would 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, and it would also impact on MRO activities in the EEA as these would need to relocate to the same locations.

In conclusion, it is not possible to relocate the use of Cr(VI)-based inorganic finish stripping processes on their own in most cases. These processes are an integral part in the production chain and cannot be separated from previous or following process steps. As a result, the entire production chain would need to be relocated which, although the most plausible scenario, is also not realistic and would lead to severe impacts on the viability of the entire value chain.

Particular difficulties would be faced by companies in the space and defence sectors. Possibilities for relocating some activities outside the EEA/UK are limited due to the difficulties related to achieving specific customer requirements, national security considerations, work share agreements, and financial restrictions. As a result, it is likely that there would need to be requests for "defence exemptions" so that those activities that contractually must be maintained in their current location could continue within the EEA/UK. It would also have implications for the manufacture of products for the European space industry, damaging its ability to remain independent.

5.1.2.2 Design-to-Build

Three of five Design-to-Build companies indicated that they would cease use of the chromates until they have a certified alternative.

Comments included:

"*The development, testing, deployment, and certification of replacements will be very costly for our company*".

"We plan to remove as many of the uses of these chromates as possible by the end of 2024. Of the remaining uses, we would probably stop using the chromates until the certified alternative is in place. Whether this work would be put on hold or outsourced to another country would depend on the suspected length of stoppage/how close any alternative was to implementation at that time, customer demand for those parts, and availability of customer-approved sources of supply elsewhere."

All respondents provide Cr(VI)-based conversion coating, two provide Cr(VI)-based anodising, and one passivation. Only one company uses a Cr(VI)- free process for inorganic finish stripping alongside their Cr(VI)-based processes.

One company stated that the decision is up to their customer and expects around a 60% decrease in turnover in the event of a refused authorisation.

The final company stated that they would focus on other aerospace uses, which would result in a 30 to 35% decrease in turnover.

5.1.2.3 Build-to-Print

As previously discussed in section 4.2.3.3, all BtP companies undertaking inorganic finish stripping do this as part of a process flow for anodising, chemical conversion coating, and or passivation of non-aluminium metallic coatings. Half (4/8) of companies responded that they are unsure what would occur in the event of a refused authorisation as the decision is up to their customer.

One company stated: *“We are Build-to-Print. The customer defines the products we must use”,* and another stated *“We will support our customers by using chromates until a feasible alternative is identified that meets our customers’ requirements”.*

One company stating that the decision is up to their customer also stated that they had facilities in China, should relocation be a requirement.

The two companies stating that they would stop using chromates until they had a certified alternative also undertake Cr(VI)-free inorganic finish stripping where this is appropriate. Both also provide anodising, conversion coating and passivation treatments, using Cr(VI)-based or Cr(VI)-free processes.

Five companies were unsure of their potential losses in turnover in the event of a refused authorisation. The ones that responded indicated losses between 30 and 100%.

5.1.2.4 MROs

For companies that operate as MROs only, there is less choice. They do not undertake manufacturing per se, only the overhaul, repair, and maintenance of 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 the services of an MRO, the required maintenance, including which surface treatment processes may be required, is not directly foreseeable. Very often, the level of work required only becomes clear after disassembling the component. The surface treatment steps required (e.g., from inorganic finish stripping to conversion coating/anodising as a “system”) for any given component is dependent on its condition and can differ for each maintenance event. As a result, not every component will pass through all potential surface treatment processes. Even where they do, levels of throughput are also dependent on the size and complexity of the component - processing times can range from 5 minutes to several days. Within these process flows, even if inorganic finish stripping 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 inorganic finish stripping as part of maintenance, repair and overhaul, may make such services unviable for those MRO sites where this is carried out. There is no scope for them to operate outside the requirements detailed in the OEMs’ service manuals, which are based on the qualified and approved uses of substances and mixtures for inorganic finish stripping. Where these requirements mandate the use of the chromates, then the MRO must use the chromates as instructed unless the manuals also list a qualified alternative.

As a result, those MRO businesses would no longer be viable and would have to cease operation in the EEA/UK. Four MROs responding to the SEA questionnaire indicated that they would have to cease their EEA/UK operations, which would be neither practical nor feasible for their defence customers or civil aviation customers. Of these companies, one indicated that they would potentially move these operations to the Middle East or elsewhere.

With respect to turnover losses, these ranged from 20 – 70% losses. However, the company indicating that direct losses would be around 20% also noted that this could have a knock-on effect leading to a further 50% loss due to impacts on other activities that would be linked from a repair and maintenance perspective. Indeed, the losses would be significant enough for this company to indicate that they may have to cease activities at the affected site.

As noted by one of the MROs: "*Even if chromate-containing materials only have to be used to a very limited extent in the context of maintenance due to airworthiness regulations, they still play an essential role in the holistic/overall, economically viable feasibility of maintenance events*".

5.1.2.5 Additional considerations

Current industry best practice does not involve identifying manufacturing plants as Cr(VI) or Cr(VI)-free. To the contrary, in the aerospace and defence industry, reliance on proven corrosion prevention systems means that Cr(VI) and non-Cr(VI) operations/processes normally exist side-by-side, are inter-reliant and non-separable. The aerospace industry has a very complex and interrelated supply chain. Nonetheless, for several essential components, only one designated supplier exists. Typically, this supplier will have worked in close partnership with its customer(s) for decades to develop a product. Critical suppliers are often located on, or adjacent to, the premises of their customers. Therefore, relocation will often be based on strategic decisions, e.g., if the customer relocates then the suppliers might do the same to retain proximity.

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

Hypothetically, stripped components could be produced outside of the EEA/UK and then be shipped back as part of MRO activities. Additionally, the added cost of transport would drastically undermine the competitiveness of EEA/UK component/assembly suppliers. By adding extra transportation, lead-times, customs, and risk of additional handling-related damages, suppliers in the EEA/UK would be put at a massive disadvantage, compared with non-EEA suppliers, in their bids/services. Furthermore, if manufacturing activities using Cr(VI) versus Cr(VI)-free were separated on both sides of the EEA/UK borders, the logistic requirements of managing the flow of components/assemblies and the level of transportation required would have dramatic impacts on resources and the environmental footprint of the sector.

5.1.3 Non-plausible scenarios ruled out of consideration

5.1.3.1 Move to a poorer performing alternative

Moving to a poorer performing alternative would not be acceptable to the OEMs, either from a Design Organisation Approval (DOA) perspective as approved by EASA[59], 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, where no alternative provides an equivalent level of performance to Cr(VI), OEMs would not accept an alternative that is less efficacious in protecting the underlying substrate whilst completing removing the inorganic finish. The use of a less effective alternative would downgrade the performance of the final product, and the impact on the underlying substrate would give rise to several unacceptable risks/impacts:

- The highly likely risk of EASA (airworthiness authorities), MoDs or European Space Agency 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, fewer flying hours, etc.; and
- Increased risks to passengers, cargo operators, and operators of military equipment.

In the purely hypothetical case where the underlying substrate is altered by finish stripping operations or where non-conforming coatings cannot be removed, 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 to these inspections. A very conservative inspection frequency would be set to ensure safety until adequate in-service performance experience is obtained.
- Increased overhaul frequency or replacement of life-limited components. Possible early retirement of aircraft due to compromised integrity of non-replaceable structural components.
- Whole fleets may be grounded until a repair/replacement plan is in place for the whole aircraft fleet (e.g., grounding Boeing 787 fleet due to battery problems).
- Due to similarity of technologies and aircraft uses, a fleet grounding event in such a scenario could impact many or all aircraft fleets.
- An increase in the number of aircraft and engines required by each airline to compensate for inspection/overhaul downtime and early retirement.
- Defence systems would have similar impacts adversely affecting the continuity of national security.

Aerospace components are portions of major systems (fuselage, wings, engines, etc.) and the components in these systems are designed to withstand similar criteria between overhauls. For

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[59] 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.

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 stripping process, the engine would require disassembly to access the blades. This means taking the engine off the wing, sending it to a repair centre, disassembling the engine, and replacing the components at much shorter intervals than needed for the remainder of the engine; thus, adding inherent inspection, maintenance, and repair costs to the manufacturers, operators, and end use customers, who will also be impacted by increased out of service times.

The lack of experience with Cr(VI)-free solutions can have a critical safety impact. The aerospace industry has a permanent learning loop of significant events and failure analysis and decisions for safety improvements. Part of this improvement is the introduction of the Maintenance Steering Group 3 Analyses (MSG-3), specifically developed for corrosion. MSG-3 provides a system for OEMs and the regulators to identify the frequency of inspection with respect to the stress, corrosion protection, and environmental ratings for any component or system.

Without adequate experience, proven success, and therefore possible unknown or hidden properties, the performance of a Cr(VI)-free system cannot be highly rated. Consequentially, a significant reduction to the maintenance interval would be required. For cases with no long-term experiences or correlation to in-service behaviour, which is normally the case, a further reduction to the maintenance interval may be required.

As a result, OEMs rule out moving to a poorer performing alternative under the non-use scenario; the risks are unacceptable to all OEMs. The primary objective of these companies is to move to an equal or higher performing alternative. However, this objective cannot be achieved without more time to identity, develop, validate, and gather 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. Inorganic finish stripping is crucial to the manufacture of aircraft components in the EEA/UK; if there are no qualified alternatives certified for use on components then manufacturing work would cease.

Given the above, switching to an alternative with reduced performance is not considered plausible.

5.1.3.2 Overseas production followed by maintaining EEA/UK inventories

To be competitive, companies must keep inventory as low as possible ("just-in-time" delivery). Maintaining inventory clearly involves substantial capital costs (as elaborated below) and ties up cash. Stockpiling is also clearly not feasible for the repair and maintenance side of the business because the main aim of repair is to make components serviceable rather than replace them with spare components (which would run counter to the sectors drive towards increased sustainability).

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

- If no certified alternative is available or is likely to become available within months after the end of the review period, then there is no clarity on how long such inventories of components must be available. For legacy aircraft, inventories will certainly be required for the next 20 years or more. Additionally, there is no visibility or clarity on customer demand in the short or longer term. Planned maintenance can be taken into account, but it is not possible to anticipate which components will be needed for unplanned maintenance and repair. Consequently, an assumption regarding the inventory that needs to be available for a sufficient duration would have to be made, leading to the risk of wasted resources or aircraft/equipment becoming obsolescent due to inadequate inventories.

- Stockpiling results in increased costs and would reduce the opportunity to invest in other projects/R&D, etc. The inventory costs would also have to be added to product costs and would therefore reduce competitiveness for operations in the EEA/UK.

- The costs of securing 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 €1,000 per m^2 to construct (a conservative estimate). It is assumed here that warehouses that act as a hub for storing inventory would be around 10,000 m^2 as a minimum, given the range of components that would need to be stored. This implies a total build cost of around €10 million as a minimum, not taking into account the costs of land purchase, site preparation, design, construction, etc., which could easily add a further 25% even after taking into account any potential economies of scale in pricing due to the large size of the warehouse[60]. If such facilities are required at around 100 sites across the EEA and UK (to cover civilian and military requirements), then warehousing costs alone would lead to €1 billion in expenditure. These costs would be on top of the losses in profits that would occur from the need to subcontract manufacture to companies located outside the EEA/UK and the consequent profit losses and increased costs of shipping, etc.

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

- Existing facilities are not sized to store the amount of multi-year inventories required. Companies would 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 for many components, such as wing and fuselage skins, because these components are not removed from the aircraft; these components only allow MRO activities in-situ. Therefore, the entire aircraft would need to be transported to a non-EEA country for repair. If the plane is not airworthy, the effort and cost relating to transportation alone (e.g., from Belgium to Egypt) would be overwhelming.

- Even then, when existing inventories are depleted and stocks are no longer available to support the necessary repairs and maintenance, increasing aircraft on ground (AoG) scenarios are inevitable, with associated costs. All transportable components would have to be sourced and produced from non-EEA suppliers.

- Being dependent upon inventories and non-European suppliers (and in turn vulnerable to local economic and political issues affecting non-EEA/UK countries), and thus unable to

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

reliably fulfil MRO activities, would lead to delays and potential cancellation of flights, fines due to longer turn-around times and AoG 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 inorganic finish stripping is still required). Consequently, it is clearly not possible to rely on a long-term stock of spare components that would fit all situations.

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

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

It is challenging to enumerate these quantitatively as they are multi-fold (i.e., increased cost of land and construction for warehousing, worker costs to secure and maintain inventory, increased delays and ‘aircraft on the ground’, writing-off stock) and there is no precedent to rely on, as this NUS is entirely contrary to current industry practice. However, it is immediately clear that the result would be that the cost of operating in the EEA/UK would increase considerably as would the impact to society.

Furthermore, for certain types of components, increasing stock inventory is not feasible. 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 inorganic finish stripping. It was confirmed though that such an approach may be feasible for a small range of components for civilian aircraft and for a limited number of components for military aircraft and equipment. However, as an overall strategy, it would not be feasible as use of Cr(VI)-based inorganic finish stripping would still be required in the EEA/UK for the majority of components and on-site maintenance and repair activities.

5.1.4 Conclusion on the most likely non-use scenario

The most likely non-use scenario is driven by the responses of the OEMs to the questions on the non-use scenario. They are the companies that carry out the R&D and testing (sometimes in collaboration with their chemical and process suppliers) to determine whether an alternative is technically feasible, qualify and gain approvals for that alternative, and then certify their suppliers against its use. In some cases, they also help their suppliers meet the financial costs of adapting existing equipment and risk management measures to enable them to move to the alternative.

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

1. EEA and UK suppliers (importers and distributers) of the chromates used in inorganic finish stripping would be impacted by the loss of sales, with the market for removal of inorganic finishes for A&D relocating outside the EEA/UK.

2. OEMs directly involved in inorganic finish stripping would move a significant proportion of their manufacturing (if not all) outside the EEA/UK, with the consequent loss of significant levels of turnover and employment. In particular, they will move those manufacturing activities reliant on the use of inorganic finish stripping where there is no qualified alternative or where implementation across suppliers is expected to take several years after the end of the current review period. The losses to the EEA/UK are estimated at 70% of manufacturing turnover. There would be a significant loss of jobs directly related to inorganic finish stripping, as well as across other manufacturing activities.

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

4. As OEMs shift their own manufacturing activities outside the EEA/UK, they will have to carry out technical and industrial qualification of new suppliers or 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 will be developed using BtP and DtB suppliers who have moved operations from the EEA/UK to third countries in order to continue supplying the OEMs. However, a significant proportion of the existing BtP companies involved in inorganic finish stripping – 50 to 75% – will cease trading in the EEA as they do not also supply other sectors and are reliant on the aerospace sector; furthermore, the types of products that they manufacture are specific to the 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. For BtP companies, 60% turnover losses are estimated, whereas 40% is estimated for DtB.

6. MROs will also be severely affected 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 65% of current relevant MRO activities would cease in the EEA/UK.

7. The re-location of MRO activities will have consequent impacts for civil aviation and military fleets, as well as for the maintenance of defence products, space equipment and aero-derivative products.

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

9. 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 considers the following factors. Although OEMs are working on substitution of the chromates in inorganic finish stripping, they will not have components with certified alternatives that have been fully implemented across their supply chains by September 2024. Many will require at least 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 that can be considered "generally available".

As noted previously, the A&D industry has a very complex and interrelated supply chain, with only one approved supplier for many essential components. As a result, relocation by the customer may lead to relocation of suppliers to retain proximity. Such relocation would involve not just the surface protection activities, but all activities, due to the potential for corrosion of unprotected surfaces during transport to another place. Using small amounts for Cr(VI) compounds for rework (or repairs) is mandatory and essential to the safety of the aircraft. Surface coating and touch-up processes cannot be disconnected in time or distance from assembly processes. When these processes are no longer available, the entire process must re-locate.

Moreover, the situation is the same even if a Cr(VI)-free alternative was successfully qualified for one or two components. **Figure 5-1** demonstrates the interdependency of every single component used, and the effect of only one component missing for the overall assembly process of the aircraft. It should be noted that this figure represents a highly simplified supply chain of components needed for the final assembly of an aircraft. If only one component cannot be produced according to Type Certification, the manufacture of the entire aircraft is jeopardised.

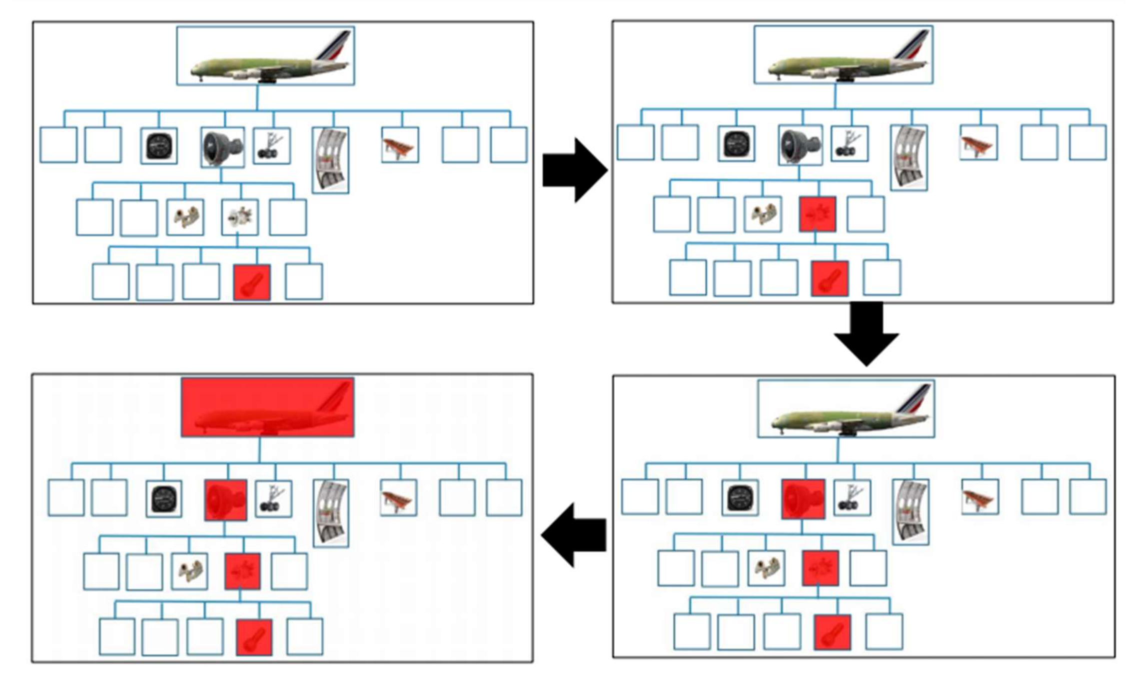

Figure 5-1: Interdependency of component availability in the manufacture of a final product
Source: GCCA (AfA 0116-01)

As noted previously, it is therefore not possible to relocate single Cr(VI)-based activities on their own in most cases. The processes are an integral part in the production chain and cannot be separated from previous or following process steps.

This also holds true for MRO activities, for example overhaul of turbine components, which would be significantly affected under the non-use scenario. It is technically not possible (or economically feasible) to do the machining and repairs of a vane or other turbine component in the EEA or UK, then ship it to a non-EEA/UK facility for surface treatment, ship it back to the EEA/UK to further process the component, ship it back to a non-EEA facility for further surface treatment and ship and put it back in the turbine in the EEA/UK. Apart from the fact that the surface of the component would likely corrode 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.

Given the above, under the NUS, the companies affected by the refused authorisation will move manufacture and repair of components and assemblies out of Europe and the UK, together with jobs, know-how and R&D investments.

Finally, although this is considered the most plausible scenario, OEMs note that the obstacles that would have to be overcome in a short period of time may make it overly optimistic. The infrastructure of the sector is based in part around manufacturing clusters or hubs (see also Annex 2), with smaller suppliers located around the sites operated by the larger OEMs. Not all these smaller sites, including those of critical suppliers, would be able to shift their activities outside the EEA/UK, leading to OEMs having to create entirely new supply chains outside the EEA/UK. This scenario also implies a huge economic investment would be carried out by the OEMs as well as their EEA/UK suppliers. This level of investment is unlikely to be feasible and hence the OEMs would be likely to cease manufacturing activities until the new industrial facilities were in place and ready to operate outside the EEA/UK.

5.2 Economic impacts associated with non-use

5.2.1 Economic impacts on applicants

Under the non-use scenario, all applicants would be impacted by the loss of sales of the chromates for use in inorganic finish stripping. At the specific supplier level, these impacts may vary in their significance, as the importance of the different chromates used in inorganic finish stripping 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 profit losses will be significant to the applicants.

Over time, as consumption of the chromates reduces in line with companies' substitution plans, sales and revenues will continue to decrease.

No quantitative estimates for these losses are included in this SEA.

5.2.2 Economic impacts on the supply chain

5.2.2.1 Introduction

It would be theoretically possible to move activities involving the chromates use outside the EEA/UK due to already existing supply chain sites in other countries, for example, the USA, Canada, China, India, etc. and to outsource manufacturing as the supply chain is spread around the world. However, there are several obstacles to such a scenario, which would make this economically unattractive even if it is the most plausible scenario. Firstly, the due diligence principle will continue to apply to the supply chain and would be exacerbated in case of relocation out of EEA/UK. Secondly, when activities are shifted to another site, there is an inevitable phase of technical and industrial preparation (site design, capital procurement and installation, worker training, pilot trials) and qualification to ensure the sustainability of these activities, including an assessment of the technical capability to deliver stringent airworthiness and certification requirements. Moreover, once the qualification phase is over, it is essential to get the right ramp up in order to meet the manufacturing rate objectives.

In the remaining time before the end of the initial review period, even if alternatives were qualified and certified across the manufacture of components and products, these two aspects are not realistic; it would require a huge economic investment that would significantly affect businesses with detrimental economic impacts. As a result, OEMs have indicated that they probably would be forced to stop manufacturing activities until the new industrial facilities and infrastructure are in place and ready to operate outside of the EEA/UK, with consequent impacts on the entire value chain. Given the current levels of civil aviation and anticipated growth, this would be catastrophic for aviation in the EEA/UK and globally.

5.2.2.2 Approach to assessing economic impacts

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

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

1. **Estimates based on loss of jobs**: The first approach takes as its starting point the number of jobs that would be lost at the sites of SEA questionnaire respondents, based on their most likely response to the Non-Use Scenario. This includes loss of jobs directly linked to use of the chromates and losses in jobs at the site reliant upon the continuation of their use, i.e., jobs in related manufacturing and assembly activities. Importantly, it excludes losses in employment at local sub-contractors providing support services. The numbers of jobs lost are multiplied by the average Gross Value Added (GVA) per job (taking into account variations by role) to provide an estimate of total GVA lost. Personnel costs associated with this GVA are then subtracted to derive the implied losses in operating surpluses per annum.

2. **Estimates based on loss of turnover**: The second approach takes as its starting point the anticipated losses in terms of percentage of turnover reported by the respondents to the SEA questionnaire. Lost operating surplus is then calculated as an average per company based on role in the supply chain and Eurostat data on GOS as a percentage of turnover.

Both approaches provide proxy estimates of profit losses based on current levels of employment and turnover. The approaches do not account for foregone future turnover that would be achieved under the continued use scenario due to growth in the global demand for air traffic. They also do not account for profit losses due to increased military and defence spending as a result of either a cessation in manufacturing activities or their relocating outside the EEA/UK.

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

5.2.2.3 Estimates based on loss of jobs (and GVA)

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 EEA. The resulting figures collected for the 38 sites are presented in **Table 5-2** below.

The figures for expected job losses have been extrapolated out to the total 110 sites expected to be carrying out inorganic finish stripping across the EEA and UK. Around 28,500 jobs (around 21,400 in the EEA and 7100 in the UK) are expected to be lost due to the cessation of inorganic finish stripping and linked manufacturing activities across product lines or to the cessation of MRO services, including as a result of companies moving operations outside the EEA.

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. Although these figures may appear high, they should be seen within the context of the roughly 890,000 employees (2019[61]) within the European aerospace and defence sector, taking into account the critical importance of Cr(VI) in inorganic finish stripping.

These predicted job losses have been combined with Eurostat data on Gross Value Added (GVA) per employee to the EEA/UK economy as part of calculating the economic losses under the Non-Use scenario. A weighted GVA has been used for BtP and DtB suppliers and NACE code specific GVAs have been used for OEMs and MROs. The resulting estimated losses are given in **Table 5-3** below.

The estimated losses in GVA equate to:

- €1,830 million per annum across the EEA and €490 million per annum for the UK, extrapolated out to the 90 EEA and 20 UK downstream user sites.

For comparison, turnover for the EEA aerospace industry is around €259 billion[62] per annum, while that for the UK aerospace and defence sectors was around €57 billion (£50 billion) in 2020[63]. Thus, although these figures appear high, they are considered to be underestimates by the ADCR members (particularly the OEMs) given the potential for much larger segments of the sector to move outside the EEA/UK should Cr(VI)-based inorganic finish stripping 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:

- €560 million per annum across the EEA and €160 million per annum for the UK, extrapolated out to the 90 EEA and 20 UK downstream user sites.

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

[62] https://www.statista.com/topics/4130/european-aerospace-industry/#topicHeader__wrapper

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

Table 5-2: SEA survey responses and extrapolations on numbers of jobs lost under the Non-Use Scenario

	No. Company Responses		Direct job losses – workers undertaking processes linked to inorganic finish stripping		Additional direct job losses – due to a cessation of manufacturing/MRO activities	
	EEA	UK	EEA	UK	EEA	UK
Build-to-Print (11 sites)	3	8	60	151	20	33
Design-to-Build (5 sites)	2	3	330	800	315	3,000
MROs (11 sites)	10	1	568	47	1,990	166
OEMs (11 sites)	10	1	1,330	121	2,630	239
Total 38 sites	**25**	**13**	**2,288**	**1,119**	**4,955**	**3,438**
Extrapolation of job losses under the Non-Use Scenario to the estimated 110 sites undertaking inorganic finish stripping						
Build-to-Print (40 sites)	30	10	600	189	200	41
Design-to-Build (19 sites)	15	4	2,475	1,067	2,363	4,000
MROs (17 sites)	15	2	852	95	2,985	332
OEMs (34 sites)	30	4	3,990	484	7,890	956
Total sites (110)	**90**	**20**	**7,917**	**1,834**	**13,438**	**5,329**
Total EEA direct and indirect across 90 sites			**21,355**			
Total UK direct and indirect across 20 sites			**7,163**			

Table 5-3: GVA losses per annum under the Non-use Scenario						
By role	**GVA per worker assumed by role**		**GVA lost due to direct job losses € million**		**Additional GVA lost due to due to a cessation of manufacturing/MRO activities - € million**	
	EEA	**UK**	**EEA**	**UK**	**EEA**	**UK**
Build-to-Print (11 sites)	59,500*	59,500*	3.56	8.95	1.19	1.96
Design-to-Build (5 sites)	59,500*	59,500*	19.57	47.44	18.68	177.88
MROs (11 sites)	85,000	85,000	48.28	4.02	169.15	14.10
OEMs (11 sites)	98,500	98,500	131.01	11.91	259.06	23.55
Total 38 sites			**202.41**	**72.32**	**448.07**	**217.49**
		Total EU	**€ 650 million per annum**			
		Total UK	**€ 290 million per annum**			
GVA losses - Extrapolation to the estimated 110 sites undertaking inorganic finish stripping						
Build-to-Print (40 sites)	59,500*	59,500*	35.58	11.19	11.86	2.45
Design-to-Build (19 sites)	59,500*	59,500*	146.75	63.25	140.08	237.18
MROs (17 sites)	85,000	85,000	72.42	8.05	253.73	28.19
OEMs (34 sites)	98,500	98,500	393.02	47.64	777.17	94.20
Total sites (110)			**647.76**	**130.12**	**1,182.83**	**362.02**
		Total EEA	**€ 1,831 million per annum**			
		Total UK	**€ 492 million per annum**			
***Weighted average GVA calculated for Build-to-Print and Design-to-Build companies as the GVA by NACE code multiplied by the NACE code counts across responding companies, divided by the total number of relevant NACE responses. MRO and OEM GVA figures from Eurostat (2018).**						

Table 5-4: Implied GVA-based gross operating surplus losses under the Non-Use Scenario

	Total GVA losses- € millions per annum		Total personnel costs associated with lost jobs - € millions per annum*		Implied operating surplus losses € millions per annum	
	EEA	UK	EEA	UK	EEA	UK
Build-to-Print (11 sites)	4.74	10.91	3.10	7.13	1.64	3.78
Design-to-Build (5 sites)	38.24	225.32	25.00	147.31	13.24	78.01
MROs (11 sites)	217.43	18.12	144.27	12.02	73.16	6.10
OEMs (11 sites)	390.06	35.46	279.58	25.42	110.48	10.04
Total 38 sites	**650.48**	**289.81**	**451.95**	**191.88**	**198.53**	**97.93**
Operating surplus losses - Extrapolation to the estimated 90 EEA and 20 UK sites undertaking inorganic finish stripping						
Build-to-Print (40 sites)	47.44	13.64	31.01	8.92	16.42	4.72
Design-to-Build (19 sites)	286.84	300.42	187.52	196.41	99.31	104.02
MROs (17 sites)	326.15	36.24	216.41	24.05	109.74	12.19
OEMs (34 sites)	1,170.18	141.84	838.73	101.66	331.45	40.18
Total sites (110)	**1,830.60**	**492.14**	**1,273.67**	**331.03**	**556.92**	**161.11**

*Weighted personnel costs calculated for Build-to-Print and Design-to-Build companies as the GVA multiplied by the NACE code counts across responding companies, divided by the total number of relevant companies. MRO and OEM GVA figures direct from Eurostat (2018) for EU/UK as available.

5.2.2.4 Estimates based on lost turnover

The SEA questionnaire also asked companies to provide information on the impacts a refused authorisation would have on turnover/revenues. Fewer companies responded to this question, although the responses provided by the OEMs (as the end customer) and MROs enable estimates of the likely percentages of turnover lost by role to be developed. These estimates take into account the number of companies indicating that they also carry out activities other than Cr(VI)-based inorganic finish stripping for the aerospace 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 (GOS) 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	
	EEA	UK	EEA	UK
Build-to-Print* (11 sites)	113.82	303.51	14.52	38.72
Design-to-Build* (5 sites)	50.59	75.88	6.45	9.68
MROs (11 sites)	463.64	46.36	45.44	4.54
OEMs (11 sites)	8,502.53	850.25	811.99	81.20
Total 38 sites	**9,130.57**	**1,276.01**	**878.40**	**134.14**
Extrapolation to the estimated 110 sites undertaking inorganic finish stripping				
Build-to-Print* (40 sites)	1,138.17	379.39	145.18	48.39
Design-to-Build* (19 sites)	379.39	101.17	48.39	12.91
MROs (17 sites)	695.47	92.73	68.16	9.09
OEMs (34 sites)	25,507.59	3,401.01	2,435.97	324.80
Total sites (110)	**27,720.61**	**3,974.30**	**2,697.71**	**395.18**

*Weighted average turnover and GOS calculated for Build-to-Print and Design-to-Build companies as the GOS multiplied by the NACE code counts across responding companies, divided by the total number of relevant companies. MRO and OEM figures direct from Eurostat (2018) for EU/UK as available.

5.2.2.5 Comparison of the profit loss estimates

The figures presented in **Table 5-5** are higher than those given in **Table 5-4** for both the EEA and UK, with the greatest differences being in the estimates for OEMs and MROs. This is considered to be due to the turnover-based estimates taking better account of the loss in associated manufacturing, maintenance or repair activities, given the importance of Cr(VI)-based inorganic finish stripping to both of these sets of companies.

- Losses in gross operating surpluses, taking into account impacts also on other associated Cr(VI)-based treatments:

  - Losses of €560 million per annum for the EEA
  - Losses of €160 million per annum for the UK

- Losses in EBITDA based approach:
  - Losses of €2,700 million per annum for the EEA
  - Losses of €370 million per annum for the UK

The two sets of figures are used in this SEA to provide lower and upper bound estimates of losses in producer surplus. It is important to note that these losses apply to commercial enterprises only. No data was provided by any of the military organisations reliant upon the continued use of Cr(VI)-based inorganic finish stripping which could be used in this analysis. These organisations simply stated that they would have to cease undertaking MRO related activities in their home country, resulting in severe impacts on their national air forces (in particular) and maintenance of other defence equipment.

Table 5-6 demonstrates the key figures provided by the respondents to the SEA questionnaire used in calculating the profit loss estimates for the upper and lower bound.

Table 5-6: Comparison of profit loss estimates

	Total job losses		% turnover lost		Ratio of lost profits based on turnover to lost operating surplus based on jobs (based on €billions lost)	
	EEA	UK	EEA	UK	EEA	UK
Build-to-Print	800	230	60%	60%	8.84	10.25
Design-to-Build	4,838	5,067	40%	40%	0.49	0.12
MROs	3,837	426	65%	65%	0.62	0.75
OEMs	11,880	1,440	70%	70%	7.35	8.08
Total sites (110)	21,355	7,163	€27.7 billion	€4 billion	4.84	2.45

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 as part of substitution, over the next four to 12 years. Any such investment in new equipment would be focused on facilitating substitution (while the capital equipment associated with the continued use of the chromates over the next seven to 12 years would not be expected to be replaced).

As there are no suitable alternatives 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 is for Cr(VI)-based treatments, which 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 authorities, the issue of potential impacts on rival firms undertaking inorganic finish stripping 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 five time periods in line with SEAC's new guidance for those cases where there are not suitable alternatives available in general. Discounted losses over 1, 2, 4, 7, and 12 years are given in **Table 5-7**.

As discussed earlier, these losses are based on Eurostat turnover figures for 2018 (most recently available by company size). They therefore represent an underestimate of the losses in turnover that would arise over the review period under the Non-Use scenario, given the anticipated level of future growth in turnover for the sector due to the importance of the EEA and UK in the global manufacture of aerospace and defence products (as highlighted by the publicly available forecasts of the demand for new aircraft cited earlier).

Table 5-7: Discounted profit/operating surplus losses under the Non-Use Scenario – Discounted at 4%, year 1 = 2025

	Lost EBITDA/Profit € millions		GVA-based Operating Surplus Losses € millions	
	EEA	**UK**	**EEA**	**UK**
1 year profit losses (2025)	2,698	395	557	161
2 year profit losses (2026)	5,088	745	1,050	304
4 year profit losses (2028)	9,792	1,434	2,022	585
7 year profit losses (2031)	16,192	2,372	3,343	967
12 year profit losses (2036)	25,318	3,709	5,227	1,512

5.2.2.6 Other impacts to 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 inorganic finish stripping across the entirety of the EEA and UK aerospace and defence sector. It is non-exclusive in this respect. It has been funded by the major (global) OEMs and MROs across the EEA and the UK, with additional support provided by their suppliers and by Ministries of Defence, to ensure the functioning of EEA and UK supply chains for their operations.

As a result, there should be no economic impacts on EEA/UK 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 Cr(VI)-based inorganic finish stripping 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 Cr(VI)-based inorganic finish stripping, they would have to be performed outside the EEA/UK until the OEMs have gained approvals and certifications for the use of alternatives on components and have adapted the manuals setting out maintenance and overhaul instructions.

If an aircraft needs unscheduled repairs (i.e., flightline or "on-wing" repairs), it will be grounded at the airport until these take place due to airworthiness constraints. This would result in AOGs and could result in an aircraft having to be dis-assembled and transported outside EEA/UK for repairs, with dramatic financial and environmental impacts.

Should MRO facilities be relocated outside the EEA/UK, airlines will also experience additional delays to routine aircraft maintenance due to transport requirements and capacity constraints at MRO facilities outside the EEA. Indeed, it may take some time to build up capacity to accommodate additional demand from EEA-based operators, potentially resulting in a large number of aircraft being grounded until maintenance can be completed.

As a result, airlines would need to have additional spare components/engines/planes to account for the added time that aircraft would be out of commission due to extended MRO times. Airports may also have to build up large inventories of spare components to replace products (including e.g., spare engines, aircraft) that currently can be repaired, with this going against the desire to ensure sustainability within the sector.

The need to have maintenance carried out outside the EEA/UK would also lead to additional operational costs being incurred through increased fuel use. Small planes (e.g., business jets) that do not have the fuel capacity or airworthiness approvals for long haul flights would need to make multiple stops enroute to non-EEA MRO facilities and back to the EEA/UK. The impacts for larger aircraft would also be significant. For example, flying from Western Europe to Turkey or Morocco is approximately 3,000 km each way and for a Boeing 737 this would take slightly less than four hours. For an airline which has 50 aircraft requiring a “D check” (heavy maintenance inspection of the majority of components, carried out every 6-10 years), this would involve 400 hours of flight time across the fleet (return trip) or 20 days of foregone revenue, equivalent to €1.4 million per annum. Scaling this up to the EEA passenger aircraft fleet, which stands at approximately 6,700, suggests lost revenues in the tens of millions per annum just due to around 700 aircraft which require a “D check” each year. Using the above estimate, 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)[64], the leasing costs alone of a plane being out of service would be roughly €14,000/£12,100 per day. On top of this, the additional losses in revenues from not being able to transport passengers or cargo would be significant. 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 additional costs for airlines. If maintenance is required unexpectedly, there could be 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[65] 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 fewer passengers and a revenue loss of 100 billion USD. In addition, COVID-19 caused a 74% decrease in passenger demand for international travel in 2020 compared to 2019. The trend though is for the aircraft industry to continue expanding globally, with pre-COVID estimates suggesting that demand for air transport would increase by an average of 4.3% per annum over the next 20 years, as illustrated in **Figure 5-2** below. Similar growth is expected in air freight transport. If this growth path were to be achieved, by 2036 the air transport industry would contribute 15.5 million in direct jobs and $1.5 trillion of GDP to

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

[65] https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf

the world economy. Once the impacts of global tourism are taken into account, these numbers could rise to 97.8 million jobs and $5.7 trillion in GDP.

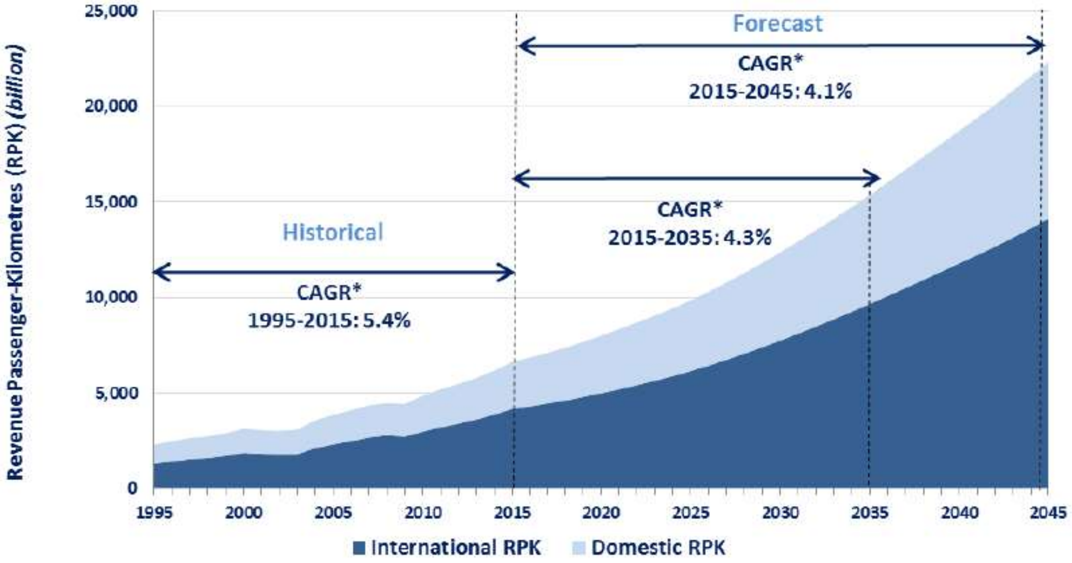

Figure 5-2: Forecast compound annual growth rates – Revenue Passenger-kilometres

Post COVID-19, projections are for a lower rate of increase in air traffic. A growth rate of around 3.9% CAGR between 2019 and 2040 is expected according to data available on the Airbus website[66]. The impact of COVID-19 has resulted in an expected 2-year lag in growth, but the forecast remains unchanged with passenger numbers expected 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[67] (covering inter-regional and intra-regional/domestic) for the period between 2018 and 2038.

This level of growth in EEA air traffic, together with the jobs and contributions to GDP that it would bring, could be impacted under the NUS. In particular, impacts on the ability of MROs to undertake repairs and carry out maintenance where this would require the use of Cr(VI)-based inorganic finish stripping to ensure the continued airworthiness of aircraft could impact on the realisation of such growth. No quantitative estimate of the level of impact can be provided, but it is clear that the closure of EU-based MRO operations in particular could impact on the availability of aircraft and hence passenger and freight transport until substitution has taken place as expected over the requested review period (unless airlines responded by buying more planes, which would inevitably give rise to increases due to the costs of holding spares and/or bringing spare planes on-line).

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.

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

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

Three national Ministries of Defence have provided direct support to the ADCR due to a concern that the non-Authorisation of the chromates in inorganic finish stripping could have a negative impact on their activities, while another has provided information to assist in the preparation of this Combined AoA/SEA. In addition, MROs providing services to a further two MODs located in the EEA have supported the ADCR to ensure that they are able to continue to maintain and repair military aircraft, ships, and ground-based systems into the future. The implications of having to cease these activities are significant. Military equipment which could not be maintained to appropriate safety standards would have to be removed from service, impacting on internal security services and emergency services. Not only would this impact on the availability of key equipment in the case of a military emergency, but it would also affect the size of potential operational forces.

It is also worth noting that military procurement agencies prefer key components of defence equipment to be produced in the EEA. Although there are also international agreements enabling manufacture in partner countries (e.g., the US, Canada and Turkey as NATO members), they are likely to be reluctant to send military aircraft to MRO facilities located in non-EU countries. As a result, shifting production to a non-EU territory could create a dependence on a non-EU supplier in a conflict situation, and could impact on mission readiness. This could, in fact, be far more impactful than the economic impacts linked to the defence sector.

As a result, it is likely that under the NUS, companies manufacturing components for and servicing military products would have to apply for defence exemptions 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[68]. 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 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 (FP7), through short-term leverage effect and long-term multiplier effects each euro spent by the FP7 generated approximately an additional €11 of estimated direct and indirect economic effects through innovations, new technologies, and products[69].

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.

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[68] https://ec.europa.eu/commission/presscorner/detail/de/MEMO_16_146

[69] https://www.evropskyvyzkum.cz/cs/storage/bf5134fec407f6e005288c0e2631ad232c38c013?uid=bf5134fec407f6e005288c0e2631ad232c38c013

5.2.5 Summary of economic impacts

Table 5-8 provides a summary of the economic impacts under the Non-Use scenario over 12 years.

Table 5-8: Summary of economic impacts under the Non-Use scenario (12 years, @ 4%)

Economic operator	**Quantitative**	**Qualitative**
Applicants	• Not assessed	
A&D companies	• Lost profits/surplus EEA: €5.2 – 25.3 billion • Lost profits/surplus UK: €1.5– 3.7 billion	Relocation costs, impacts on R&D, impacts on supply chain coherence, impacts on future growth
Competitors	Not anticipated due to sectoral coverage of the application	Not anticipated due to sectoral coverage of the application
Customers and wider economic effects	Not assessed	• Impacts on airlines, air passengers, customers • Impacts on military forces' operation capacity and mission readiness • Lost employment multiplier effects due to impacts on civil aviation and loss of defence sector spending • Loss of spin-off effects – innovation and new technologies

5.3 Environmental impacts under non-use

As well as leading to increases in operating costs and lost revenues to airlines, the increased distances that airlines would need to fly planes in order for them to undergo normal maintenance and overhaul schedules would lead to significant increases in fuel consumption and hence CO_2 emissions.

The most plausible non-use scenario in the event of a refused Authorisation - even if it may not be practical and would involve huge levels of investment - would be to shift the activity involving use of the chromates to another country (outside the EEA or UK).

Under this scenario, as noted above, the environmental impacts would be real and the effects enormous. If manufacturing activities using Cr(VI) and not using Cr(VI) are separated on both sides of the European border, huge logistics and transport related requirements would have to be introduced with dramatic impacts on the aerospace and defence sectors' environmental footprint.

For MRO activities, each time an aircraft would need a minor repair requiring Cr(VI)-based Inorganic finish stripping, 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 create excess waste and would go against the principles underlying the Circular Economy and the sustainable use of raw materials, by limiting the ability of the sector to repair and re-use components and assemblies. The industry has been active in trying to decrease buy-to fly ratios (the ratio of material inputs to final component output), and the non-use scenario would significantly undermine these efforts as the more frequent production of new components would increase the waste and scrappage generated. Scrap is material 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, since it is well aware that aviation continues to grow significantly.

Even despite the impact that the COVID-19 pandemic had on air traffic and the whole civil aviation industry, aviation is expected to double in the next 20 years. Consequently, a refused authorisation renewal would lead aircraft manufacturing and MRO activities involving Cr(VI)-based uses to move outside the EEA. In addition to the socio-economic consequences this would have, the drastic increase in CO_2 emissions, would outweigh all the benefits achieved by aviation efforts to reduce fuel consumption and CO_2 emissions of in-service aircrafts.

5.4 Social impacts under non-use

5.4.1 Direct and indirect job losses

5.4.1.1 Estimated level of job losses

As argued above, if Cr(VI)-based inorganic finish stripping was no longer allowed in the EEA or UK, the manufacture of entire components/final products may need to move as components need to be coated (and touched up) within the same production line to ensure against corrosion of the unprotected components, including during the intermediate steps of the production process. For certain processes, such as the removal and re-application of conversion coatings, there are time limits between the stripping of the inorganic finish and performance of the next process step, in order to ensure the integrity of the overall corrosion protection process.

As a result, the main social costs expected under the NUS are the redundancies that would occur due to the cessation of inorganic finish stripping, and the associated effects for the relocation of other manufacturing activities. As indicated in the assessment of economic costs, it is assumed that job losses will occur in proportion to the decreases in output expected under the NUS. Direct job losses will impact on both workers at the sites involved in Cr(VI)-based inorganic finish stripping as well as the other treatments/processes linked to this use, and those whose jobs depend on such activities continuing at these sites. These are all referred to here as direct job losses (for avoidance with confusion of multiplier effects).

While redundant workers are expected to face a period of unemployment, in line with ECHA's guidance it is assumed that such a period would be only temporary. However, the length of the average duration of unemployment varies greatly across European countries, as do the costs associated with it.

It should be noted that the ECHA methodology has been followed here despite the fact that 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 direct job losses that would arise at downstream users' sites under the NUS were presented above. For ease of reference, the totals are repeated in **Table 5-9** below. The magnitude of these figures reflects the importance of inorganic finish stripping in manufacturing, as well as to maintenance and repairs of such components at a subset of MRO facilities. No consideration is given to job losses at those companies providing services that are contracted to provide cleaning and other services to the BtPs, DtBs, MROs, and OEMs.

As context, the civil aeronautics industry alone employees around 405,000 people in the EU, while the defence sector employs more than 500,000 and supports a further 1.2 million[70].

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

Role	Total job losses due to cessation of manufacturing activities or relocation under the NUS	
	EEA	**UK**
Build-to-Print (40 sites)	800	230
Design-to-Build (19 sites)	4,838	5,067
MROs (17 sites)	3,837	426
OEMs (34 sites)	11,880	1,440
Total sites (110)	**21,355**	**7,163**

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[71]). 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[72] as a whole that varies according to the mean duration of unemployment. These vary by country, with the mean duration of unemployment weighted by the number of employees for each country relevant to aerospace and defence sector production sites, varying from 7 months to 1.6 years.

These figures are combined with the ratio of social costs per job loss provided in Dubourg (2016) and annual wages to calculate the social costs per lost job. Data were collected in the SEA questionnaire on the average salary for workers involved in the use of the chromates. The typical range given is from €30k to €50k, rising to an average maximum of around €76k, across all of the companies and locations. For the purposes of these calculations, a figure of €40k[73] 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

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[70] https://www.eudsp.eu/event_images/Downloads/Defence%20Careers%20brochure_1.pdf

[71] 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

[72] At the time of publication the UK was still an EU Member State.

[73] The weighted average personnel costs tend to be higher than €45k based on the number of companies falling into the different NACE codes. However, €40k has been adopted here to err on the side of conservatism, given the mix of companies by size and geographic location covered by this Combined AoA/SEA.

underestimate the average salary given that aerospace and defence jobs are higher paid than those in other industries.

The resulting estimates of the social costs of unemployment are given in **Table 5-10** based on consideration of the geographic distribution of Article 66 notifications, the location of SEA respondents, and the location of suppliers in the ADCR members' supply chains, as well as MROs. The estimated social costs under the NUS are around €2.38 billion for the EEA and €600 million for the UK due to the cessation of inorganic finish stripping 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	7,261	920,635,204
Poland	1,922	180,659,070
Italy	2,563	310,579,848
Germany	2,990	310,921,520
Spain	1,708	191,336,320
Czech Republic	854	93,618,128
Netherlands	427	40,146,460
Sweden	641	57,144,642
Romania	214	20,414,902
Ireland	214	20,927,410
Hungary	214	23,489,950
Norway	427	46,467,392
Belgium	214	19,560,722
Finland	427	29,725,464
Portugal	214	19,475,304
Slovakia	214	22,208,680
Denmark	214	14,862,732
Lithuania	214	17,852,362
Bulgaria	214	19,133,632
Greece	214	22,379,516
Total EEA	**21,355**	**2,381,539,258**
United Kingdom	7,163	598,826,800
Total	**28,518**	**2,980,366,058**

5.4.2 Wider indirect and induced job losses

5.4.2.1 Aerospace and defence related multiplier effects

Employment in one sector is often the input to employment in another sector, so that fluctuations in employment of the latter will inevitably affect the former.

It is clear that, under the NUS, there could be significant wider impacts on jobs given the likelihood that some of the largest players in the EEA/UK aerospace and defence sector would relocate their activities elsewhere with a partial or full cessation of manufacturing in the EEA/UK.

A UK Country Report on the "Economic Benefits from Air Transport in the UK" produced by Oxford Economics (2014) indicates the following with respect to the aerospace sector's contribution to UK employment in 2012:

- Indirect employment effects: 139,000 jobs implying a multiplier effect of 1.36 indirect jobs for every direct job; and
- Induced employment effects: 86,000 jobs implying an additional multiplier effect of 0.84 induced jobs for every direct job.

Indirect employment effects will, to a degree, be captured by the estimates of lost jobs presented in **Table 5-10** given that it includes the loss of jobs in suppliers to the aerospace OEMs and DtB companies. It excludes, however, other service providers to these companies whose services would no longer be required. Induced effects are not captured by the above estimates and an employment multiplier of 0.84 suggests that they may be significant given the predicted numbers of jobs that would be lost across the key countries in which aerospace-related manufacturing takes place.

The loss of jobs within companies that serve the defence industry would have their own multiplier effects. The external evaluation of FP7 referenced above[74] quotes an employment multiplier of between 2.2 to 2.4, 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[75] (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 45 aerospace clusters across 18 countries, covering the entire A&D value chain in Europe. **Figure 5-3** below is a "snip" taken from the EACP website highlighting the location of these different hubs across Europe, to provide an indication of where effects may be experienced at the regional level.

Under the non-use scenario, the economic impact on each region could have severe consequences. For example, Aerospace Wales consists of over 180 members, which employ 23,000 employees with a turnover of over £6.5 billion in Wales alone. The Andalucía Aerospace Cluster has over 37 members, 16,000 employees, and over €2.5 billion turnover (See Annex 2). Both of these clusters are an essential part of the local economy.

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[74] 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

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

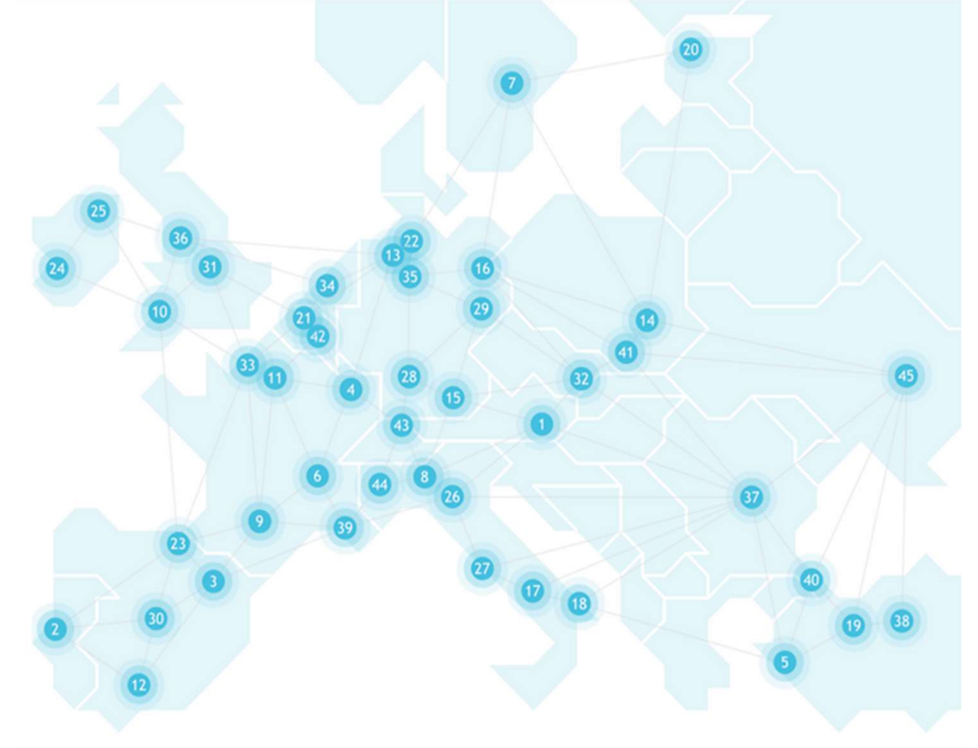

Figure 5-3: Aerospace clusters across Europe
Source: https://www.eacp-aero.eu/about-eacp/member-chart.html

5.4.2.2 Air transport multiplier effects

A 2019 "Aviation Benefits Report"[76] produced by a high level group formed by the International Civil Aviation Organisation (ICAO) provides an assessment of the economic impacts of the aviation sector. These are linked to its direct impact as well as indirect, induced, and catalytic effects. At a regional level, it is estimated that air transport supports 12.2 million jobs in Europe. 2.6 million of these jobs are direct within the aviation sector, with the remaining 9.6 million stemming indirectly from the aviation sector or relating to induced or catalytic effects.

Clearly not all these jobs would be impacted under the NUS, although some impact would be expected should there be reductions in the number of flights, increased delays, and other effects from the loss of EEA/UK based MRO activities in particular.

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

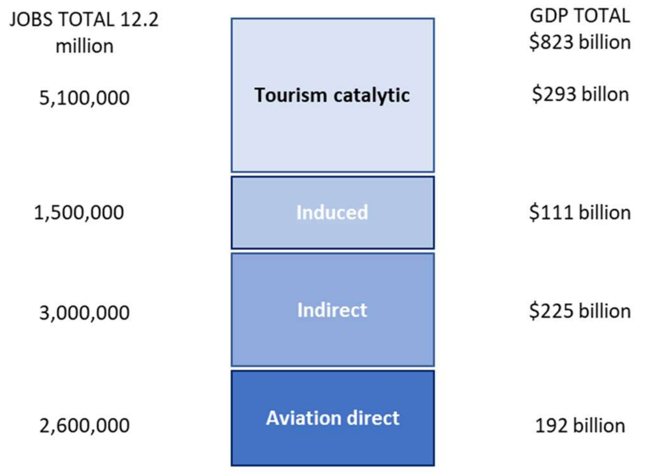

Figure 5-4: Aviation related multiplier effects
Based on: **https://www.icao.int/sustainability/Documents/AVIATION-BENEFITS-2019-web.pdf**

The potential employment losses associated with a decline in European aviation can be seen by reference to the impacts of COVID-19[77]. 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, it is clear that a disruption to civil aviation could have significant employment impacts.

5.4.3 Summary of social impacts

In summary, the social impacts that would arise under the NUS include the following:

- Direct job losses:
    - Around 21,400 jobs in the EEA due to the loss of inorganic finish stripping and linked assembly and/or manufacturing activities, and
    - Over 7,200 jobs in the UK due to the loss of inorganic finish stripping and linked assembly and/or manufacturing activities;

- Social costs of unemployment:
    - €2.38 billion for the EEA associated with direct job losses, and
    - €600 million for the UK associated with direct job losses;

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

- Indirect and induced unemployment at the regional and potentially national level due to direct job losses: not quantified but may be significant at the regional level; and

- Direct, indirect, and induced job losses in air transport due to disruption of passenger and cargo services: Not quantified but may be significant at the regional level.

5.5 Combined impact assessment

5.5.1 Complication of socio-economic impacts

Table 5-11 sets out a summary of the societal costs associated with the non-use scenario. Figures are provided as annualised values, with social costs also presented as a present value over a 2-year period as per ECHA's latest guidance; note that restricting losses to only those occurring over the first two years of the non-use scenario will significantly underestimate the profit losses to the A&D companies as well as the applicants. Most A&D companies would incur losses for at least a 4-year period, with over 60% incurring losses over a 12-year period as they continue work towards testing, qualification, certification, and industrialisation of an alternative over the full 12-year period requested.

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**
Producer surplus loss due to ceasing the use applied for[1]: Impacts on applicants - Lost profits EEA - Lost profits UK Impacts on A&D companies[1]: - Lost profits EEA - Lost profits UK	Applicants: Not assessed A&D companies EEA: €1,100 million – 5,100 million UK: €300 – 750 million	Applicants: Not assessed A&D companies EEA: €560 million – 2,700 million UK: €160 – 370 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: €2.4 billion UK: €600 million	EEA: €1.2 billion UK: €300 million
Spill-over impact on surplus of alternative producers	Not assessed due to sector level impacts	Not assessed due to sector level impacts
Sum of monetised impacts	EEA: €3.4 – 7.5 billion UK: €900 million – 1.3 billion	EEA: €1.8 – 3.9 billion UK: €460 – 700 million
2. Additional qualitatively assessed impacts		
Impacts on A&D sector	Impacts on R&D by the A&D sector, impacts on supply chain, impacts on technological innovation	
Civilian airlines	Wider economic impacts on civil aviation, including loss of multiplier effects, impacts on airline operations, impacts on passengers including flight cancellations, ticket prices, etc.	

Table 5-11: Summary of societal costs associated with the Non-Use Scenario	
Description of major impacts	**Monetised/quantitatively assessed/qualitatively assessed impacts**
Ministries of Defence	Impacts on the operational availability of aircraft and equipment, premature retirement of aircraft and equipment, impacts on mission readiness
1) Lower bound figures represent lost EBITDA estimates, upper bound lost operating surpluses. 2) Lower bound reflects job losses for those directly involved in inorganic finish stripping only, upper bound reflects job losses in linked processes and subsequent manufacturing activities	

6 Conclusion

6.1 Steps taken to identify potential alternatives

Potential alternatives to Cr(VI) for inorganic finish stripping should be "generally available"[78]. At present, this condition has not been met, as there are no alternatives which have met the strict regulatory requirements within the A&D industry for all components onto which inorganic finish stripping containing Cr(VI) is currently undertaken.

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 inorganic finish stripping are shown in **Figure 6-1**:

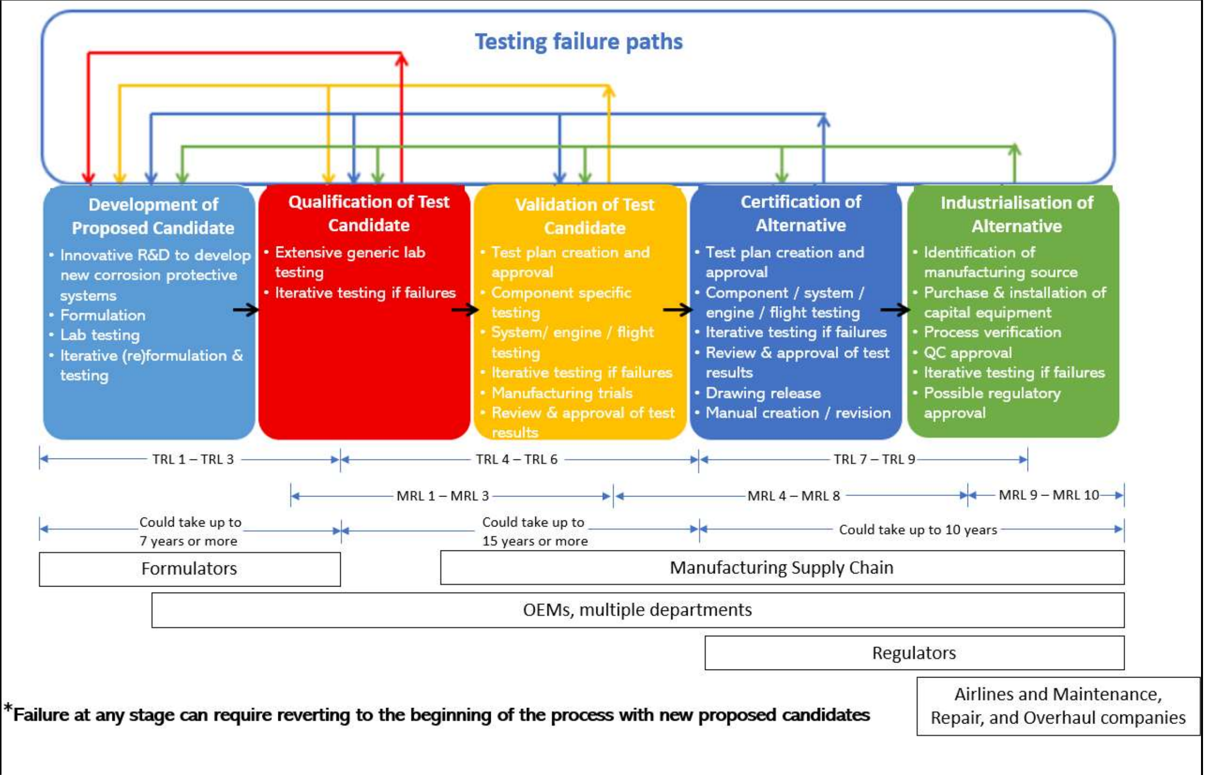

Figure 6-1: Schematic showing the key phases of the substitution process.
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note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

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[78] 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 inorganic finish stripping. Individual members often have multiple substitution plans within inorganic finish stripping, reflecting the different coatings to be stripped, 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 for certain coatings, thereby reducing their Cr(VI) usage, many technical challenges remain – particularly where the key functionality of ensuring negligible or no effect on the underlying substrate whilst supporting the efficient removal of the inorganic finish is required.

As discussed in Section 3.7.2 and shown in **Figure 6-2** below, of the 20 distinct substitution plans for inorganic finish stripping assessed in this combined AoA/SEA, 10% of them are expected to have achieved MRL 10 by September 2024. 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 and eliminated in inorganic finish stripping 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 30% in 2028, 85% in 2031, and 90% in 2036. The potential need for more than 12 years has been identified by some OEMs due to their inability to identify any technically feasible alternatives to date, or due to the need by MROs and MoDs for continued use in the maintenance and repair of in-service (legacy) final A&D products.

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

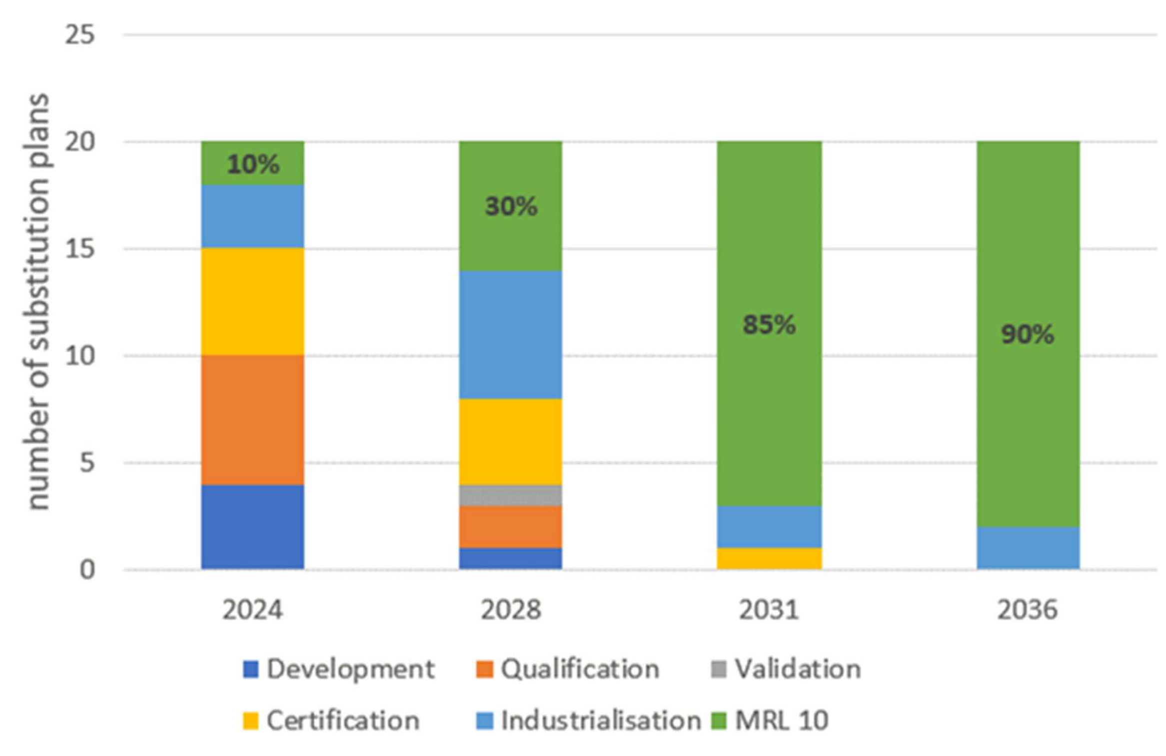

Figure 6-2: Expected progression of substitution plans for the use of Cr(VI) in inorganic finish stripping, by year

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

Source: RPA analysis, ADCR members

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

6.3 Comparison of the benefits and risk

Table 6-1 summarises the socio-economic benefits of continued use of the chromates in inorganic finish stripping by companies in the aerospace and defence sector. Overall, net benefits of between ca. €3.4 to 7.5 billion for the EEA and €900 to 1,300 million for the UK (Net Present Value social costs over two years/risks over 12 years, @4%) can be estimated for the Continued Use scenario. These figures capture continued profits to the applicants and the A&D companies and the social costs of unemployment. They also include the monetised value of the residual risks to workers and humans via the environment (estimated at €460k and €110k for the EEA and UK respectively over 12 years).

As can be seen from **Table 6-1**, the ratio of the benefits of continued use to the monetised value of the residual health risks is around 16,539 on the lower bound assumptions for the EEA and 18,156 on the lower bound assumptions for the UK.

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

Societal costs of non-use		**Risks of continued use**	
Monetised profit losses to applicants	Losses in profits from reduced sales of the chromate substances and associated formulations. Losses quantified in the Formulation SEA	Substance imported/risks of formulation covered in formulation SEA	
Monetised profit losses to A&D companies	EEA: €1.1 – 5.1 billion (£0.9 – 4.4 million) UK: €300 – 750 million (£260 – 640 million)	**Monetised excess risks to directly and indirectly exposed workers** **(€ per year over 12 years)**	EEA: €440k (£380k) UK: €98k (£84k)
Social costs of unemployment	EEA: €2.4 billion (£2 billion) UK: €600 million (£520 million)	**Monetised excess risks to the general population** **(€ per year over 12 years)**	EEA: €18k (£15k) UK: €12k (£10k)
Qualitatively assessed impacts	Wider economic impacts on civil aviation, impacts on cargo and passengers. Impacts on armed forces including military mission readiness. Impacts on R&D and technical innovation. Impacts from increased CO_2 emissions due to MRO activities moving out of the EEA/UK; premature redundancy of equipment leading to increased materials use.		
Summary of societal costs of non-use versus risks of continued use	- NPV (2 years societal costs/12 years excess health risks): ○ EEA: €3,400 – 7,500 million (£3,000 – 6,400 million) ○ UK: €900 – 1,300 million (£800 – 1,200 million) - Ratio of societal costs to risks: ○ EEA: 7,498:1 to 16,319:1 ○ UK: 8,216:1 to 12,234:1		

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 would be lost to aerospace and defence downstream users in the EEA and UK

⇩

Due to certification and airworthiness requirements, downstream users would be forced to undertake inorganic finish stripping 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 components 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 processes reliant upon inorganic finish stripping as OEMs relocate, 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 use of chromate-based inorganic finish stripping is an essential part of maintenance, repairs and overhaul activities

↓

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

↓

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

↓

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

Overall, it is clear that the benefits of the continued use of the chromates in inorganic finish stripping significantly outweigh the residual risks from continued use.

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 that could lead to a recommendation of a long review period (12 years)[79]:

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.*

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[79] https://echa.europa.eu/documents/10162/13580/seac_rac_review_period_authorisation_en.pdf/c9010a99-0baf-4975-ba41-48c85ae64861

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 change quickly. 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, the applicants assert that qualification and certification requirements combined with the need for approvals from EASA, the ESA and MoDs are consistent with the requirements under criterion 4 above.

Further discussion was held at the 25th Meeting of Competent Authorities for REACH and CLP (CARACAL) of 15 November 2017. A document endorsed by CARACAL suggests that "*in order to consider a review period longer than 12 years, in addition to the criteria for a 12-year review period established in the document "Setting the review period when RAC and SEAC give opinions on an application for authorisation", two additional conditions should jointly be met*:

6. *As evaluated by the RAC, the risk assessment for the use concerned should not contain any deficiencies or significant uncertainties related to the exposure to humans (directly or via the environment) or to the emissions to the environment that would have led the RAC to recommend additional conditions for the authorisation. In the case of applications for threshold substances, the appropriateness and effectiveness of the applied risk management measures and operational conditions should clearly demonstrate that risks are adequately controlled, and that the risk characterisation ratio is below the value of one. For applications for non-threshold substances, the applied risk management measures and operational conditions should be appropriate and effective in limiting the risks and it should be clearly demonstrated that the level of excess lifetime cancer risk is below* $1x10^{-5}$ *for workers and* $1x10^{-6}$ *for the general population. For substances for which the risk cannot be quantified, a review period longer than 12 years should normally not be considered, due to the uncertainties relating to the assessment of the risk.*
7. *As evaluated by the SEAC, the analysis of alternatives and the third party consultation on alternatives should demonstrate without any significant uncertainties that there are no suitable alternatives for any of the utilisations under the scope of the use applied for and that it is highly unlikely that suitable alternatives will be available and can be implemented for the use concerned within a given period (that is longer than 12 years)"* (CARACAL, 2017)(CARACAL, 2017).

As far as the second criterion above is concerned, the same document provides some relevant examples, one of which (Example (d)) reads as follows:

> "(…) *the use of the substance has been authorised in accordance with other EU legislation (e.g., marketing authorisation, certification, type-approval), the substance being specifically referred to in the authorisation/certification granted and substitution, including the time needed for modification of the authorisation/certification/type-approval, would not be feasible within 12 years and would involve costs that would jeopardise the operations with regard to the use of the substance*".

6.4.2 Criterion 1: Demonstrably Long Investment Cycle

The aerospace and defence industry is driven by long design and investment cycles, as well as very long in-service time of their products. As noted previously, the average life of a civil aircraft is typically 20-35 years, while military products typically last from 40 to >90 years. Furthermore, the production of one type of aircraft or piece of equipment may span more than 50 years.

These long investment cycles and long product lives have been recognised in the FWC Sector 26 study on the Competitiveness of the EEA aerospace industry[80]. They are a key driver underlying the difficulties facing the sector in substituting the use of the chromates in inorganic finish stripping across all components within final products. The long service life of aircraft and other products makes it difficult to undertake all of the tests required to qualify and certify a component with the substitute, due to the level of investment and costs that would be involved in such an activity for out of production A&D products; it would require testing at multiple levels (components, sub-assemblies, assemblies, final aircraft/defence equipment).

The ADCR would like to emphasise the crucial role every component within an A&D product plays with respect to its safety. An aircraft is a complex system involving not only design of the aircraft itself, but also its use and maintenance history in varied climates and service. For example, an aircraft engine is exposed to massive forces and extremely high stress levels due to high velocities and environmental stressors. Therefore, every single component needs to be designed, manufactured, and maintained with serious attention and care.

In a complex system, change introduces new forms of potential failure. Any change will bring failures that can be anticipated – and some that are unanticipated. The components in an A&D product are very precisely engineered and need to fit with each other to very close tolerances. 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. Systematic TRL-style implementation is time consuming but 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.

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[80] 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.

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 legally only 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 components and the final products they are used in.

As such, a review period of at least 12 years is warranted and requested for the highly complex 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 inorganic finish stripping; 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 data have 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 inorganic finish stripping represents the baseline that alternatives must match to demonstrate equivalence.

For example, modern commercial aircraft in their entirety consist of between 500,000 to 6 million components, depending on the model. Depending on the materials of construction, 15-70% of the entire structure of an aircraft requires treatment using Cr(VI) at some point during the manufacturing process. Older models generally require a larger percentage of Cr(VI) surface treatments as the aerospace industry has worked diligently to incorporate new base materials and Cr(VI)-free protective coatings in newer models wherever it is safe to do so.

There are literally billions of flight hours' experience with components on which Cr(VI)-based inorganic finish stripping has been performed. Conversely, there is still limited experience with Cr(VI)-free formulations on components. It is mandatory that components which have had finishes removed using a Cr(VI)-free alternative are demonstrably every bit as safe as they had been when stripped using a Cr(VI)-based 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 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 stripping process, 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 would add inherent maintenance time and costs to the manufacturers; operators; and eventually end-use customers.

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 ongoing for several decades. Although use continues, it should be recognised that significant achievements have been made over this period in the substitution of the use of the chromates by alternative substances, formulations, or technologies. This is illustrated by the achievements of one of the OEMs in reducing by 75% (reduction by weight) of their level of dependency on use of the chromates across all processes (see **Figure 6-3**).

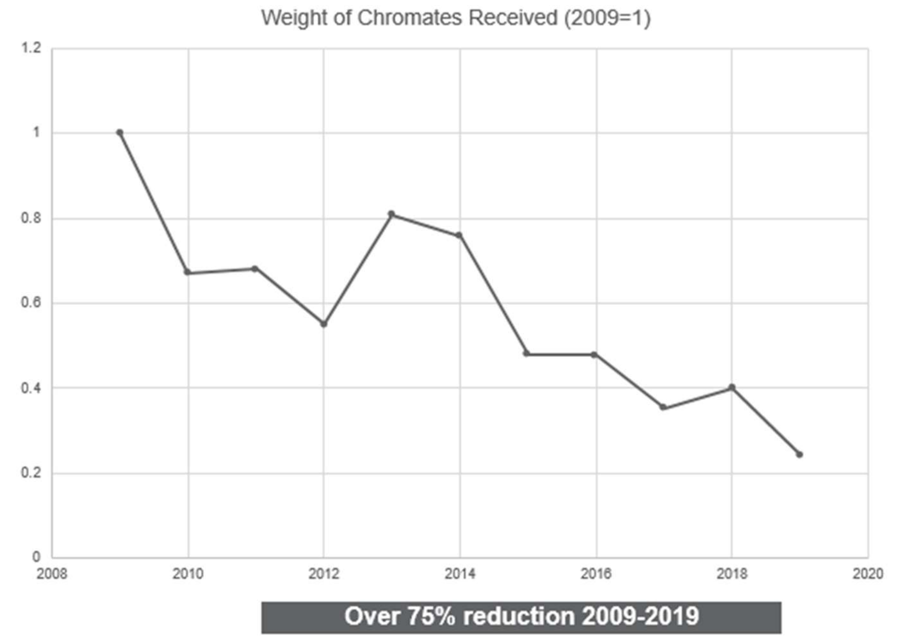

Figure 6-3: Reductions in chromate dependency over the period 2009 -2019

This 75% reduction in the use of the chromates by weight reflects the massive efforts and investment in R&D aimed specifically at substitution of the chromates. Although these efforts have enabled substitution across a large range of components and products, this OEM will not be able to move to substitutes for Cr(VI)-based inorganic finish stripping across all components and products for at least 12 years, and perhaps longer for those components and products which have to meet military requirements (including those pertaining to UK, EEA and US equipment).

Testing corrosion protection systems in environmentally relevant conditions to assure performance necessarily requires long R&D cycles. A key factor driving long timeframes for implementation of fully qualified components using alternatives by the A&D industry is the almost unique challenge of obtaining relevant long-term corrosion performance information. In the case of inorganic finish stripping, it requires testing of changes in a process of corrosion protection, which may include changes in the primers (another possible step in the process) applied to a treated component or product which has been stripped using chromates.

As a result, there are very long lead times before technologies developed from a research project can be implemented into real products. Technologies which are available on the market today are the result of extensive research, including research funded by grants and conducted over the last 25 plus years. In 2020, the European A&D industries spent an estimated €18 billion in Research and Development (with an approximate 40:60 split between civil and military activities, and investment in R&D in the US roughly four times higher)[81].

A PricewaterhouseCoopers (PwC) study[82] refers to the high risks of investments in the aerospace industry: "Historically, step changes have been the norm in aircraft R&D. But recent development efforts have been so expensive that it is unclear whether the companies will earn the anticipated return on their investments. Furthermore, slips in the programme schedule have worsened the economics".

As stated many times already, A&D companies cannot simply apply a less effective stripping process as aerospace and defence substantiation procedures demand component performance using alternatives to be equal or better. If such performance is not achieved, then the alternatives cannot be used. The implications for repair, maintenance, and overhaul must also be understood before moving to an alternative. It must be recognised that the performance delivered by one component is dependent upon the performance of other components; thus, the performance delivered by a final product is dependent upon the components used. The number of configurations of components and final products is immense, and each configuration may differ from the next in terms of its behaviour with a Cr(VI) alternative. There is a complex relationship between each component and its performance requirements within its own unique design parameters, which requires component certification for each individual substitution.

6.4.5 Criterion 4: Legislative measures for alternatives

As discussed in detail in Section 3.1.2, the identification of a test candidate Cr(VI)-free formulation is only the first stage of an extensive multi-phase substitution process leading to implementation of the alternative. This process, illustrated below, requires that all components, materials and processes incorporated into an A&D system must be qualified, validated, certified and industrialised before production can commence. Each phase must be undertaken to acquire the necessary certification to comply with airworthiness and other safety-driven requirements.

From start to finish, significantly more than 12 years is required to move from Phase 1 to Phase 5 (i.e., to identify, qualify, validate, certify and industrialise alternatives) for all critical A&D applications. The ADCR OEMs and DtBs as design owners are currently working through this process with the aim of implementing chromate-free inorganic finish stripping by 2036; their current substitution plans are designed to ensure they achieve TRL9 and MRL10 within the next 12 years or sooner. This includes gaining airworthiness certification or military safety approvals, both of which can take up to several years to ensure safety. It may take more than 12 years to gain final approvals for some defence uses,

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

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

particularly with respect to repairs, although the design owners are working to resolve current difficulties by 2036.

Several of the ADCR members also note that military procurement agencies prefer key components of defence equipment to be produced in the EEA, although there are also international agreements enabling manufacture in partner countries. In contrast to other industry sectors, shifting production to a non-EU territory and import of finished surface treated components or products into the EEA is more complex, as it could create a dependence on a non-EU supplier in a conflict situation.

Furthermore, the provision of defence exemptions, as allowed for in Article 2 (3) of the REACH regulation, is **not** a suitable instrument to ensure the continued availability of the chromates for inorganic finish stripping 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 inorganic finish stripping 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 chromate-based inorganic finish stripping. On the basis of a defence exemption alone, the quantities demanded would not be sufficient for manufacturers, and surface treatment companies to continue to offer their services and products. As a result, inorganic finish stripping for military aircraft and equipment would not continue in the EEA or UK if other civilian applications were not also possible. This can only be ensured by the granting of an authorisation.

6.4.6 Criterion 5 and 6: Comparison of socio-economic benefits and risks to the environment and effective control of the remaining risks

As demonstrated by the information collected by the SEA questionnaire, A&D companies have invested in monitoring and the installation of additional risk management measures in response to the conditions placed on the continued use of the chromates under the initial (parent) authorisations. This has resulted in both reduced exposures for workers and reduced emissions to the environment. As substitution progresses across components and assemblies and the associated value chains, consumption of the chromates will decrease, and exposures and emissions will reduce further over the requested 12 year review period. As a result, the excess lifetime risks derived in the CSR for both workers and humans via the environment will decrease over the review period. These risks will also be controlled through the 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[83].

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

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[83] 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

were employed in 2020[84]) and Europe's trade balance (55% of products developed and built in the EEA are exported).

Civil aeronautics alone accounted for around €99.3 billion in revenues, with military aeronautics accounting for a further €47.4 billion in turnover; overall taking into account other defence and space turnover, the sector had revenues of around €230 billion. Of the €99.3 billion in civil aeronautics turnover, €88.3 billion represented exports from the EU.

Both acknowledged market reports of Airbus and Boeing find a growing trend in the aerospace industry. Passenger air traffic is predicted to grow at 3.6% CAGR for 2022-2041 and freight traffic to grow at 3.2% CAGR globally, according to Airbus' Global Market Forecast. By 2041, there will be some 46,900 aircraft in service, with this including an estimated 39,500 new passenger and freight 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.[85]

Boeing's 2022 Commercial Market Outlook[86] indicates a similar level of increase, noting that the global fleet will increase by around 80% through to 2041 with the forecast value of new airplane deliveries at around US $7.2 trillion (based on a slightly higher growth in traffic at around 3.8% CAGR.

The socio-economic benefits of retaining the key manufacturing base of the EEA and UK A&D industries are clearly significant, given that they will be major beneficiaries of this growth in demand. As demonstrated in the socio-economic analysis presented here, even without accounting for such growth in demand under the continued use scenario, the socio-economic benefits clearly outweigh the associated risks to human health at social costs to risk ratios of over 3,560 to one for the EEA and 1,426 to one for the UK.

6.5 Substitution effort taken by the applicant if an authorisation is granted

As the AoA shows, where alternatives have been proven as technically feasible – on a component-by-component basis – they have been, or are in the process of, being implemented. However, there are still many cases where components do not have technically feasible alternatives available. **Figure 3-2** highlights the actions that are being taken by A&D design owners to develop, qualify, validate, certify and industrialise alternatives for individual components.

This work will continue over the requested review period with the aim of phasing out all uses of chromate-based inorganic finish stripping. As illustrated in Section 3.7, on-going substitution is expected to result in significant decreases in the volumes of the two chromates used in inorganic finish stripping 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.

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

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

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

6.6 Links to other Authorisation activities under REACH

This combined AoA/SEA is one of a series of applications for the re-authorisation of the use of chromates in surface treatments carried out by the A&D industry. This series of combined AoA/SEAs has adopted a narrower definition of uses originally Authorised under the CTAC, CCST and GCCA parent Applications for Authorisation.

In total, the ADCR will be submitting 11 Combined AoA/SEAs covering the following uses and the continued use of chromium trioxide, sodium dichromate, potassium dichromate, sodium chromate and/or dichromium tris(chromate):

1) Formulation
2) Pre-treatments
3) Electroplating (hard chrome plating)
4) Passivation of stainless steel
5) Anodising
6) Chemical conversion coating
7) Anodise sealing
8) Passivation of non-aluminium metallic coatings
9) Inorganic finish stripping
10) Chromate rinsing after phosphating
11) Slurry coatings

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8 Annex 1: Standards applicable to inorganic finish stripping

Table 8-1 lists examples of standards and specifications reported by ADCR members applicable to the use inorganic finish stripping. 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 inorganic finish stripping

Standard Reference	Standard Description	Technical feasibility criteria/Standard type
ASTM B117	Standard Practice for Operating Salt Spray (Fog) Apparatus	Corrosion resistance
ASTM B137	Standard Test Method for Measurement of Coating Mass Per Unit Area on Anodically Coated Aluminium	Complete removal of finish
ASTM B244	Standard Test Method for Measurement of Thickness of Anodic Coatings on Aluminium and of Other Nonconductive Coatings on Nonmagnetic Basis Metals with Eddy-Current Instruments	Complete removal of finish
ASTM B499	Standard Test Method for Measurement of Coating Thicknesses by the Magnetic Method: Non-magnetic Coatings on Magnetic Basis Metals	Complete removal of finish
ASTM E467	Standard Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System	No impact upon residual stress, surface roughness and fatigue properties.
ASTM F2111	Standard Practice for Measuring Intergranular Attack or End Grain Pitting on Metals Caused by Aircraft Chemical Processes	Mitigation of end-grain pitting and intergranular attack.
ASTM F519	Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating/Coating Processes and Service Environments	Does not induce hydrogen embrittlement
SAE ARP1755	Effect of Cleaning Agents on Aircraft Engine Materials Stock Loss Test Method	Compliance with component drawing post treatment

Source:
ADCR members
"Brief description" obtained from https://standards.globalspec.com

9 Annex 2: European Aerospace Cluster Partnerships

Table 9-1: European Aerospace Clusters

Cluster Name	Country	City	Number of Companies	Employees	Sales/turnover
ACSTYRIA MOBILITÄTSCLUSTER GMBH	Austria	Styria	80	3000	650 million Euros
Aeriades	France	Grand Est	65	3100	500 million Euros 7% of total French GDP
Aerospace Cluster Sweden	Sweden	Älvängen	50		
AEROSPACE LOMBARDIA	Italy		220	16000	5.4 billion Euros
AEROSPACE VALLEY	France	Toulouse	600	147000	
Aerospace Wales Forum Limited	UK	Wales	180	23000	£6.5 billion
Andalucía Aerospace Cluster	Spain	Andalusia	37	15931	2.5 billion Euros
Aragonian Aerospace Cluster	Spain	Zaragoza	28	1000	
ASTech Paris Region	France	Paris		100000	
Auvergne-Rhône-Alpes Aerospace	France	Rhône-Alpes	350	30000	3.3 billion Euros
AVIASPACE BREMEN e.V.	Germany	Bremen	140	12000	
Aviation Valley	Poland	Rzeszow	177	32000	3 billion Euros
bavAIRia e.V.	Germany	Bavaria	550	61000	
Berlin-Brandenburg Aerospace Allianz e.V.	Germany	Berlin	100	17000	3.5 billion Euros
Czech Aerospace Cluster	Czech Republic	Moravia	53`	6000	400 million Euros
DAC Campania Aerospace District	Italy	Campania	159	12000	1.6 billion Euros
DTA Distretto Tecnologico Aerospaziale s.c.a.r.l	Italy	Apulia	13	6000	78 million Euros
Estonian Aviation Cluster (EAC)	Estonia	Tallinn	19	25000	3% of GDP
Flemish Aerospace Group	Belgium	Flanders	67	3300	1.2 billion Euros
Hamburg Aviation e.V	Germany	Hamburg	300	40000	5.18 billion Euros
HEGAN Basque Aerospace Cluster	Spain	Basque Country	56	4819	954 million Euros
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[87]

The UK aerospace sector is considered by the government to be "hugely important to the UK economy"[88], 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)[89]. To date, this co-funded programme has invested £2.6 billion, across all parts of the UK. It is anticipated that the UK aerospace sector will continue to grow into the future, due to the global demand for large passenger aircraft, as discussed further below.

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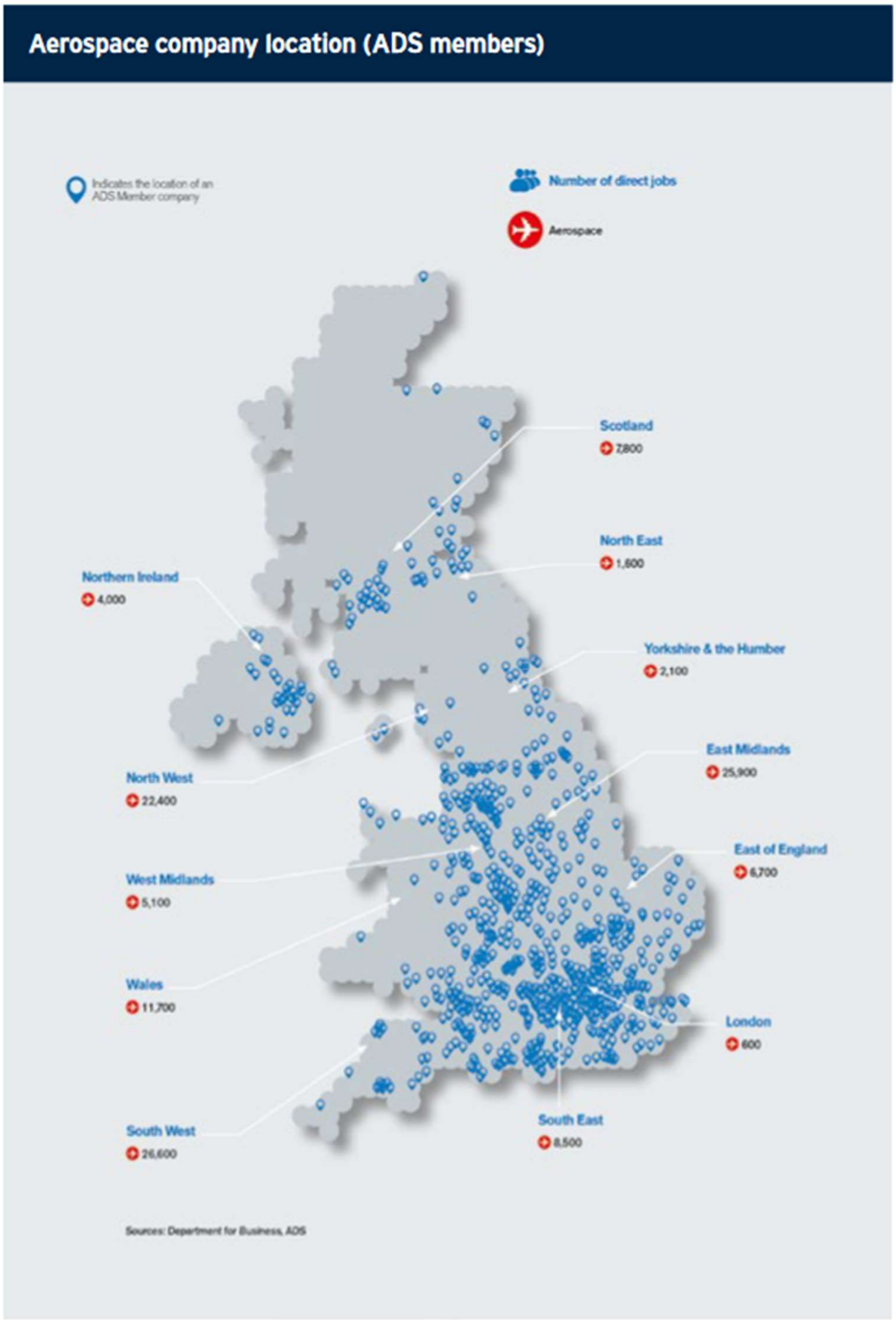
[87] https://www.adsgroup.org.uk/wp-content/uploads/sites/21/2022/06/ADS-FF2022-Twit-header-72.jpg

[88] BEIS, Aerospace Sector Report, undated.

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



Sources: Department for Business, ADS

Figure 10-2: Location of aerospace manufacturing sites and associated jobs in the UK[90]

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[90] 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**[91]. Again, the importance of the sector to UK exports and value added, as well as employment is clear from the figure below.

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

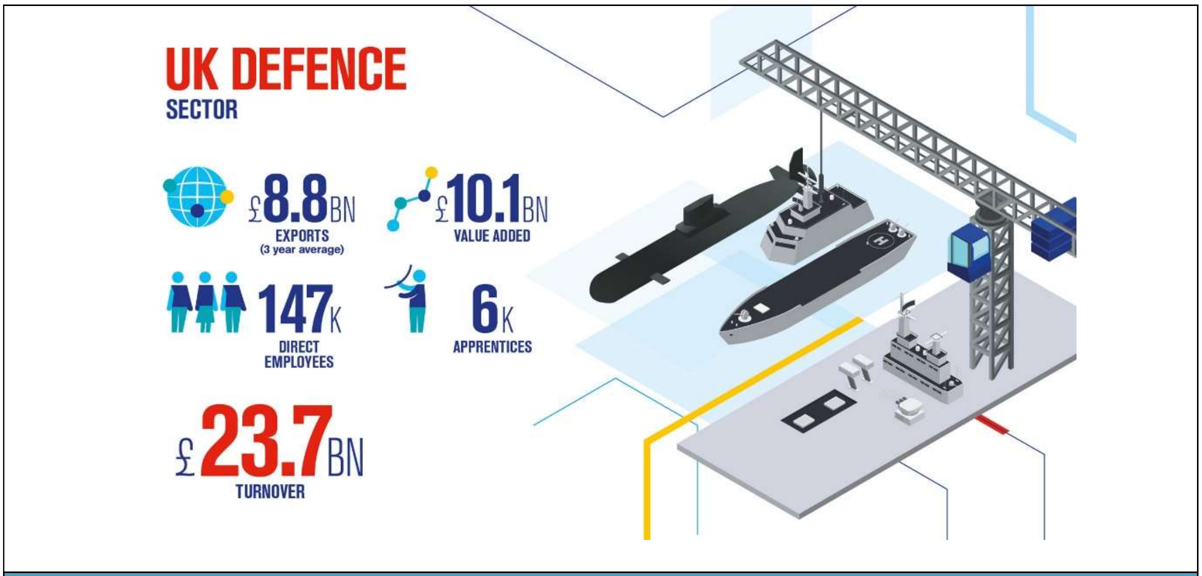

Figure 10-3: UK defence sector contribution to the economy in 2021