ANALYSIS OF ALTERNATIVES

and

SOCIO-ECONOMIC ANALYSIS

Complete version

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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

CCC – Chemical Conversion Coating

CCST – Chromium VI Compounds for Surface Treatment

CMR – Carcinogen, Mutagen or toxic for Reproduction

Cr(VI) – Hexavalent chromium

CSR – Chemical Safety Report

CT – Chromium trioxide

CTAC – Chromium Trioxide Authorisation Consortium

DtB – Design-to-Build manufacturer

DtC – Dichromium tris(chromate)

EASA – European Aviation Safety Agency

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

ECHA – European Chemicals Agency

EEA – European Economic Area

ESA – European Space Agency

GCCA – Global Chromates Consortium for Authorisation

GDP – Gross domestic product

GOS – Gross operating surplus

GVA – Gross value added

ICAO – International Civil Aviation Organisation

MoD – Ministry of Defence

MRL – Manufacturing readiness level

MRO – Maintenance, Repair and Overhaul

NADCAP – National Aerospace and Defence Contractors Accreditation Program

NATO – North Atlantic Treaty Organisation

NUS – Non-use scenario

OELV – Occupational Exposure Limit Value

OEM – Original Equipment Manufacturer

RAC – Risk Assessment Committee

REACH – Registration, Evaluation, Authorisation and restriction of Chemicals

RR – Review Report

SC – Sodium chromate

SD – Sodium dichromate

SEA – Socio Economic Analysis

SEAC – Socio Economic Analysis Committee

SME – Small and medium-sized enterprises

SVHC – Substance of Very High Concern

T&E – Testing and Evaluation

TRL – Technology Readiness Level

UK – United Kingdom

WCS – Worker contributing scenario

Glossary

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

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

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

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

DECLARATION

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

Also, we request that the information blanked out in the "public version" of the Analysis of Alternatives and Socio-economic analysis is not disclosed. We hereby declare that, to the best of our knowledge as of today 14 December 2022 the information is not publicly available and, in accordance with the due measures of protection that we have implemented, a member of the public should not be able to obtain access to this information without our consent or that of the third party whose commercial interests are at stake.

Signatures: L. C. Copeman. Date: 14 December 2022

Brenntag UK LTD

– Louise Copeman.

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 passivation of stainless steel[1] is still required for many products. This remains critical to both flight safety and to military mission readiness, and hence to society. The socio-economic impacts of a refused authorisation are therefore significant not just for the sector but also for the EEA and UK societies and economies more generally. Furthermore, at the EU level, the A&D sector is one of the 14 sectors highlighted by the EU's New Industrial Strategy[2] as being important to innovation, competition and a strong and well-functioning single market.

The parent authorisations to this review report covered multiple surface treatments and different individual chromates. This combined AoA/SEA covers only one of the currently authorised types of surface treatment – passivation of stainless steel – 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.

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

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

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

1) *Passivation of stainless steel using chromium trioxide or sodium dichromate in the Aerospace and Defence industry and its supply chains*

The “applied for use” involves the continued use of chromium trioxide and 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/final product’s certification requirements.

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

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

The potential for double counting is significant given that approximately 125 sites in the EEA and 25 sites in Great Britain are anticipated as undertaking passivation. This includes sites in involved in the production of components and end products, as well as maintenance, repair and overhaul services for both civil aviation and military bodies, as well as aeroderivative uses.

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

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

	Chromium trioxide	Sodium dichromate
EEA	Up to 8.4 t/y	Up to 17.5 t/y
UK	Up to 2.4 t/y	Up to 5 t/y

1.2 Availability and suitability of alternatives

For the past several decades, ADCR members who are “design owners” (including Original Equipment Manufacturers (OEMs) and Design-to-build manufacturers (DtB) selling products used in civil aviation and military aircraft and ground and sea-based defence systems, and aeroderivatives have been searching for alternatives to the use of the chromates in passivation of stainless steel as a specific use. At the current time, the remaining uses form a part of an overall system providing the following key functions:

- Corrosion resistance[3];
- Embrittlement/heat treatment; and
- Adhesion promotion of subsequent layer.

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

Passivation of stainless steel is a key use of chromium trioxide and sodium dichromate by the A&D industry. It involves the removal of embedded iron/steel particles from the substrate and oxidation of the surface chromium in the alloy. The processes creates a chemical film that acts as a barrier against rust, and provides corrosion resistance, enhanced adhesion and prevention of embrittlement (whilst withstanding heat treatment). It enhances the natural passive properties of the stainless steel and is used for newly machined stainless steel components.

The OEMs and DtB manufacturers (as design owners) that are the design owners for A&D final products (aircraft, helicopters, military jets, missile systems, tanks, etc.) have conducted a full analysis of their requirements into the future, taking into account progress of R&D, testing, qualification, validation and certification and industrialisation activities.

The companies are at different stages in the implementation of alternatives, with some indicating that they expect to be able to substitute the above chromates in passivation of stainless steel across some of their current components, final products and MRO (maintenance, repair and overhaul) processes within the next four to seven years; others face greater challenges due to the more demanding requirements of their products and have not yet been able to identify technically feasible alternatives for all components and products that will meet performance requirements. They will require up to a further 12 years to gain certifications and to then implement current test candidates; a further set are constrained by military and/or MRO requirements which may mean that it will take at least 12 years to implement technically feasible substitutes.

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

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

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[3] Corrosion resistance is synonymous with the term corrosion protection

passivation if this is specified in the Maintenance Manuals provided to them by the OEMs. MROs (military and civilian) are legally obliged to carry out their activities in line with the requirements set out in Maintenance Manuals, given the importance of these to ensuring airworthiness and the safety and reliability of final products. As a result, they rely on the completion of the R&D, testing and certification activities of the OEMs and the update of the Maintenance Manuals before they are able to adopt alternative substances or processes. This applies not only to MROs involved in servicing civilian aircraft but also military MROs servicing military equipment.

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

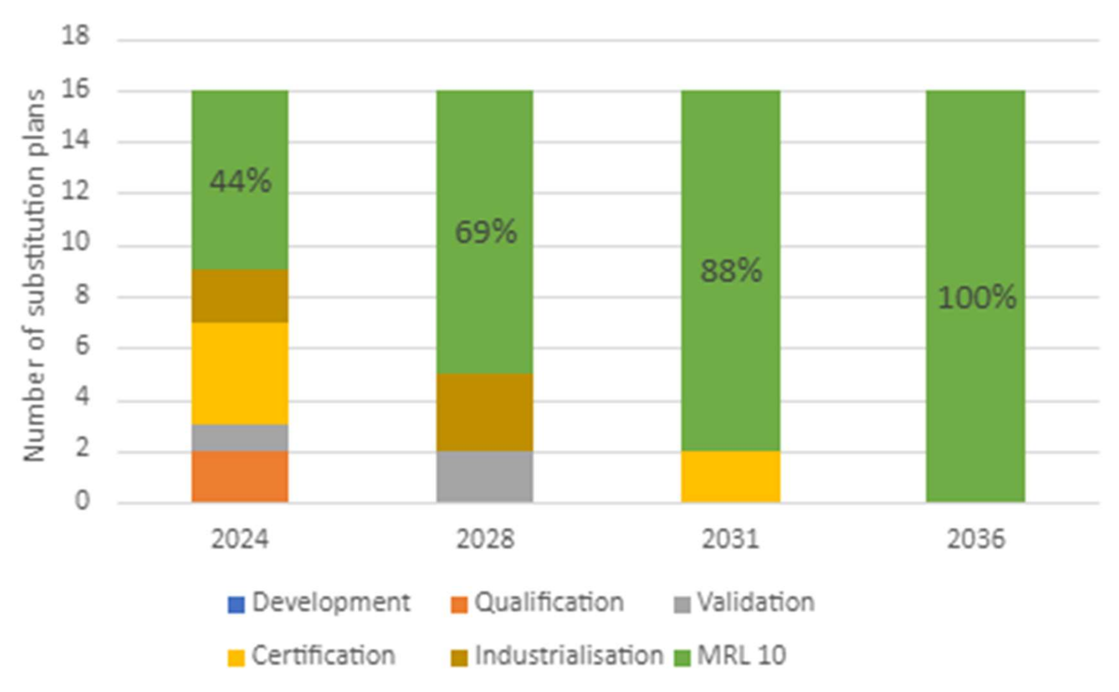

Figure 1-1: Expected progression of substitution plans for the use of Cr(VI) in passivation of stainless steel, by year

The vertical axis refers to number of substitution plans (some members have multiple substitution plans for passivation of stainless steel). The percentage value shown on each of the green bars indicates the proportion of substitution plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which there is expected to be a significant reduction in Cr(VI) usage.

Source: RPA analysis, ADCR members

1.3 Socio-economic benefits from continued use

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

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

- Importers and formulators of the chromates as substances and mixtures used in passivation will continue to earn profits from sales to the A&D sector.

- OEMs will be able to rely on the use of chromates by their EEA and UK suppliers and in their own production activities. The profit losses[4] to these companies under the non-use scenario would equate to between €397 – 2,309 million for the EEA and €225 – 289 million for the UK, over a 2-year period (starting in 2025, PV discounted at 4%). These figures exclude the potential profits that could be gained under the continued use scenario from the global increase in demand for air transport;

- Build-to-Print (BtP) and Design-to-Build (DtB) suppliers would be able to continue their production activities in the EEA/UK and meet the performance requirements of the OEMs. The associated profit losses that would be avoided under the continued use scenario for these companies are calculated at between €99 – 329 million for the EEA and €13 – 128 million for the UK over a 2-year period (starting in 2025, PV discounted at 4%);

- Under the non-use scenario, MRO companies which provide maintenance and repair services to both civil aviation and/or military forces, would be forced to move some operations outside the EEA/UK, with the consequent profit losses equating to between €81 – 297 million for the EEA and €0.65 – 14 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 passivation are estimated at €1,180 million in the EEA and €236 million in the UK. These benefits are associated with the protection of almost 11,600 jobs in the EEA and 2,354 jobs in the UK;

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

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

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

It is clear that the level of disruption that would be caused through the inability to continue passivation activities to A&D customers, and society, would outweigh the losses to the A&D companies and their value chains (including OEMs, BtP and DtB suppliers, MROs and MoDs).

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

1.4 Residual risk to human health from continued use

The parent authorisations placed conditions on the continued use of the two chromates in surface treatments, including in passivation of stainless steel. The A&D sector has made huge efforts to be compliant with these conditions, investing not only in risk management measures but also improved worker and environmental monitoring. Significant technical achievements also 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 70 EEA sites where chromate-based passivation is anticipated as taking place, an estimated total of 1,190 workers (including 420 incidentally exposed workers) may be exposed to Cr(VI); for the 20 UK sites where passivation takes place, a maximum of approximately 340 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 passivation is considered to take place, an estimated 36,000 people in the EEA and 26,600 people in the UK[5] are calculated as potentially being exposed to Cr(VI) due to chromate-based passivation activities.

The predicted number of cancer cases per annum and the annualised economic value of these social costs for both workers and humans via the environment are[6]:

- EEA: 0.22 fatal cancers and 0.06 non-fatal cancers over the 12-year review period, at a total social cost of €327,000; and
- UK: 0.07 fatal cancers and 0.02 non-fatal cancers over the 12-year review period at a total social cost of €99,400.

1.5 Comparison of socio-economic benefits and residual risks

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

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[5] 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.

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

- EEA: 6,036 to 1 for the lower bound of profit losses and unemployment costs or 11,930 to 1 for the upper bound profit losses and unemployment costs, where economic impacts are assessed over 2 years and residual risks over 12 years;

- UK: 4,780 to 1 for the lower bound of profit losses and unemployment costs or 6,707 to 1 for the upper bound profit losses and unemployment costs, where economic impacts are assessed over 2 years and residual risks over 12 years.

The above estimates represent a significant underestimate of the actual benefits conferred by the continued use of chromium trioxide and sodium dichromate in passivation of stainless steel as carried out by the A&D industry, as it only encompasses benefits that could be readily quantified and monetised. The true benefit-cost ratios must be assumed to also encompass:

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

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

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

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

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

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

- The sector has reduced the volume of chromates used in stainless steel passivation, with consumption of sodium dichromate now estimated as a very maximum at under 17.5 tonnes per annum in the EEA and 5 tonnes per annum in UK, and chromium trioxide at 8.4 tonnes per annum across the EEA and up to 2.4 tonnes per annum in the UK (based on maximum identified use at any site multiplied by the estimated number of sites). These quantities are expected to start reducing significantly by 2028 and continue reducing until use is phased-out in 2036.

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

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

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

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

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

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

- The strict regulatory requirements that must be met generate additional, complex requalification, recertification, industrialisation activities, to ensure the continued airworthiness of aircraft and the safety and reliability of defence equipment (including air, naval and land-based systems). These requirements mean that there is no simple or single drop-in replacement for the chromates in passivation processes, which can be considered to be "generally available" following the European Commission's definition[7]. 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 to the chromates. They will not be able to qualify and certify a proposed or test candidate for some components within a four or seven year time frame. It is also of note that passivation is used throughout the supply chain and by large numbers of smaller suppliers. As a result, sufficient time will be required to fully implement alternatives through the value chain once they have been certified.

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

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

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

- As highlighted above and demonstrated in Section 5, **the socio-economic benefits from the continued use of chromium trioxide and sodium dichromate in the passivation of stainless steel are demonstrably significantly outweigh the risks of continued use.** The European A&D

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[7] 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)

sector is a major exporter of final products and is facing a growing market for both its civilian and defence products which it can only serve if it retains its current strong industrial and supply chain base in the EEA and UK. It will not be able to respond to this increased market demand if the continued use of chromates in passivation is not authorised while work continues on developing, qualifying and certifying alternatives.

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

2 Aims and Scope of the Analysis

2.1 Introduction

2.1.1 The A&D Chromates Reauthorisation Consortium

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

The use of the chromates in passivation 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 passivation in defence, space and in aerospace derivative products, which include non-aircraft defence systems, such as ground-based installations or naval systems. Such products and systems also have to comply with numerous comparable requirements including those of the European Space Agency (ESA) and of national MoDs.

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

As a result, the analysis presented here is based on an extensive programme of work funded and carried out by the main OEMs and DtBs, and key suppliers where this includes small, medium, and other large actors within the sector. It is based on sector-specific data and detailed information obtained from the ADCR members (which includes OEMs, DtBs, BtPs, MROs and MoDs) and collected from their A&D suppliers throughout the supply chain. In total, data were collected from companies covering over 260 A&D sites in the EEA and UK, with data for 58 of those sites used in developing this combined AoA/SEA.

In addition, to ensure consistency and continuity of global supply chains under both EU REACH and UK REACH, this document covers the requirements of A&D supply chains in both the EEA and the UK[8]. Where important, information is separated out for the EEA and UK, so that authorities in both jurisdictions have a clear view of impacts.

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

2.1.2 Aims of the combined AoA and SEA document

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

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

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

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

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

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

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

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

2.2 The Parent Applications for Authorisation

This combined AoA and SEA covers the use of the following chromates in passivation of stainless steel:

• 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 properties (Cat. 1B). As CT is mainly used in aqueous solution in passivation, 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 their CMR properties as it is classified as carcinogenic (Cat. 1B), mutagenic (Cat. 1B) and reproductive toxicants (Cat. 1B).

These two chromates were granted authorisations for use in passivation of stainless steel across a range of applicants and substances. **Table 2-1** summarises the initial applications which are the parent authorisations for this review report.

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

Table 2-1: Overview of Initial Parent Applications for Authorisation					
Application ID/ authorisation number	**Substance**	**CAS #**	**EC #**	**Applicants**	**Parent Authorisation – Authorised Use**
0032-04/ REACH/20/18/14, REACH/20/18/16 REACH/20/18/18	Chromium trioxide	1333-82-0	215-607-8	ChemServices as OR for Brother; Boeing Distribution Ltd; Cromital (CTAC consortium)	Surface treatment for applications in the aeronautics and aerospace industries, unrelated to functional chrome plating or functional chrome plating with decorative character, where any of the following key functionalities is necessary for the intended use: corrosion resistance/active corrosion inhibition, chemical resistance, hardness, adhesion promotion (adhesion to subsequent coating or paint), temperature resistance, resistance to embrittlement, wear resistance, surface properties impeding deposition of organisms, layer thickness, flexibility, and resistivity
0043-02/ REACH/20/5/3 REACH/20/5/5 24UKREACH/20/5/3	Sodium dichromate	10588-01-9	234-190-3	Brenntag Chemicals Distribution (Ireland) Ltd AD International BV (CCST consortium)	Use for surface treatment of metals (such as aluminium, steel, zinc, magnesium, titanium, alloys), composites and sealings of anodic films for the aerospace sector in surface treatment processes in which any of the key functionalities listed in the Annex is required (corrosion resistance, adhesion to subsequent layer, embrittlement/heat treatment)

2.3 Scope of the analysis

2.3.1 Brief overview of uses

2.3.1.1 Process description

Stainless steel contains chromium as an alloying element and passivates naturally by forming a very thin chromium oxide (Cr_2O_3) layer on the surface of the stainless steel. The chromium oxide layer is critical for the corrosion resistance of stainless steel. However, this natural film may not be fully continuous and may exhibit free iron on the surface that can act as corrosion seeds. Therefore natural passivation films are not as strong as when the stainless steel is passivated by surface treatment. The mechanism is dependent in part upon the surface being clean and free from organic or inorganic contamination. Mechanical processing e.g., by machining or forming of stainless steel with steel tools can damage the natural oxide layer and may cause small iron/steel particles to be incorporated into the stainless steel surface, which may initiate rust spots under certain environmental conditions such as elevated humidity or in the presence of salt spray. In the process of passivation of stainless steel these iron/steel particles are chemically removed, and a new thin chromium oxide layer is formed to restore the natural corrosion resistant passive oxide layer. The chromate used in the passivation solution serves to enhance and supplement the formation of the passivating chromium oxide (Cr_2O_3) layer on the surface of the stainless steel alloy.

Passivation of stainless steel is a chemical, non-electrolytic process which is in most cases carried out by immersion of components in treatment baths. Typically, the treatment baths for passivation of stainless steel are positioned in a large hall where baths for other immersion processes are also present; some of these baths might also involve the use of Cr(VI) although they may be unrelated to the present use. The immersion tanks can be placed individually or within a line of several immersion tanks. Usually, at least one rinsing tank with water is positioned after an immersion tank, for rinsing off the passivation solution from the component(s).

In some cases, when small components need touching up, passivation of stainless steel is carried out by applying the solution with a brush or pad. This activity is usually performed on a dedicated bench.

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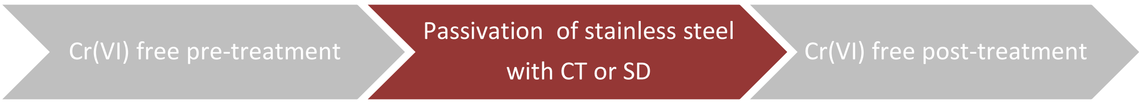
Figure 2-1: Passivation of Stainless-Steel bath

2.3.1.2 Choice of chromate

Either chromium trioxide (CT) or sodium dichromate (SD) can be used for passivation of stainless steel 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 chromate having proven performance in a component, final product or a system. Design owners' performance requirements or drawings (in BtP) may identify a chromate, but normally it is not the chromate that is specified but a formulation that contains the chromate. When a specific chromate is not mandated by the design owner, 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.

2.3.1.3 Relationship to other uses

The passivation of stainless steel with CT or SD is normally not combined with any Cr(VI)-containing pre-treatment or post-treatment. Only Cr(VI)-free pre-treatments (e.g., alkaline cleaning, descaling, etching) or post-treatment (e.g., neutralisation) may be applied. For components with very specific requirements, sometimes two Cr(VI) passivation steps may be carried out in sequence. In the event of sequential passivation, the second passivation step is typically applied using SD, with a higher Cr(VI) concentration, a higher temperature and a longer immersion duration than the first passivation step.



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

Figure 2-2: Schematic presentation of treatment steps

2.3.2 Temporal scope

Because of the lack of qualified and viable alternatives for the use of CT and SD in passivation for aerospace components, it is anticipated that it will take ADCR members and their supply chains between four and 12 years to develop, qualify, certify, and industrialise alternatives; the longest timeframes are required by MROs and companies acting as suppliers of defence products. Over this 12-year period, the temporal boundaries adopted in this assessment take into account:

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

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

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

2.3.3 The supply chain and its geographic scope

2.3.3.1 The ADCR Consortium

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

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

With respect to passivation of stainless steel:

- Nine of the 24 larger ADCR members (OEMs, DtBs and a MRO) are supporting the reauthorisation of this use in the EU; this includes for their own use as well as for use by their suppliers (who must use the chromates to meet OEM's and DtB's contractual requirements) in their supply chains.

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

The nine larger ADCR members involved with passivation of stainless steel include OEMs, DtB companies and MROs. The smaller members are BtP companies but may also undertake some work as a MRO. The larger companies may operate across multiple sites within the EU and/or UK. As a result, the number of sites represented by these members is far greater.

2.3.3.2 Suppliers of chromate substances and mixtures

Three generic chromate products have been identified as being used in the passivation of stainless steel; these are listed in **Table 2-3**.

Table 2-3: Products used in passivation of stainless steel

Product A	Solid sodium dichromate (powder), pure substance (75-100%)
Product B	Solid chromium trioxide (flakes), pure substance (100%)
Product C	Aqueous solution of sodium dichromate as purchased (50-75.5% SD (w/w))

As indicated above, the chromates are used as pure substances in solid form with sodium dichromate also being used in a strong aqueous solution.

Chromium trioxide and sodium dichromate are not manufactured within the EU (or the UK). Once the substances are imported into the EU, they are delivered to the downstream user either directly or via distributors. Some distributors operate across many EU countries while others operate nationally.

2.3.3.3 Downstream users of the chromates for passivation of stainless steel

Passivation within the A&D sector is performed exclusively in industrial settings and is carried out by actors across all levels in the supply chain:

- Original equipment manufacturer (OEM) – generally large companies which design manufacture, assemble and sell engines, aircraft, space and defence equipment to the final customer;
- Design-to-build[9] (DtB) – companies which design and build components;
- Build-to-print (BtP) – companies that undertake specific processes, dictated by their customers, involving chromates on components; and
- Maintenance, Repairs and Overhaul (MRO) – companies that service aircraft, space and defence equipment.

It is important to note that companies may fit into more than one of the above categories, acting as an OEM, DtB, and MRO[10], where they service components they designed and manufactured which are

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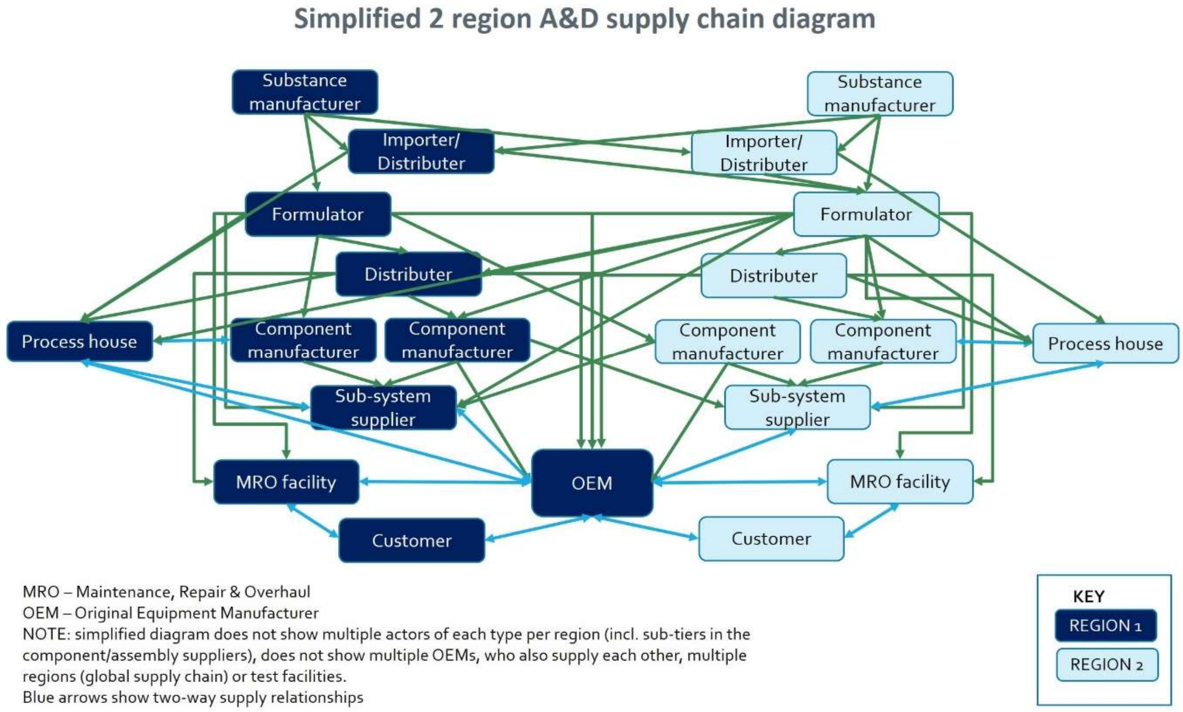
[9] Also referred to as "design and make" or "design responsible" suppliers

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

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.



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

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

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

Table 2-4: Distribution by role of SEA questionnaire respondents providing information on passivation

Role	Number of companies	Number of sites
OEMs	5	13
Design and build	7	7
Build-to-print	23	29
MRO mainly (civilian and/or military)	4	9
Total	39	58

2.3.3.4 OEMs, DtB and BtP Manufacturers

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

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

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

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

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

2.3.3.5 Maintenance, Repair and Overhaul

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

A representative life cycle of a typical aerospace product – a commercial aircraft - is illustrated in **Figure 2-4**. This highlights that: the development of a new aerospace system can take up to 15 years;

the production of one type of aerospace system may span more than 50 years; and the lifespan of any individual aircraft is typically 20-30 years. **Figure 2-5** provides an overview of the life cycle of weapon systems, which are usually used much longer than the originally projected lifetime. Such life cycles can be significantly longer than 50 years. For such systems, it is extremely costly to identify and replace legacy applications of chromates without impacting performance, where performance has been assured for many decades.

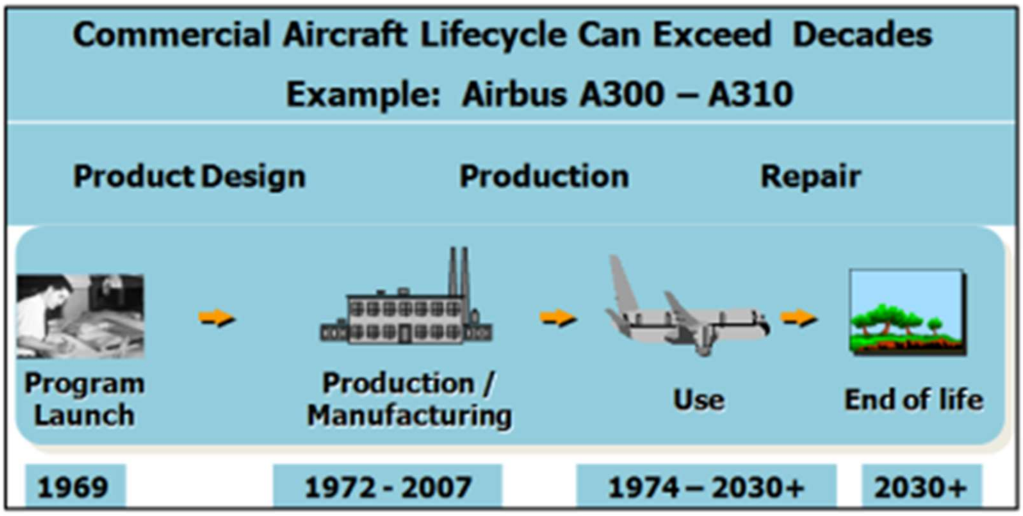


Figure 2-4: Commercial Aircraft Service Life, from ECHA & EASA (2014)[11]

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

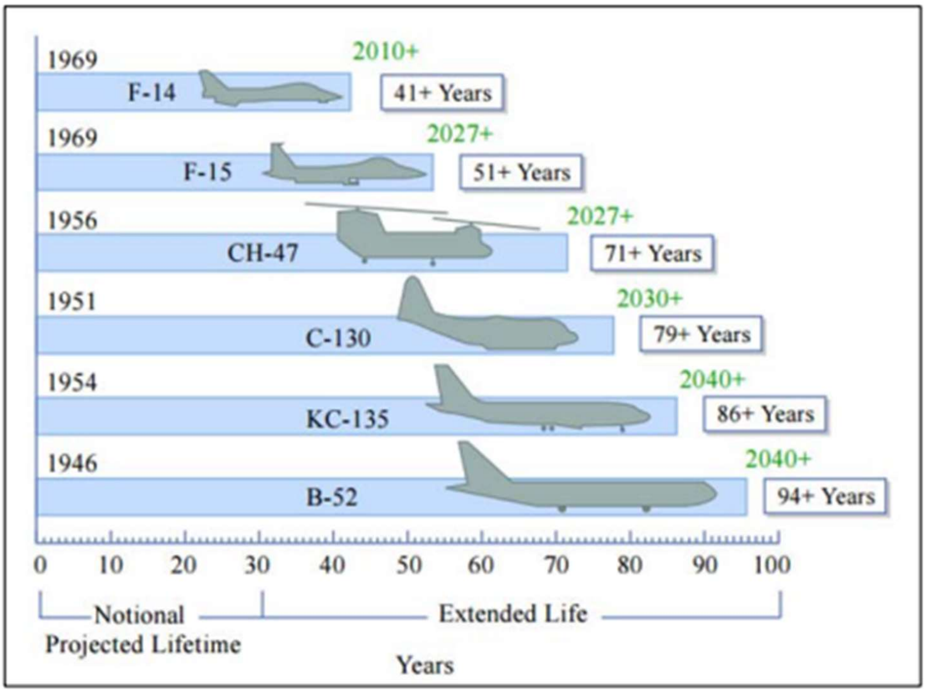

Figure 2-5: Life cycles of defence aircraft, from A Haggerty (2004)[12]

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

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

2.3.3.6 Estimated number of downstream user sites

For the EEA, based on the information provided by ADCR members, it appears that each of the main OEMs and DtBs that is supporting the passivation of stainless steel has, on average, between seven and 10 approved suppliers and/or own sites involved in passivation of stainless steel. This suggests that there could be up to approximately 70 (= 7 x 10) sites involved in passivation of stainless steel across the EEA.

For the UK, based on the information provided by the OEMs and DtB companies, as well as considering relevant members of the Institute of Materials Finishing and the Surface Engineering Association, it

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

would appear that there are around 20 sites (across the UK) involved in the passivation of stainless steel.

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 various REACH Authorisations listed above covering 508 sites across the EU-27 (and Norway). The distribution of notifications by substance and authorisation is summarised below. It is important to note that some sites may draw on more than one Authorisation for use of the same substance.

There are more sites than notifications, reflecting the fact that some notifications cover more than one site[13]. However, several of the authorisations cover 'surface treatment' which covers more treatments than just passivation. As such, the number of sites undertaking passivation will be far fewer than the indicated 508. Furthermore, some sites will be using more than one of the chromates for passivation lowering the figure even further. Indeed, some ADCR members may use both of the chromates at an individual site for passivation.

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

With these points in mind, the estimated 70 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 also reflects the fact that not all of the original CTAC applicants are supporting the ADCR, with this expected to lead to some changes in the number of customers being supplied the chromates by the ADCR applicants. In addition, the figure of 70 sites takes into account the fact that some of the A&D sector will be covered by the non-ADCR applicants

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
Total notifications			**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

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[13] Article 66 reporting is by legal entity, which can have multiple sites using a chromate for passivation of stainless steel. 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.

2.3.3.7 Geographic distribution

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

Table 2-6: Number of sites assumed to be undertaking passivation of stainless steel based on distribution of sites notified to ECHA as of 31 December 2021, ADCR member data and SEA responses

Country	**# Sites**
France	9
Germany	10
Italy, Spain, Poland	22
Czech Republic, Sweden, Norway	11
Finland, Netherlands, Belgium	14
Denmark, Austria, etc.	4
Total EU (plus Norway) sites	**70**
Total UK	**20**

2.3.3.8 Customers

The end actors within this supply chain are the customers of A&D final products treated via passivation

With respect to civil aviation, the global air transport sector employs over 10 million people to deliver in a normal year some 120,000 flights and 12 million passengers a day. In 2017, airlines worldwide carried around 4.1 billion passengers. They transported 56 million tonnes of freight on 37 million commercial flights. Every day, airplanes transport over 10 million passengers and around US$ 18 billion (€16 billion, £14 billion) worth of goods. Across the wider supply chain, subsequent impacts and jobs in tourism made possible by air transport, assessments show that at least 65.5 million jobs and 3.6% of global economic activity are supported by the industry[14]. More specifically to Europe, in 2019 over 1 billion passengers travelled by air in the European Union, with net profits of over US$ 6.5 billion (€5.8 billion, £5.1 billion).[15] These benefits cannot be realised without the ability to undertake regular maintenance works and to repair and maintain aircraft as needed with replacement components manufactured in line with airworthiness approvals.

In 2020, total government expenditure on defence across the EU equated to 1.3% of GDP, with Norway spending around 2% of GDP[16]. Roughly 38% of this expenditure related to military aviation, with an uncertain but significant proportion also spent on non-aviation defence products that rely on the use of passivation.

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

2.4 Consultation

2.4.1 Overview

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

- Consultation with the Applicants (importers and formulators) to gather Article 66 downstream user notifications data, and information on volumes placed on the market and numbers of customers; this has included consultation with the formulators to gather information on their

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

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

[16] *Source:* Eurostat (gov_10a_exp)

efforts to develop alternatives on their own, in collaboration with the downstream users, and as part of research projects funded by national governments, the EC and more internationally;

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

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

Further details of each are provided below.

2.4.2 Consultation with Applicants

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

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

2.4.3 Consultation with Downstream users

2.4.3.1 ADCR Consortium Members

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

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

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

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

3) Phase 4 collected information for the SEA component of this document, with this including:
    a. Base data on the economic characteristics of different companies
    b. Additional information on volumes used of the chromates and for what processes, and trends in this usage over the past 7 years and as anticipated into the future
    c. The importance of chromate-using processes to the turnover of individual companies
    d. Past investments in R&D into alternatives
    e. Past investments into capital equipment related to on-going use of the chromates as well as to their substitution; this included investment in new facilities outside the EEA
    f. Numbers of employees directly involved in use of the chromates as well as the total number of employees at sites that would also be directly impacted under the Non-Use scenario
    g. Economic and social impacts under the Non-use scenario.

2.4.3.2 Design-to-build and Build-to-print suppliers to ADCR members

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

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

As a final count, data for 58 sites operated by the ADCR OEMs and their DtB and BtP suppliers provided responses to these questionnaires. The information provided by the companies forms the basis for the SEA component of this document.

2.4.3.3 MROs

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

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

3 Analysis of Alternatives

3.1 SVHC use applied for

3.1.1 Substance ID and Overview of the key functions and usage

The definition of passivation of stainless steel, as agreed by ADCR members, is:

"Passivation of stainless steel both removes embedded iron/steel particles from stainless steel and oxidises the surface chromium in the alloy to augment its natural corrosion resistant passive oxide layer."

Passivation is a process to treat metallic substrates so that they can withstand adverse environmental conditions and are less affected by air, water, and chemical reactions, such as with acidic and other corrosive agents. Passivation reduces the chemical reactivity of the exposed layer of a metal by covering the outermost metal surface with a resistant material, such as a metal oxide, which is protective and shields the substrate metal against external factors that would otherwise cause degradation.

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

Passivation of stainless steel is a chemical, non-electrolytic process which is in most cases carried out by immersion of components in treatment baths, refer to **Figure 2-1**. In some cases, when small components need touching up, passivation of stainless steel is carried out by applying the solution with a brush or pad. This activity is usually performed on a dedicated bench

The key functions of the chromates in passivation of stainless steel are:

- Corrosion resistance[17]
- Embrittlement/heat treatment
- Adhesion of subsequent layer.

Stainless steel contains a minimum of 10.5% chromium (Thyssenkrupp AG, 2022) amongst other beneficial elements which directly affect the properties of the steel. Other elements may include nickel molybdenum, titanium, aluminium, manganese, niobium, copper, nitrogen, sulphur, phosphorus, or selenium. If the substrate surface is free of contaminants, oxidation of chrome crystallites following diffusion of chromium atoms at the surface of the substrate generates a dense continuous layer enriched with Cr(III) (hydr)oxide in approximately 24 to 48 hours providing a natural

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[17] Corrosion resistance is synonymous with the term corrosion protection

corrosion resistance to the steel (Vezina, no date). This process is described in **Figure 3-1**: Diffusion of chromium atoms forming natural passivation layer.

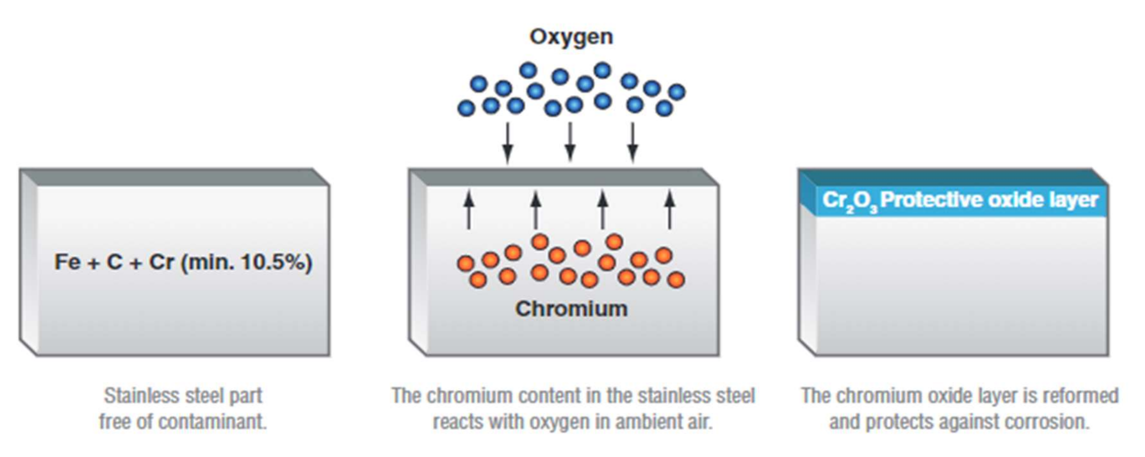

Figure 3-1: Diffusion of chromium atoms forming natural passivation layer ***(Vezina, n.d.)***

Formation of the natural passive chromium oxide layer is dependent upon diffusion of chromium atoms onto the substrate leading to formation of chromium oxide on the alloy surface. This diffusion process is strongly influenced by the surface topography of the substrate which in turn is linked to the composition of the stainless steel alloy (Ma *et al.*, 2019). Chromium atom surface diffusion is constrained in some stainless steel alloys (e.g., martensitic and free-machining austenitic grades[18]) which lack the advantageous surface topography due to heterogenous features such as large microstructural inclusions exposed at the surface. Surface treatment of vulnerable alloys via passivation enhances and maintains the natural corrosion protection afforded by the chromium oxide passive layer.

The naturally passive layer is very thin, in the order of less than 10 molecular layers thick. This can be a weakness if not enhanced via surface treatment. Machining or surface preparation processes such as shot peening can compromise the integrity of the natural passive layer. Passivation via surface treatment supplements the natural layer providing corrosion protection by renewing the layer and removing embedded iron from machining processes and also iron rich microscopic domains on the surface of the metal which could lead to the formation of corrosion sites.

A key function is that passivation of stainless steel should not induce damaging hydrogen embrittlement of the treated substrate. Hydrogen embrittlement is a phenomena 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. Heat treatment can be used to purge hydrogen before damage can occur, however this is dependent upon the substrate, or component, fabricated from the steel alloy not being sensitive to heat. If heat treatment is required to purge hydrogen from the metal substrate, this is also an important

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[18] Stainless steel grades

consideration when shortlisting proposed candidates; ensure compatibility with the heat treatment process. Therefore, it is a requirement of the passivation process, and any test candidate, not to cause detrimental hydrogen embrittlement and also be compatible with any subsequent heat treatment process.

Passivation of stainless steel is a post-fabrication step for newly machined stainless steel components which enables the following benefits:

- Provides a more robust protective passive layer by creating a chemical barrier against rust degradation of the substrate allowing use in more aggressive environments;
- Removes contaminants from the substrate surface such as embedded iron particulates from machining processes;
- Decreases frequency of maintenance of the stainless steel part;
- Extends life of the product via corrosion resistance;

    - Corrosion resistance is important to increase the life of the component in service, especially in situations where the component is relatively inaccessible and cannot be easily or frequently inspected. Corrosion resistance is also important to prevent corrosion of the component during intermediate steps in the manufacturing process.

- Improves chemical resistance (which is closely related to corrosion resistance). Chemical resistance refers to the ability of the component to withstand contact with fluids encountered in the service life of the part, such as lubricants, hydraulic fluids, greases, fuels, solvents, de-greasers, cleaning fluids, and de-icing fluids); and
- Does/may not detrimentally effect adhesion to subsequent layer. This may refer to paints, primers, and sealants but can also apply to other functional coatings layers such as lubricants.

The benefits of the above attributes are discussed in more detail below.

Application is typically via dip/immersion in a tank containing the passivating solution, followed by rinsing in water. For maintenance and repair operations (MRO) application can be with a brush or pad, for example when small parts need touching up. Refer to Section 2.3.1.1.

3.1.1.1 Usage

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

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

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

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

Source: (GCCA, 2017a)

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

It would not be acceptable to introduce Cr(VI)-free alternatives where they are known to result in a decrease in the level of corrosion protection and wear resistance, since some or all of the following consequences may occur (GCCA, 2017):

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

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

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

Service life and maintenance intervals of parts and assemblies

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

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

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

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

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

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

3.1.2.1 Introduction

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

In the civil aviation sector of the Aerospace industry, large numbers of aircraft **safely carry billions of people every year**[19]**,** whilst defence aircraft and systems are required to operate safely and reliably for 40 to more than 90 years before they are finally taken out of service**.** This requires A&D components to successfully fulfil a wide range of extremely challenging safety-related requirements, including but not limited to:

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

Successful, reliable, and safe performance against these parameters is the result of decades of experience and research, and a high level of confidence in the systems currently employed to provide corrosion and wear resistance. Years of performance data, as well as thorough reviews following any incidents, have resulted in improvements to the designs, manufacturing or 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.

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[19] 4.5bn passengers carried and 38.3m departures in 2019. https://www.icao.int/annual-report-2019/Pages/the-world-of-air-transport-in-2019.aspx

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

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

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

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

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

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

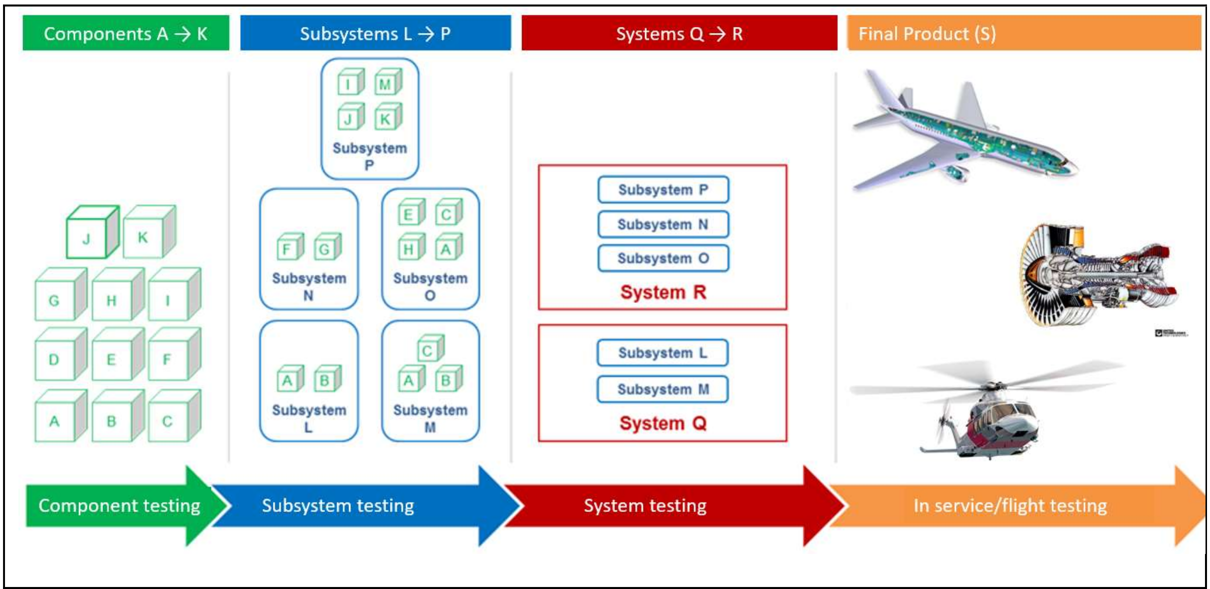

Figure 3-2: Assessment requirements in the implementation of alternatives
Source: Adapted from GCCA white paper

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

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

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

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

[a] Breadboard: integrated components, typically configured for laboratory use, that provide a representation of a system/subsystem. Used to determine concept feasibility and to develop technical data.

[b] Mission: the role that an aircraft (or system) is designed to play.

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

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

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

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

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

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

MRL	Definition	Description
	production practices in place	changes are few and generally limited to quality and cost improvements. System, components or items are in full-rate production and meet all engineering, performance, quality and reliability requirements. Manufacturing process capability is at the appropriate quality level.

Source: Manufacturing Readiness Level (MRL) - AcqNotes

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

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

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

3.1.2.2 Process, requirements, and timeframe

Identification & Assessment of need for substitution

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

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

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

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

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

Definition of requirements

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

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

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

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

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

- The substitute exhibiting behaviours or interactions which are different to the original product. Where unexpected behaviour is seen, sufficient operational feedback to technically

understand the phenomenon and refine the requirements is essential to ensure non-regression;
- Consolidating requirements from multiple customers and suppliers into an existing design;
- Evolution of EHS regulations; and
- Need to substitute multiple chromates to the same timeframe.

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

Key phases of the substitution process

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

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

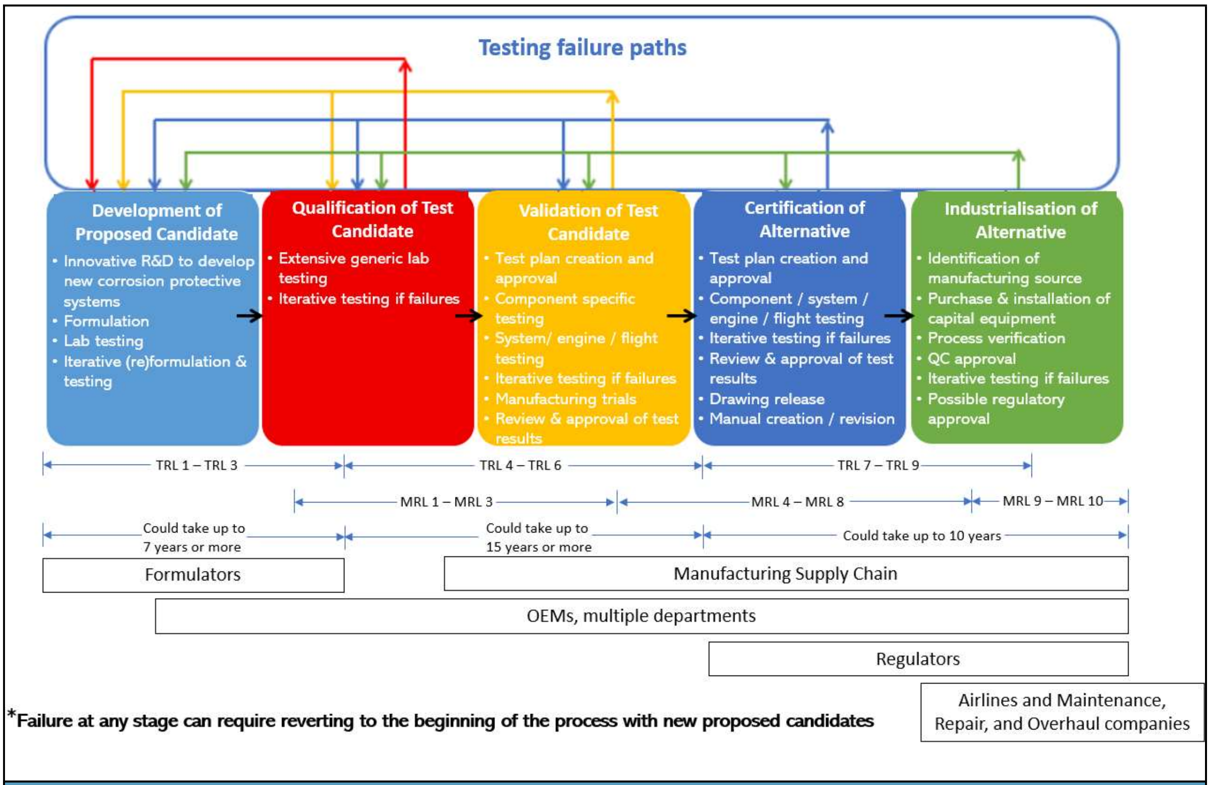

Figure 3-3: Schematic showing the key phases of the substitution process.
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note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

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

Development of proposed candidates

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

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

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

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

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

Qualification of test candidate

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

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

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

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

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

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[21] GCCA

Validation of test candidate

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

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

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

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

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

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

Certification of alternative

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

Steps in the Certification stage include:

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

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

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

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

> *"Importantly, even if an alternative is in use in one component in aerospace[23] system A, it cannot be inserted into what appears to be the same part [component] in another aerospace system B (e.g., model B) until it is fully reviewed/validated/certified to ensure that either the design parameters are identical or that the alternative is fully acceptable for the different design parameters. Extensive experience shows that an alternative that is successfully certified in one component in one model cannot necessarily be successfully certified in another. In other words, the circumstances for each component in each model are unique and extrapolation is impossible without validation and certification."*

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

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

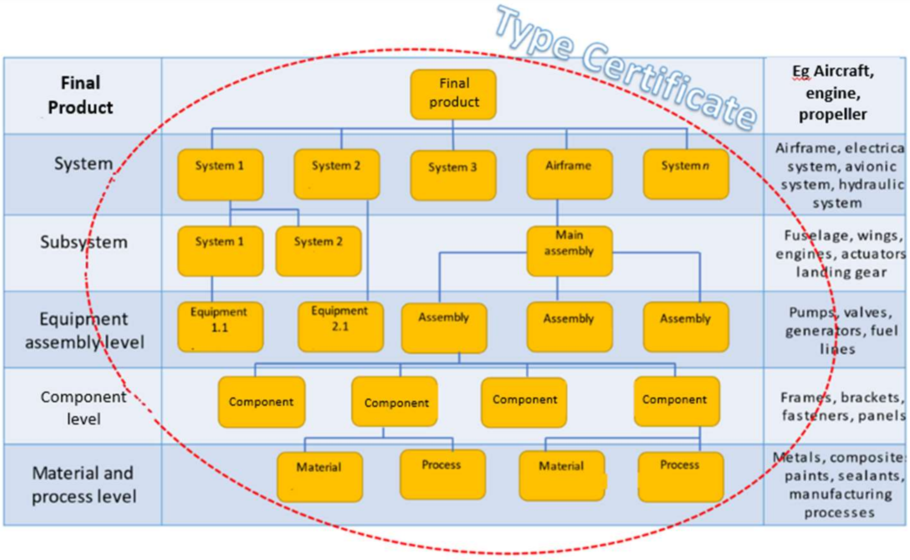

Figure 3-4: System hierarchy of a final product showing the interconnection of each level in the system hierarchy, and how changes at a lower level have impacts on higher levels.
Source: ADCR Member

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

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

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

Industrialisation of alternative

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

Elements of the Industrialisation of alternative process include:

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

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

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

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

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

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

Using the example of a commercial aircraft, a simplified example of the process, described above and leading to industrialisation of the alternative, is illustrated in **Figure 3-5** below.

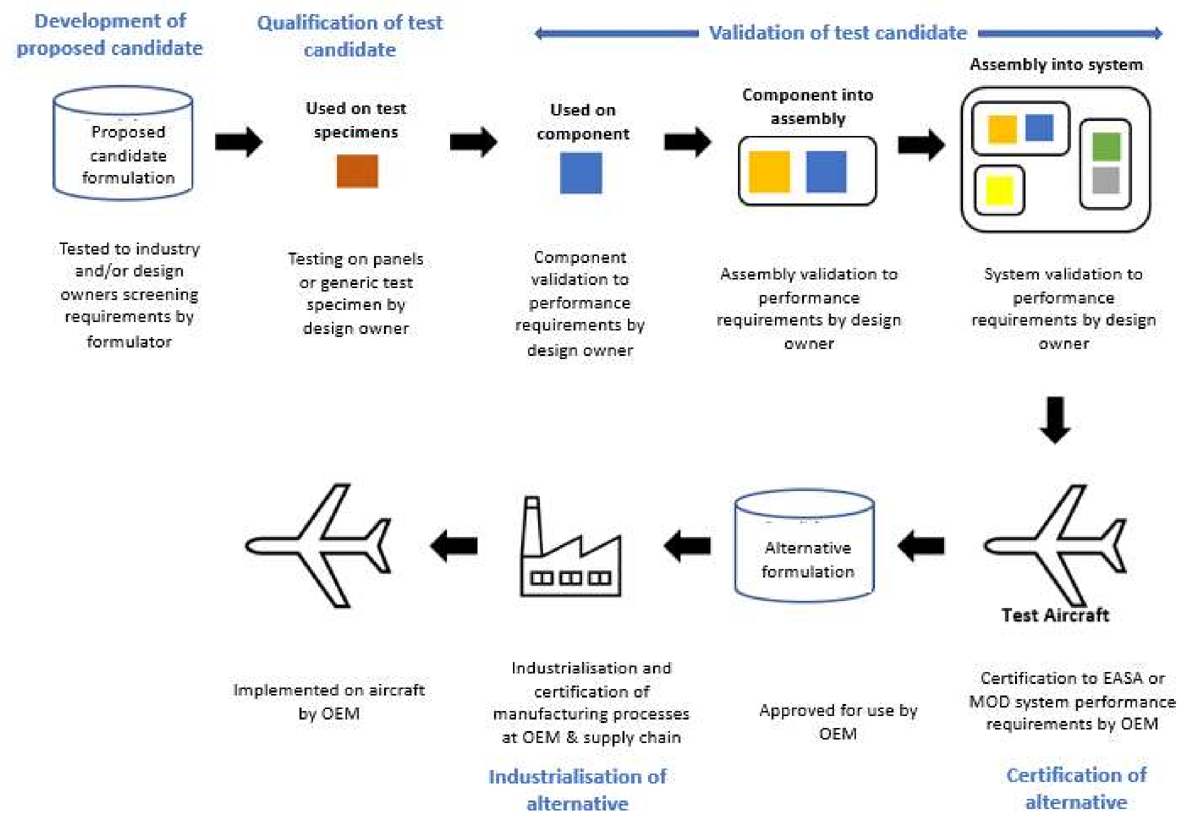

Figure 3-5: Process to Certify a Formulation for use on Aircraft.
Formulations used in production have completed this process. New or reformulations must follow same process for use in production.
Source: ADCR Member

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

3.2.1 Technical feasibility criteria for the role of the chromates in passivation of stainless steel

3.2.1.1 Introduction

The development of technical feasibility criteria for chromates in passivation of stainless steel (and proposed candidates) has been based on a combination of assessment of the parent AfAs, consultation with ADCR consortium members, and non-exhaustive reviews of available scientific literature and patents within the field.

Using detailed written questionnaires (disseminated throughout 2021 and 2022) the ADCR consortium members were asked to thoroughly describe the technical feasibility criteria and associated performance requirements that chromates and test candidates (substances and technologies) need to meet in order to deliver the functions tied to passivation of stainless steel.

In parallel scientific literature describing specificities of passivation of stainless steel and the assessment of the technical feasibility of specific alternatives has been collated (with the assistance of the ADCR consortium members) and incorporated into the analysis.

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

- Corrosion resistance;
- Embrittlement/heat treatment; and
- Adhesion of subsequent layer.

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

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

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

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

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

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

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

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

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

Figure 3-6: Multi-climate chamber for simulated environment testing
(Airbus SAS, 2022)

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

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

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

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

(GCCA, 2017b) considers variables that could impact essentially the same part design which can influence behaviour and compatibility with a treatment system, and therefore delivery of technical feasibility criteria is listed below[24]:

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

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

- Exposure to chemicals e.g. de-icer, lubricants, salts, sea water/moisture;
- Temperature;
- Galvanic influences from different metals in contact with one another; and
- Mechanical effects; galling[26], vibration, erosion.

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

3.2.1.3 Technical feasibility criterion 1: Corrosion resistance

Corrosion resistance to counteract potential corrosive degradation as a result of machining and other surface preparation processes is important to the service life, reliability, and safety of components, especially where access for inspection is limited, and therefore infrequent, or not possible. As a consequence there is a need to ensure complete passivation of all surfaces of the component/assembly as specified by the design owner. In addition to protecting the fabricated component, passivation is also important to prevent corrosion of the substrate during intermediate steps in the manufacture of the component, especially if the production process is over an extended time period with prolonged gaps between production steps.

The chromium oxide layer passivates stainless steel substrates by resisting the ingress of oxygen and outward migration of other alloying elements via a combination of its high density and very low diffusivity (Cao, Wells and Short, 2017). In addition, chromium oxide is relatively insoluble in water and acid aqueous environments.

As described in Section 3.1.1 Substance ID and Overview of the key functions, the natural corrosion protection mechanism exhibited by stainless steel alloys may also be described as inherently self-healing as a consequence of the spontaneous oxidation of chromium atoms diffused onto the alloy surface when in the presence of an oxidising agent (Ma *et al.*, 2019)

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

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

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

Naturally occurring passive oxide films most commonly do not exceed a few nanometres in thickness, are hydroxylated, well adherent, and effectively isolate a substrate from a corrosive environment. They are, however, sensitive to localized degradation under certain conditions. With sufficient time, in the presence of aggressive species (e.g., chlorides), accelerated dissolution of the alloy substrate at localized sites; pitting, can occur (Ma *et al.*, 2021). Degradation of the natural passive film can happen under oxygen poor environments such as at mechanical joints or poorly finished welds. Another source of corrosion is via iron contamination. Various scenarios could initiate iron contamination; using carbon steel tooling, inadequate clean down practices from use of handling equipment for multiple metal types, and fabrication, including cutting, of mixed metals without appropriate segregation or cleaning procedures, are all examples of potential sources of iron contamination (Acciai & Terni, 2007).

Iron particles in or on the steel substrate oxidise, form rust, and degrade the steel when exposed to oxidising agents including oxygen in air. The resulting porous corrosion products, if allowed to form, will create pitting damage through crevice corrosion effects. The resulting pits will create stress concentrations that can result in premature component failure due to cracking. Therefore, embedded iron and microscopic iron rich domains on the substrate must be removed using the passivation solution in order to prevent iron-initiated corrosion. Oxidation of metallic chrome crystallites at the surface of the steel substrate serves to renew and supplement the natural continuous passive chromium oxide layer present on many stainless steel alloys.

Immersion of stainless steel in an acid bath, dissolves free iron from the surface (either contamination such as embedded iron, or iron rich microscopic domains). This dissolution leaves behind a uniform surface that contains a higher proportion of chromium than the underlying bulk material. Removal of this free iron from the surface both removes opportunities for corrosion to start and facilitates formation of a smooth chromic oxide layer. This higher proportion of chromium at the surface allows for the formation of a thicker, more protective chromium oxide layer than the one that would form naturally. Redox-triggered deposition of Cr(III) will occur from the chromated passivation solutions to the stainless steel surfaces to counterbalance iron oxidation

Atomic resolution studies of the air passivation of stainless steel alloys shows that red rust prevention is created by surface diffusion of chromium atoms along specific surface topographic features. As described, oxidation of the chromium atoms leads to the formation of the passive chromium oxide layer which is crystalline; crystallinity is favoured with potential and time (Marcus, 2017). Many stainless steel alloys can be passivated using nitric or citric acid solutions that do not contain Cr(VI), as removing free iron from the surface is sufficient to allow for the spontaneous passivation mechanism to take place. However, Cr(VI)-free nitric and citric acid have performance deficiencies on certain stainless alloys that may be explained by those alloys' surface topographies. For example martensitic and free-machining austenitic grades lack the advantageous surface topography due to heterogenous features such as large microstructural inclusions exposed at the surface. For those alloys, the needed chromium to establish the passive chromium oxide film may require Cr(VI) passivation as the source.

3.2.1.4 Technical feasibility criterion 2: Embrittlement/heat treatment

A key function is that passivation of stainless steel should not induce damaging hydrogen embrittlement of the treated substrate. Hydrogen embrittlement is a phenomena 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. Heat treatment can be used to purge hydrogen before damage can occur, however this is dependent upon the substrate, or part, fabricated from the steel alloy not being sensitive to heat. If heat treatment is required to purge hydrogen from the metal substrate, this is also an important consideration when shortlisting proposed candidates; ensure compatibility with the heat treatment process. Therefore, it is a requirement of the passivation process, and any candidate alternative, not to cause detrimental hydrogen embrittlement and be compatible with any subsequent heat treatment process.

3.2.1.5 Technical feasibility criterion 3: Adhesion of subsequent layer

A variety of subsequent coatings may be applied to stainless steel substrates depending upon the service environment of the component/assembly. These may include primers (for structural bonding for example), paints, or metal cladding/plating.

As previously described, technical feasibility criteria are interdependent. To achieve adequate adhesion of the subsequent layer, the passivation treatment providing corrosion resistance should be compatible with the subsequent layer, or any process required to promote adhesion of the subsequent coating to the stainless steel substrate. For example, adhesion promoters can be used following passivation of stainless steel to facilitate adhesion. Where this is the case, the passivation treatment must exhibit compatibility with the subsequent treatment that is comparable to that delivered by Cr(VI) and not detrimentally effect adhesion of a subsequent layer.

Alternatively, it may be necessary to remove the passivate layer prior to the application of a subsequent layer or coating. An example of this scenario includes passivation of substrate at an intermediate stage in the production process. This removal or stripping process must not cause excessive etching or degradation to the underlying stainless steel substrate which if left unchecked could render the component damaged beyond repair, or necessitate restorative action adding time, complexity, and expense to the overall production process.

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

It is understood that a chromium oxide layer passivates stainless steel substrates by resisting the ingress of oxygen and outward migration of other alloying elements via a combination of its high density and very low diffusivity (Cao, Wells and Short, 2017). Chromium oxide is relatively insoluble in water and acidic aqueous environments. In addition, unlike most corrosion inhibiting compounds, chromates are both anodic and cathodic inhibitors, meaning that they can restrict the rate of metal dissolution, and simultaneously reduce the rate of reduction reactions (oxygen and water reduction) in many environments and over a wide pH range (Gharbi *et al.*, 2018). This highlights Cr(VI) compounds as crucial to ensuring the corrosion protection required for safety critical operations typical of A&D products.

With regard to the replacement of chromates, despite the fact that the aerospace sector is widely seen as the instigator of technology change in multiple essential engineering disciplines (including the use of new metals, composites, and plastics) (Royal Academy of Engineering, 2014), this should be set against the diversity of applications of stainless steel across the sector. Aerospace and Defence sector finished products include fixed wing aircraft, rotary wing, powered lift aircraft, land-based equipment, military ordnance, and spacecraft. Examples of finished products within the scope of the ADCR are shown in **Figure 3-7**. Consequently the industry requires a diverse range of stainless steel alloys to fulfil all performance requirements that these various applications demand. Considering these factors, combined with the strict safety and certification requirements as described in Section 3.1.2, the pace of research and development will not be uniform across the sector.

Figure 3-7: Potential A&D applications of stainless steel

Rheinmetall – Systems & Products, n.d.; Royal Navy, 2021

As highlighted throughout, the substitution of chromates in the aerospace and defence sector is met by particularly strong challenges. (Rowbotham and Fielding, 2016) highlight the nature of such challenges, noting that there are an estimated three million components in each of the 20,000+ aircraft in service. Due to the demanding nature of service environments in the aerospace and defence sector, and potential for serious consequences if only one component should fail, very stringent measures must be adopted and enforced in the development and qualification of chromate alternatives.

Various R&D activities were reported within applications for authorisation relating to this combined AoA/SEA for the use 'passivation of stainless steel.'

Both nitric and citric acid were identified as being used for selected applications within the use passivation of stainless steel for many years, although with the caveat that not all stainless steel alloys are compatible with these acids, so they had not been universally adopted. An example of implementation was reported for nitric acid; qualified for some austenitic and martensitic stainless steel alloys for specific applications (CCST Consortium, 2015).

Other areas of research had investigated the application of organic corrosion inhibitors such as amines for the prevention of flash rusting[27] of steel. It was reported that use of these inhibitors was limited and were observed to be detrimental if the steel was subsequently painted. In conclusion, this family of alternatives was unlikely to provide adequate corrosion protection for A&D applications (CCST, 2015).

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

A summary of the collaborations relevant to passivation of stainless steel is provided below.

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

Relevant collaborations/projects include:

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

- **Noblis Cadmium and Hexavalent Chromium Alternatives 5-Year Strategy and Roadmap**: Noblis is a not-for-profit independent organisation, based in Virginia USA. In May 2016 it published the review "Cadmium and Hexavalent Chromium Alternatives 5-Year Strategy and Roadmap" summarising the current status of research and implementation of Cr(VI) alternatives, primarily in US DoD applications. The review was commissioned by the Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) supporting the US Department of Defense (DoD), Environmental Protection Agency (EPA) and Department of Energy (DoE). The report summarises an extensive variety of research initiatives and the organisations, including ADCR members, involved in past and ongoing development of Cr(VI) free technologies Noblis identifies nitric acid as a mild oxidant chemical treatment used to enhance passive film formation which serves to protect stainless steel substrate. Citric acid was identified as a Tier 2 priority action for the US Department of Defence with a one year project exploratory project, anticipated to commence in quarter four of 2016, and scheduled to last for one year. The work programme was to evaluate and qualify citric

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[27] Rapid onset of rust on metal substrate (Corrosionpedia, 2022)

acid across 10 alloys within 300-series, precipitation hardening steels, and 400 series steel alloys (Noblis, 2016);

- **Airbus Chromate-Free (ACF)**: Launched in 2006 by Airbus in collaboration with stakeholders to develop new Cr(VI) free alternatives for a wide selection of aerospace uses including pickling of austenitic and martensitic steels including those more sensitive alloys with greater than 0.8% carbon (Airbus, 2009);

- **Project NAPOLET** Replacement of surface anticorrosive materials used in aerospace with more environmentally friendly technologies, reference number FW01010017. This project is within the TREND Programme. Passivation of stainless steel is captured with sub-project reference WP3 investigating the use of nitric and citric acids[28]**;** and

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

3.4.2 Consultations with customers and suppliers of alternatives

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

3.4.3 Data Searches

3.4.3.1 High level patent review

A patent search was performed with the aim to identify examples of potential technologies related to passivation of stainless steel. The search was performed using Espacenet[29], the European Patent Office (EPO) open access search portal. Espacenet contains over 120 million patent documents held by patent offices around the world, including North America and Asia (EPO, 2020) .

By way of example, the search term "Passivation of stainless-steel without chromate" was filtered via the main group classification filters C23 and C25; descriptions below.

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

- C25: Electrolytic or electrophoretic processes; apparatus therefore

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[28] ADCR member

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

This search returned 37 results **Table 3-4** summarises the chemistries identified in the above non-exhaustive patent search. Search results associated with passivation of stainless steel substrate are summarised. Plating, galvanising, or zinc coated treatments for example are not included in the summary as these are not within the scope of the ADCR use passivation of stainless steel.

Table 3-4: Patent search technology summary

Title	Patent publication reference	Technology
Passivating film formation liquid and application thereof	CN104342681A·2015-02-11	Molybdate, tungstate, phosphate, silicate, thiocarbamide, benzotriazole
Stainless steel pickling passivator and preparation method thereof	CN107012472A·2017-08-04	Citric acid, hydrochloric acid, formic acid,
Passivating of tin, zinc, and steel surfaces	WO2004050581A2·2004-06-17	Hydroxy benzoic acid
Seamless steel pipe machining process	CN110938815A·2020-03-31	Molybdate, phosphoric acid, ethyl alcohol, titanyl sulphate, resin emulsion
Siloxane oligomer treatment for metals	US2008118646A1·2008-05-22	Siloxane oligomers.
Surface-treated steel material	US11136659B2·2021-10-05	Galvalume bath containing Mg: coating composition containing a coating film-forming resin, a cross-linking agent, a predetermined vanadium compound, and tri-magnesium phosphate
Vitreous coatings made using the sol-gel process for protecting metals against corrosion	ES2359550A1·2011-05-24	Vitreous coating with stabilised Ce^{3+} ions via Sol-gel process
Anticorrosion Sol-Gel Coating For Metal Substrate	US2013029134A1·2013-01-31	Sol-gel which is combined with a polyaniline solution
Surface-treating agent for metallic material	TW201024460A·2010-07-01	Silicic acid compound, organoalkoxysilane, a metallic compound (C) containing at least one metal element selected from the group consisting of Zr, Ti, Co, Fe, V, Ce, Mo, Mn, Mg, Al, Ni, Ca, W, Nb, Cr, and Zn, at least one compound (D) selected from the group consisting of phosphoric acid compounds and fluoro compounds
Wet on wet method and chrome-free acidic solution for the corrosion control treatment of steel surfaces	CN101321894A·2008-12-10	Acidic aqueous solution of a fluoro complex of at least one element M selected from the group consisting of B, Si, Ti, Zr and Hf, rinsed with water and then coated with a cathodically depositable electrodeposition coating material
Water soluble substituted imidazolines as corrosion inhibitors for ferrous metals	US2015354067A1·2015-12-10	Imidazoline, or hydrolysis product + zinc thereof
Specific 3-alkylamino-2-hydroxysuccinic acids and their salts as corrosion inhibitors for ferrous metals	US2015345031A1·2015-12-03	3-alkylamino-2-hydroxysuccinic acid compound + zinc

Table 3-4: Patent search technology summary

Title	Patent publication reference	Technology
Surface-treated steel material	JP2021059749A·2021-04-15	Coating: Resin containing crosslinking agent and magnesium oxide over aluminum/zinc alloy plating layer,
Q-POSS modified metal surface pre-treatment agent as well as preparation method and application thereof	CN106835093A·2017-06-13	silane as a main film forming agent, fluozirconate and/or fluozirconic acid as a second film forming agent and added $C_{40}H_{112}Si_{16}O_{20}N_8$ (amino Q-POSS)as a film sealing agent and a repairing agent
Surface-treated steel sheet with excellent corrosion resistance and method for manufacturing same	KR100805428B1·2008-02-20	Aqueous epoxy resin dispersion, a silane coupling agent, phosphoric acid and/or hexafluorometallic acid. The paint composition for the upper layer film contains a high molecular weight epoxy group containing a water average molecular weight of 6000 to 20000.

(EPO, 2020)

Table 3-4 includes eleven patents describing a coating or layer deposited onto the substrate. Passivation of stainless steel deposits a very thin protective layer of chromium oxide. The passivated component will often need to operate within a very demanding service environment. To achieve the required performance thresholds required, components are often engineered to high degrees of precision with narrow dimensional tolerances. An increase in layer thickness, in excess of that achieved from passivation of stainless steel via deposition of chromium oxide, may render the component outside of dimensional tolerances therefore this impact would need to be carefully monitored for all stainless steel components subject to passivation. A redesign of the affected component may be required to accommodate the increased thickness in the deposited layer. As single components are often integral to a sub-assembly/assembly, one design modification may cascade to multiple modifications of inter-related components. Adoption of a test candidate which impacted the dimensional tolerance of a component would need to be carefully reviewed to assess both the technical and economic impact of the change on the affected component(s) and wider assemblies.

Restricting oxygen diffusion through the deposited layer as well as resistance to water are key requisites of corrosion and chemical resistance delivered via passivation. If sufficient oxygen can diffuse through the layer and iron contamination is still present on the alloy surface, corrosion and/or pitting may be initiated at these sites. Additional consideration concerns the compatibility and resistance of the deposited layer or coating to all types of chemicals within the service environment of the component. The passive layer should be resistant to aggressive chemicals, and also compatible with subsequent treatments that may be used in the production process as introduced in Section 3.2.1.2.

As with all patents, they introduce concepts and developments that may be advantageous within a given field in the fulness of time. However, it should be remembered that patents are granted for their novelty. Novelty does not necessarily translate to feasibility or applicability. Patented technologies are still bound to the requirements of the substitution process which will determine if a novel concept can be transformed into a feasible test candidate. Patents can also introduce limitations on the availability of a particular technology for example through the requirements for licencing.

Where this is the case, a third party may obtain access to the technology if a licensing or some other commercial arrangement is available and meets the requirements of both parties.

3.4.3.2 High-level literature review

A non-exhaustive technical literature review was carried out using Science Direct (Journals and Books)[30] on-line service using the keyword search term 'chromate free passivation of stainless steel'[31]. The purpose of this search was to identify examples of alternatives to Cr(VI) for the passivation of stainless steel that have been investigated in the academic field or within other industry sectors. Although it is acknowledged that technical requirements for the passivation of stainless steel in another sector may not be relevant within A&D, this non-exhaustive review demonstrates any potential sources of cross-fertilisation from other industries or academic research. This exercise is an example of initial screening for candidates from industry and academia. The high-level literature review compliments the parallel non-exhaustive patent search. The results returned from the search are summarised in **Table 3-5.** These were filtered according to their 'Open Access' status; documents available to the public without payment of a licence fee. Of the 1422 returned results, 46 were within the Open Access category. A review of these sources identified 10 within the broad scope of applications of stainless steel across a multi-sectorial base, these articles are summarised in **Table 3-6.**

Table 3-5: Literature search for chromate free passivation of stainless steel in Science Direct[(a)]

Name of Column 1	Returned results	Review articles	Open access
Chromate free passivation of stainless steel	1422	154	46

(a) "Open access" documents are ones with unrestricted access, that are available in full without payment of a licence fee

Table 3-6: Science Direct Open Access sources: Passivation of stainless steel technology reviews

Ref.	Article Title
1	Amino acids and their derivatives as corrosion (Review Document) inhibitors for metals and alloys B. El Ibrahimi et al. (2020)
2	Comparison of oxide layers formed on the low-cycle fatigue crack surfaces of Alloy 690 and 316 SS tested in a simulated PWR environment J. Chen et al. (2019)
3	Corrosion Behavior of Eutectic Molten Salt solution on Stainless Steel 316L F. Subari et al. (2015)
4	Corrosion protection of stainless steel by polysiloxane hybrid coatings prepared using the sol–gel process V.H.V. Sarmento et al. (2010)
5	Corrosion protection of steel elements in façade systems – A review L. Soufeiani et al. (2020)
6	Corrosion resistances of metallic materials in environments containing chloride ions: A review Xian-man ZHANG et al. (2021)

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

[31] Literature search conducted 19 August 2022

Table 3-6: Science Direct Open Access sources: Passivation of stainless steel technology reviews	
Ref.	**Article Title**
7	Downhole corrosion inhibitors for oil and gas production – a review M. Askari et al. (2021)
8	Ionic liquids as corrosion inhibitor: From research and development to commercialization M. Zunita et al. (2022)
9	Recent developments in research of double glow plasma surface alloying technology: a brief review S. Yuan et al. (2020)
10	Synthesis and characterization of multicomponent (CrNbTaTiW)C films for increased hardness and corrosion resistance P. Malinovskis, et al. (2018)
(Elsevier B.V., 2022)	

A number of alternative surface treatment and modification strategies are encompassed within the ten Open Access papers summarised in **Table 3-6**. These explore to varying extents a diverse range of technologies from initial formative research with minimal industrial or commercial development to more mature technological processes.

(El Ibrahimi et al., 2020) provide a brief overview of rare earth (RE) compounds as alternatives to chromate corrosion inhibitors. Although these RE compounds have proven to be effective corrosion inhibitors the authors cite a number of draw backs from the use of RE compounds as corrosion inhibitors, including:

- Refining and separation of RE elements from one another;
- Waste generated from extraction processes, including some radioactive elements; and
- Supply chain vulnerability; instability of the RE market.

In addition to the above, the discussion of barrier coatings and corrosion inhibitors is out of scope of virtually all ADCR passivated stainless steel components as using the inhibitors require either a separate coating layer or a modification of the service environment,

The authors describe the application of high concentrations of cysteine to inhibit corrosion of 304 L stainless steel alloy in de-aerated molar sulphuric acid. Laboratory results indicated that this caused the metal surface to be electrochemically active, although no further details are given for stainless steel. Increased corrosion was reported for lower concentrations of cysteine on low carbon steel while higher concentrations of cysteine, enhanced by de-aeration of the solution, providing up to 86% protection at a concentration of 5mM on mild steel. It is notable that this process did not afford complete corrosion protection of the substrate. Other amino acids covered in the review with positive inhibition performance include methionine, used with mild steel on sulphuric acid medium, alanine, glycine, and leucine to inhibit steel corrosion in hydrochloric acid (HCL) solutions of varying strength. Reported corrosion inhibition ranged from 28% to 91%. Glycine exhibited good corrosion resistance for low alloy steel against 0.5M HCL tested against ASTM A213. Incomplete inhibition is reported for arginine on steel; 60% to 79% at 0.9g/l in molar HCL and 3.5% sodium chloride solutions respectively. Other studies are summarised for histidine and tryptophan on carbon steel in 0.5M acetic acid. Up to 80% corrosion inhibition was reported using a concentration of 10^{-2} M of the amino acids.

A study of eutectic molten salt mixtures used for heat transfer and thermal storage purposes within the energy sector concluded that sodium and potassium nitrates are efficient corrosion inhibitors for 316L stainless steel, results for other alloys are not reported. Efficiency is proportional to concentration; however, efficiency of inhibition may decrease with elevated temperature (Subari, Maksom and Zawawi, 2015)

Sol-gel systems are a recognised barrier for corrosion inhibition. For example (Sarmento *et al.*, 2010) describe polysiloxane hybrid films composed of both inorganic and organic components, for the inhibition of corrosion on 316 L stainless steel. The technique forms a crack free optically transparent film on the substrate surface; layer thickness reported as 500nm to 540nm. Analysis by X-ray photoelectron spectroscopy (XPS) demonstrated no corrosion effects after 18 days immersion at 25 °C in 80 mL of naturally aerated and unstirred 0.05 mol L^{-1} sulphuric acid + 0.05 mol L^{-1} NaCl solution, and in neutral 3.5% NaCl solution. The best performance and diffusion barrier properties was with exposure to neutral salt solution. Although the corrosion performance of the hybrid sol-gel film is good under the stated laboratory conditions, results under more demanding conditions replicating service environments were not available. In addition, the effect of the film layer thickness on the dimensional tolerances of components would also require examination.

A review of corrosion protection mechanisms used for stainless steel in engineering applications within tropical climates, Australia, includes nano-coatings; nitrogen, sulphur and chloride modified nanotube-titanium dioxide composites. Results indicated both good adherence and corrosion protection from these composites (Soufeiani et al., 2020). A selection of other studies related to coating processes applicable to carbon and stainless steel are listed below[32]:

- Multi-layered coatings, conducting polymers polyaniline, polypyrrole; reduced corrosion rate and eliminated pitting action from chloride. Chemical diffusion and physical barrier properties, strong adhesion to stainless steel;

- Aluminium oxide coatings deposited by chemical vapour deposition; corrosion protection proportional to layer thickness up to 500 – 600nm; and

- Bi-layered polypyrrole doped with molybdophosphate and naphthalene disulphonate anions; prevents corrosion of steels via 3.5% NaCl for an undisclosed period of time.

A variety of organic coatings are discussed by (Zhang et al., 2022). These include single layer or multilayer graphene films. However these may be compromised from diffusion of water molecules weakening adhesion to the substrate causing delamination. Other challenges to surmount for some organic coatings is control of degradation from ageing, or exposure to sunlight. When factoring in maintenance costs to ensure the coatings remain viable, these coatings may become economically infeasible for some applications or sectors. Superhydrophobic materials inspired by the lotus leaf, offer a potential corrosion protection route for some substrates. A combination of the hydrophobic molecule and trapped air affords a physical barrier preventing corrosive species interacting with the substrate. However, reproduction of the superhydrophobic coating over extended surface areas needs to be carefully controlled and maintain density and integrity of the coating. This can be a weakness of the system possibly leading to infiltration from corrosive species such as chlorides, and corrosion at locations such as pores, inclusions, and cracks in the coating. The presence of any contaminants on the substrate or natural oxide films can weaken the adhesion of the coating to the

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[32] (Soufeiani *et al.*, 2020), Table 3

substrate. Contaminants and/or corrosion sites at defects in the coating may lead to delamination of the coating and substrate .

Halogenated salt acetylenic compound mixture are reported as effective corrosion inhibitors for certain stainless steels challenged with 15% HCl at temperatures up to 100°C. This work was in support of use in oil and gas well infrastructure. Use of plant extracts to inhibit corrosion of super austenitic stainless steel exposed to a mixture of 4M HCL and carbon dioxide saturated saline solution reportedly obtained over 90% inhibition efficiency over an undisclosed exposure time. Further development of plant extract based inhibitors is required to establish which of the molecules provide the inhibitory effect; remaining questions include whether it is possible to synthesise the inhibitor to reduce costs, whether they can be sustainably sourced, a determination of the hazard profile, and what is the effect of the inhibitor compounds in the environment including potential for bioaccumulation. These aspects need to be fully understood to establish the feasibility of mass production of plant extract inhibitors (Askari *et al.*, 2021).

The role of ionic liquids such as cationic molecules for example imidazolium, phosphonium, pyridazinium, and pyridinium is reviewed by Zunita et al. Studies suggest these can be effective inhibitors for metals including stainless steel, with evaluation on still water acidic media and at temperatures below 100°C. Before adoption of ionic liquid corrosion inhibitors water treatment facilities may have to be enhanced as not all degrade ionic liquids sufficiently to not impact the environment if released without adequate controls. As reported by (Zunita and Kevin, 2022) in addition to evaluation of technical and economic feasibility the sustainability of this category of corrosion inhibitors may require further exploration before adaptation or wider adoption across the breadth of stainless steel alloys.

Technological developments within the arena of surface modification includes the development of the technique Double Glow Surface Alloying (DGSA). This is a process developed to allow the surface modification of a substrate metal with an alloying element(s) via evaporation and deposition onto the target work piece. The chemical composition of the modified layer can be enhanced or altered to resist corrosion via the infusion of alloying elements. The technique require the use of a vacuum chamber and therefore this is a limiting factor when scaling for industrial applications. Yuan et al. report that this technique can be utilised to improve the high temperature oxidation resistance of stainless steel, for example by the deposition of Cr_3Si film on 304 stainless steel. This process is conducted at 800°C over a time period of 3 hours therefore requires significant energy input (Yuan *et al.*, 2020).

Multicomponent carbide films also referred to as High Entropy Alloy Thin films (HEA) are inclusive of elements such as Cr, Nb, Ta, Ti, and W. The film is deposited via a magnetron sputtering technique at a temperature of approximately 300°C. HEA films allow the surface modification of substrates with the application of very hard films which can be tuned to provide excellent corrosion resistance. Early studies have shown comparable corrosion resistance compared to stainless-steel, however phase separation and chemical reactivity is reported to promote or pitting corrosion (Malinovskis *et al.*, 2018). Development is required to mature this technology before it can be utilised as an alternative to passivation of stainless-steel in aerospace and defence applications.

3.4.4 Shortlist of alternatives

Proposed test candidates for alternatives to replace Cr(VI) in passivation of stainless steel are shown below. This list comprises all the alternatives that were reported in the parent AfAs. These proposed candidates have been the focus of research and progression by the ADCR members, based on an assessment of technical feasibility and potential to be suitable alternatives to Cr(VI):

- Acidic surface treatments

  - Nitric acid;
  - Nitric & hydrofluoric acid mixture; and
  - Citric acid.

These are discussed in more detail in Section 3.5.

3.4.5 Performance requirements and testing

As noted above in Section 3.2.1, the key functionalities required by passivation of stainless steel are:

- Corrosion resistance;
- Embrittlement/heat treatment; and
- Adhesion of subsequent layer

In support of initial screening, testing, also referred to as critical to quality tests, are conducted to assess performance of proposed candidates in the laboratory environment for each of the key functionalities. Corrosion resistance may be measured according to confidential internal specifications or publicly available standards, for example (SAE) QQ-P-35, Type II and SAE AMS 2700 and BS EN 2516 C2. Hydrogen embrittlement can be assessed using ASTM F519[33], and a standard used for measuring adhesion includes ISO 2409. ISO 2409 measures adhesion, the resistance of paint coatings to separation from substrates when a right-angle lattice pattern is cut into the coating, penetrating through to the substrate.

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.

It is critical that the passivation of stainless steel process does not negatively impact the fatigue strength of a treated component. Failure of a component at an undeterminable point in the future due to fatigue, must be prevented. Therefore, thorough testing to determine the effect of passivation on this attribute is routinely required when assessing the technical feasibility of proposed candidates. The service environment of the component may induce stress/fatigue which a change in the passivation process must not negatively affect. Testing required to measure fatigue strength debit will vary depending upon the service environment of the component.

Chemical resistance as with fatigue strength, is a performance requirement of passivation of stainless steel that a proposed candidate should maintain and not degrade. Chemical resistance may be measured using ISO 2812-1. This standard provides a method for the determination of individual or

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[33] Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating/Coating Processes and Service Environments

multi-layer coating systems resistance to the effects of liquids, other than water, or paste-like products.

Chemical resistance refers to the ability of the surface to withstand contact with fluids encountered in the service life of the component, such as lubricants, hydraulic fluids, greases, fuels, solvents, de-greasers, cleaning fluids, and de-icing fluids.

The principal mechanism for chemical resistance of the passive layer is the insolubility of the primary constituent chromium oxide, (Cr_2O_3). Inspection of the potential/pH (Pourbaix) diagram for the chromium/chlorine/water system, shows that insoluble Cr_2O_3, shaded in grey, **Figure 3-8**, is stable and prevails over the potential/pH environmental conditions experienced by aerospace components in most conditions. It is also apparent that Cr_2O_3 is immune to attack by chloride ions as low as pH 2, and values above. A similar chemical resistance holds for other corrosive species (Jaworowski, 2000).

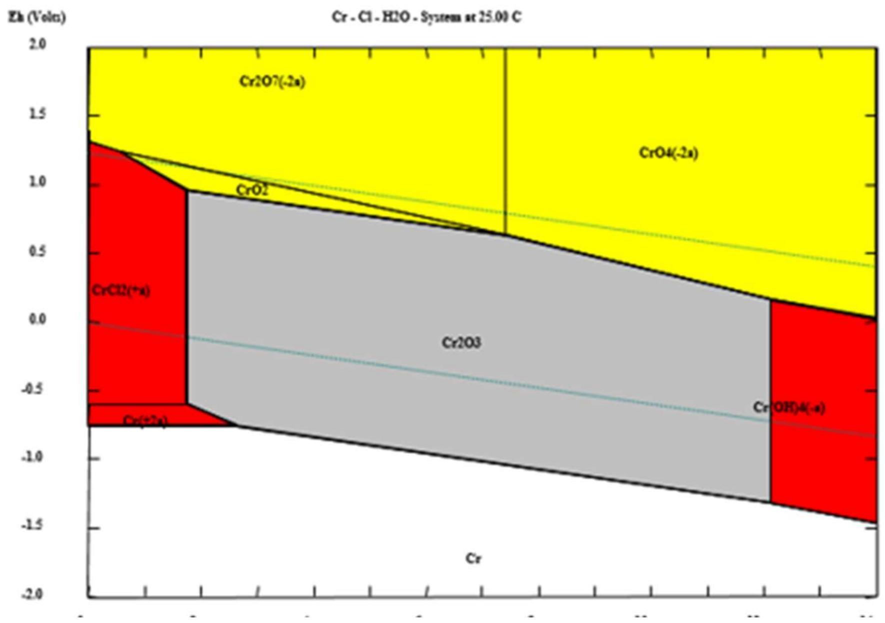

Figure 3-8: Pourbaix diagram for chromate species, insoluble Cr_2O_3 shown in grey chromate coatings provide a wide zone of protections; chemical resistance *(Jaworowski, 2000)*

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

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

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

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

3.5 Alternatives: Acid surface treatments

3.5.1 Introduction: Status of acid surface treatments reported in original applications

This section summarises the status of alternatives for passivation of stainless steel as reported in the parent AfAs submitted in 2015. **Table 3-7** summarises the test candidates identified within the parent Authorisations for the substances supported by the ADCR for the use passivation of stainless steel. Alternatives are captured within the over-arching term of acidic surface treatments, namely nitric acid, nitric/hydrofluoric acid mixture, and citric acid.

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[34] Breadboard: integrated components, typically configured for laboratory use, that provide a representation of a system/subsystem. Used to determine concept feasibility and to develop technical data

Table 3-7: Passivation of stainless-steel summary of alternatives from previous AfAs

No.	Alternative	TRL	Years to implement concept	AfA	Consortium/substance
1	Acidic surface treatments; nitric acid[(a)]	N/A	Limited implementation	0032-04	CTAC/chromium trioxide
2	Acidic surface treatments; citric acid[(a)]	N/A	Limited implementation	0032-04	CTAC/chromium trioxide
3	Nitric acid/hydrofluoric acid mixture[(b)]	N/A	Limited implementation	0032-04	CTAC/chromium trioxide
4	Acidic surface treatments. Technical feasibility assessment of inorganic acids for creating stable oxide coatings or converted oxide layers or passive films (Nitric acid, citric acid) [(c)]	3	12 – 15	0044-02	CCST /Potassium dichromate
5	Nitric acid passivation (qualified for certain austenitic and martensitic steels for particular applications) [(d)]	5	12 – 15	0043-02	CCST/sodium dichromate
6	Citric acid passivation (austenitic and certain non-austenitic steels) [(e)]	5	12 – 15	0043-02	CCST/sodium dichromate

a) Section 7.1.1.1, implemented for selected stainless steels
b) Section 7.2.1: Pickling of stainless steel; term is interchangeable with passivation of stainless steel
c) Section 7.1.1.2, Table 10
d) Section 7.1.1.6
e) Section 7.1.1.2: Passivation of stainless steel

Nitric acid, nitric/hydrofluoric acid mixture and citric acid were reported as implemented under limited applications but by no means universally across all stainless steel alloys applicable to the A&D sector. Indeed, it must be noted that the scope of implementation of each required further extensive testing before these alternatives could be qualified for all stainless steel alloys used across the sector. A factor in the implementation of nitric and citric acid was the availability in the required quantities of the test coupons for all affected stainless steel alloys for laboratory screening (CCST Consortium, 2015).

Challenges affecting universal implementation included; as reported above, availability of test coupons in all production alloy varieties, and controlling adverse accelerated etching manifesting as degradation; grain pitting and intergranular corrosion (CTAC, 2015)

The use of a mixture of nitric and hydrofluoric acid was reported by the aerospace industry as a common means of pickling stainless steel. The term 'pickling stainless steel' is interchangeable with passivation of stainless steel in parts of the surface finishing industry and hence included within this summary. Although this mixture of acids was in common use, it was not universally adopted for stainless steel alloys while process controls were still being developed and refined (CCST Consortium, 2015)

Nitric acid was reported as qualified for certain martensitic and austenitic stainless steel alloys in limited production applications with restricted corrosion resistance requirements. CTAC reported that for some martensitic and precipitation hardening corrosion resistant steels, critical to the sector, citric acid passivation may need to be supplemented with the application of post-treatments to meet performance requirements (CTAC, 2015)

Although the maturity of nitric acid passivation was reported as already at production readiness for selected substrates, the economic impact of potentially complex processing controls, process changes for different alloys passivated by different acids was yet to be fully understood.

3.5.2 Progression reported by ADCR members

3.5.2.1 Introduction

Prior to applying the main passivation treatment, where required surface preparation steps ensure that the substrate is clean and free of contaminants, such as scale and surface oxides, that could interfere with the passivation process. Examples of possible contaminants include grease, oily residues, and oxidation products. Pre-treatments include the following, none of which are reliant on Cr(VI):

- Alkaline degreasing;
- Acidic etching in a solution of nitric acid or proprietary formulations;
- Mechanical processes such as:
  - Grit blasting,
  - Shot peening
  - Abrasive blasting
- Ultrasonic cleaning.

ADCR consortium members have included at least one of these acid surface treatments in their R&D programmes. Some development programmes are ongoing, while others have transitioned to formal approval against required certification, approval, and industrialisation processes albeit targeted to specific stainless steel alloys and components. None of the acid surface treatment test candidates have achieved universal adoption across all combinations of stainless steel alloys used by all OEMs.

To achieve certification or approval by the relevant authority, each component must meet the required performance and safety requirements provided by the incumbent Cr(VI) based treatment. A complete suite of tests should include evaluation of all stainless steel alloys subject to passivation of stainless steel. This is to rule out any outlier results or impacts on niche alloy grades prior to adoption of the candidate alternative. Approval of the test candidate must include a complete understanding of the influence of the adjacent treatments within the process flow containing of the main treatment i.e. passivation of stainless steel. This represents the surface treatment system in its entirety. It could be the case that the same test candidate may behave differently in contact with different substrate alloys, or in combination with other supporting treatments within the system leading to variability in the performance of use which may impact approval of the test candidate for different part designs.

Mindful of the above extensive testing and evaluation regimes, ADCR members have progressed the development of acid surface treatments since the parent applications were submitted. Acid based treatments are in use for some components and selected alloys, however, these alternatives are by no means fully implemented and further testing is ongoing; the timeframe for completion of testing extends beyond the current review period.

Key technical performance issues to be resolved are:

- Inadequate corrosion protection
- Suitability for all types of alloys
- Organic contamination makes bath unusable (citric acid)

Barriers to achieving higher TRL levels include:

- Approval of alternatives by OEMs/Airlines/Ministries of Defence; and
- Completion of the relevant evaluation steps/TRLs within the substitution process.

3.5.2.2 Technical feasibility/Technical Readiness Level of Acid surface treatments

Critical to quality (CtQ) tests are a means of assessing performance of test candidates in the laboratory environment against technical feasibility criteria and performance attributes; corrosion resistance, embrittlement/heat treatment , adhesion, chemical resistance, and fatigue strength. Reproducible measurement of performance thresholds are detailed in standardised methodologies described in Section 3.4.5. Annex 1 lists examples of standards for each technical feasibility and performance criterion.

As explained, performance needs to be as good as or better than the incumbent Cr(VI) treatment; demonstrating no regression. Members' experience has shown that there can be difficulty in transferring good laboratory test results to an industrial environment when scaling up to replicate in-service environments, therefore evaluation of the performance of a test candidate is subject to passing the latter stages of the TRL testing regime applying rigorous simulated in-service testing environments. The TRL status of acid surface treatments echoes the different rate of progression that can occur between different applications and approaches to the delivery of the test alternative.

For those stainless steel alloys not already using an alternative to Cr(VI), the majority of substitution has advanced to TRL5 to TRL 9 for nitric acid, with industrialisation within 2-4 years. Exceptions exist for ferritic alloy, including forge hardened alloy steel which failed the corrosion resistance tests. To facilitate the use of nitric acid for alloys more sensitive to corrosion, for example martensitic steels, operational parameters have to be adjusted to reduce contact time during processing. By way of example, the specification AMS 2700 permits use of nitric acid with a limited number of corrosion resistant steels compared to those alloys approved with Cr(VI). Phased transition across different production lines is reported as a means of managing the implementation of nitric acid and the necessary changes to processing parameters. In one example, refining processing conditions (temperature and concentration, for example) has failed to reproduce the same performance achieved with Cr(VI) in combination with post-treatments, such as a bonding primer. Consequently the whole passivation and bonding system needs to be replaced in unison. To date, even in combination with a Cr(VI) bonding primer, performance of the non-Cr(VI) acid surface treatment is inferior to that delivered with Cr(VI). Work continues to resolve the compatibility issue observed to date and the consequential failed adhesion of subsequent primers following passivation of stainless steel with acid surface treatments. Further steps are required prior to industrialisation of nitric acid, including the modification of design drawings, incorporating the use of nitric acid across additional designs, and industrial qualification of suppliers in accordance with new process instructions.

Nitric and hydrofluoric acid (HF) mixture is an adopted option permitted in some OEM specifications. An additional tank is required to segregate from other acid treatments and avoid cross-contamination from carry-over of fluoride treated components. Treatment with hydrofluoric acid leads to the formation of iron hexafluoride complex which is kept in solution. Process conditions need to be monitored as HF at the appropriate concentration can etch stainless steel alloys which may be detrimental to the part design.

Citric acid has achieved TRL 3 to 5, and the qualification process is ongoing. A potential issue to overcome with the use of citric acid is microbial contamination. Citric acid is a potential food source for microbes which if allowed to multiply can form a biofilm[35] which has the potential to foul processing equipment; pipework and tanks, as well as the treated components themselves. Dosing processing equipment e.g. tanks, and pipework, with an appropriate biocide may be required to control microbial growth if biofilm development and release into the treatment solution is a distinct risk. Indeed it is reported that adding biocide as a preventative measure to control microbial growth is required. This outcome could render the test candidate unsuitable if technical feasibility criteria or performance attributes were negatively affected either from the presence of biofilm fragments in the treatment solution, or as an indirect consequence of the use of a biocide. Further work is required to assess the potential risk and impact of biocides on the treatment system, as well as the need to establish a reliable, regulatory compliant, and cost effective supply chain for any biocidal agent introduced into the production environment. As described previously, the introduction of another non-certified substance into the production process would also need to be factored into the timeline for overall substitution. This is to ensure it is fully compatible with all relevant part designs as appropriate, and fully integrated into the production process.

Steps required prior to industrialisation of citric acid include modification and linkage of the substance to design drawings, qualification of suppliers in accordance with new process instructions, identification and qualification of the biocide (if deemed necessary) for maintenance of processing equipment.

Table 3-8 summarises the expectation by members for progression to TRL 9 and implementation beyond. This is with the caveat that all steps in the substitution process are met, and no iterative steps are required thereby delaying the approval sequence and prolonging the time to industrialisation and implementation. Where TRL 9 has already been attained, industrialisation and implementation of acid surface cleaners includes the caveat that the use of the test candidate is only approved for new, or redesigned components, and/or specific alloy types. Although the test candidate is qualified in their relevant production process, for those sites manufacturing for multiple design owners, not all will have received universal approval to apply the test candidate alternative process for all affected designs. Under these circumstances, if production facilities allow, parallel manufacturing lines are required to accommodate both Cr(VI) and non-Cr(VI) processes until all design owners approve the alternative. Therefore, it is not possible to report that implementation is universal across all alloy and component combinations that currently utilise Cr(VI) for passivation of stainless steel due to the great number of configurations of alloy and component/design within the A&D sector. **Table 3-8** summarises where at least one production line or process has transitioned to the alternative, or is expected to, by the given year.

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[35] A biofilm is an assemblage of microbial cells that is irreversibly associated (not removed by gentle rinsing) with a sur-face and enclosed in a matrix of primarily polysaccharide material (Donlan, 2002)

Table 3-8: Proportion of ADCR companies expecting to achieve TRL 9, and industrialise by year

	2022	2025	2028	2029	2030	2036
% of members expecting to achieve TRL 9, by year	35	45	55	65	75	100

3.5.2.3 Economic feasibility

In some cases it is not anticipated that there will be any change to plant or associated processing times using nitric acid based systems. Other suppliers report increased raw material costs and energy requirements across all processing areas, making it difficult to quantify any direct economic impact from implementation of acid surface treatments. As raw material and energy costs continue to be in a degree of flux, SME suppliers have been unable to provide an accurate assessment of the potential economic impacts of substitution. This will have to be assessed when design owners decide on an alternative process. However, to accommodate the requirements of certain specifications for the use of nitric acid with different steel alloys e.g. AMS 2700, it can be necessary to install additional tanks for the different solutions required for the different alloys as these tanks cannot be routinely emptied and refilled when different solution strengths are required for different alloys. It is not always practical or feasible to install the additional immersion tanks and support lines required. On the other hand citric acid can be utilised across different alloys without the need for proliferation of different solution strengths. Therefore if proven technically feasible, this test candidate could be preferable to nitric acid from an economic feasibility point of view.

Members report that raw material costs for citric acid may be higher than current chromate costs, however, this may be offset to some extent from cheaper waste disposal costs as chromate waste requires a certified waste handler for disposal. Acidic waste from use of acid surface treatment alternatives is easier to process via neutralisation prior to disposal.

Reported in Section 3.5.2.4 is the link between the test candidate hydrofluoric acid (HF) and the Directive 96/82/EC, also referred to as Seveso III. The legislation includes lower and upper tier obligations which require ever more stringent practices to be implemented by the operating site. Should Seveso III be triggered, or implementation of HF cause transition to the upper tier obligations of Seveso III, operations within the site would have to be assessed against the relevant Directive obligations. This would have potential impacts on the timeline to integrate the new alternative, as well as economic impacts associated with meeting all obligations. Potential economic impacts include the position of the site itself. Seveso III restricts the proximity of affected sites to local residential areas. If major changes in the layout of the site to accommodate requirements for the storage and on-site transportation of the affected substance is not geographically or economically possible, site relocation may need to be considered. In many cases relocating a site due to the obligations of Seveso III may render the adoption of HF as an alternative too expensive and/or impractical.

The direct challenge of substitution using acid-based surface treatment alternatives is mainly the increase in the operational costs and potential infrastructural costs during the transition phase. It is not anticipated that there will be any permanent change to plant or associated processing times providing acid-based surface treatment systems, however, there is a potential need for additional plant during the time of transition. The transition phase is the period in which both Cr(VI) and non-Cr(VI) lines need to run at the same time. Hence, there is a significant expenditure for the companies during the transition phase. Many SMEs cannot afford such large capital investments. Only a qualitative assessment of economic feasibility can be provided here due to the difficulties in extracting specific quantitative data since there is an overall increase in costs reported from all processing areas for the implementation of acid-based surface treatments.

The operational costs will increase due to the following impacts:

- Raw material prices: Members report that the price of raw materials for the potential candidate is higher than the price of the chromates currently in use. An increase in the concentration used in the treatments will also increase the cost;
- Energy Cost: The energy cost is expected to increase, especially when higher tank operating temperatures are required;
- Additional operational cost: the need for additional additives including but not limited to adhesion promoters, biocides to control biofilm in the case of use of critic acid; and
- Other costs: Indirect changes like drawing changes, specification updates, customer approvals and software updates of affected automatic lines produce an increase in costs.

Given the above, a switch to the test candidate is not economically feasible for some companies/sites within a four or seven-year period. Additional time is required for smoothing their expenditure and optimising their production capabilities to avoid incurring unaffordable losses that could result in the closure of some operations.

Another major cost factor identified is related to the certification process. The time required is due to both the tests required for validation and qualification of the use of the potential candidate on components, as well as the process for qualifying or accrediting suppliers against the implementation of the potential candidate. According to many companies, the time needed during the R&D phase is significant due to the need to undertake a range of tests to assess performance with limited availability and access to specialist bespoke purpose built test facilities. This is exacerbated by the time required to gain certifications due to the large number of new certifications requested, and limits to available resources to process and approve these. The latter is the single biggest obstacle faced by those companies who report that they are at, or approaching, TRL 9 in their progression of an alternative.

3.5.2.4 Health and Safety considerations related to using acid surface treatments

For the purpose of understanding the risks associated with the test candidate acid surface treatments, **Table 3-9** summarises the key identifiers assigned to each of the substance within its scope.

Table 3-9: Acid surface treatment test candidate general information

Substance	Index number	EC Number	CAS number	IUPAC Name
Nitric acid	007-004-00-1, 007-030-00-3	231-714-2	7697-37-2	Nitric acid
Citric acid	N/A	201-069-1	77-92-9	Citric acid
Hydrofluoric acid	009-002-00-6, 009-003-00-1	231-634-8	7664-39-3	Hydrogen fluoride

(*Information on Chemicals - ECHA*, no date)

Analysis of the hazard profiles of each substance demonstrates a reduction in overall risk is achieved from transition to the test candidate acid surface treatments irrespective of the substance employed. The hazard classification and labelling status according of each substance is given in **Table 3-10**

Table 3-10: Summary of hazard properties of Acid Surface Treatments

Substance	EC Number	CAS number	CLP Classification
Nitric acid (≤ 70%)	231-714-2	7697-37-2	Ox.Liq.2; H272, Skin Corr. 1A; H314, Acute Tox. 3; H331, EUH071[(a)]
Citric acid	201-069-1	77-92-9	Skin Irrit. 2; H315, Eye Irrit. 2; H319; STOT SE 3, H335[(b)]
Hydrofluoric acid	231-634-8	7664-39-3	Acute Tox, 2; H300, Acute Tox. 1; H310, Skin Corr. 1A; H314, Acute Tox. 2; H330 [(a)]

(a) – Harmonised classification according to Annex VI of Regulation (EC) 1272/2008 (CLP)
(b) – Based on Proposal for Harmonised Classification and Labelling submitted by MS CA
Source: ECHA – Search for chemicals (https://echa.europa.eu/home)

Exposure assessment analysis by ADCR members concludes that the introduction of both acid surface treatment alternatives, citric acid, and nitric acid, would reduce the risk associated with the use passivation of stainless steel from high to medium or low as production facilities transition from the use of Cr(VI) to the alternatives. All of the substances identified under the category 'Acid surface treatments' exclude the hazard statements associated with CMR[36] hazard classification.

Hydrofluoric acid has a more severe hazard profile than citric and nitric acids: H300, Fatal if swallowed; H310 Fatal in contact with skin; H330, Fatal if inhaled. However, this substance is not on the Candidate List of substances of very high concern for Authorisation[37] and therefore does not currently constitute a potential for regrettable substitution. Therefore, with adequate risk management measures in place it would constitute a risk reduction when measured against the authorised chromate substances.

As shown in **Table 3-10** hydrofluoric acid (HF) includes hazard statements (H-phrases) subject to Council Directive 96/82/EC[38] ; Seveso III namely H310 + H330. This Directive requires sites storing qualifying substances to comply with a series of obligations designed to reduce the likelihood of, or consequences from, major industrial accidents.

3.5.2.5 Availability of acid surface treatments

Each of the substances defined within acid surface treatment are available on the EU market. Expectation is that all will be available in sufficient quantities subject to meet production capacity requirements. Integration of substance quality parameters into internal quality control specifications is not universal; variation may be necessary to accommodate different production parameters applicable to different alloys and components. Qualification of the supply chain is in process, utilising

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[36] Carcinogenic, Mutagenic, Toxic to Reproduction

[37] Search date 25 August 2022

[38] EC (2012) available at: Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/ECText with EEA relevance (europa.eu) accessed 13 October 2022

or modifying existing production lines where possible, for example to avoid carry over of fluoride where hydrofluoric acid is used. Phased transition as supply lines are built up; storage and handling capabilities are increased to meet demand across all production lines.

Acid surface treatments have been progressed to mature TRLs and in some instances nitric acid has been implemented and in others reached TRL 9 in readiness for industrialisation. However, in the context of being available from a regulatory perspective; fulfilling the substitution process described in detail in Section 3.1.2, additional work and time to gain regulatory approval is required. Implementation has been delayed in order to address issues reported from the use of nitric acid. For example, refining process parameters when used in conjunction with sensitive alloys and ensuring that other processes within the treatment system are compliant with the test candidate to achieve the require adhesion properties from the treatment required when used prior to post- treatments; primers.

3.5.2.6 Suitability of acid surface treatments

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[39]. In order to be considered as suitable in the European Union (EU) the alternative should demonstrate the following:

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

A reduction in risk is achieved as evidenced from each of the classification and labelling reviews provided in Section 3.5.2.4. Members reported the use of a mixture containing hydrofluoric acid and nitric acid. Although both are hazardous, neither was reported as a candidate for SVHC. Therefore, it is reasonable to conclude that both represent progression to a safer alternative in the context of this Review Report. Citric acid also represents a reduction in hazard level compared to the Authorised substance and is not on the Candidate list as a SVHC. All substances within the scope of acid surface treatments are considered readily available in a variety of grades within the EU. Although supply chains exist and are expected to meet production capacities, acid surface treatments may not be considered available in all instances. When considering all alloy types, for all associated affected components, and where production processes are interdependent, i.e. to the extent that one treatment cannot be separated from the other, acid surface treatments are not available for all substitution scenarios. This necessitates the need to approve the treatment system as a whole. An example is the requirement for bonding and adhesion properties to meet required performance thresholds exhibited by Cr(VI) when passivation is followed by primer uses, such as for structural bonding purposes. These processes cannot be substituted in isolation and therefore acid surface

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[39] 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

treatments are not regarded as available in light of the regulatory requirements of placing them on the market, until performance requirements of the treatment system are fulfilled, including all certification obligations as stipulated within the Airworthiness Directives[40].

Assessment against the technical feasibility criteria is mixed and dependent upon the alloy and component types selected. Acid surface treatments are technically feasible within the EU and proven for some applications within the A&D sector; however, work is still required for adhesion for example to meet the performance requirements attributed to Cr(VI). Acid surface treatments cannot, therefore, be deemed technically feasible to the applicant under these circumstances. Further work and time is required to develop and approve a system that provides the means to use passivation and primer processes that are compatible with one another, as well as modify designs that utilise alloys that are not technically feasible or compatible with the acid surface treatment alternative.

3.5.2.7 Conclusions on suitability

Table 3-11 summarises the current development status of the test candidates to replace Cr(VI) for passivation of stainless steel. It considers the availability to the downstream users and hence the applicant, from the perspective of technical and economic feasibility as well as regulatory requirements that must be met before a test candidate can be qualified, validated, certified, and therefore approved and implemented, and hence how this affects its suitability. To confirm, in all cases 'high' represents an increased level of alignment with the requirement of the individual criteria.

Table 3-11: Current development status of acid Surface treatments

Alternative	Technical feasibility	Economic feasibility	Risk reduction	Availability	Suitability
Nitric acid	Moderate	High	Moderate	Moderate	Moderate
Citric acid	Moderate	Moderate	High	Moderate	Moderate
Hydrofluoric acid	Moderate/high	Moderate	Low	Moderate	Moderate/Low

Section 3.1.2 describes in detail the process that must be followed before an alternative can be implemented. The overriding reason for these strict protocols is to ensure that the aircraft, and defence equipment whether used on land or in the air, is airworthy, reliable, and safe to use within all operational environments and climatic conditions.

All civil aircraft operating in the EU are subject to Airworthiness Directives issued by the EASA on behalf of the EU and its Member States, and European third countries participating in the activities of EASA. Changes to design of a product are subject to certification (EU, 2018) , and can only be made following approval from the Regulator following the requirements of the appropriate Airworthiness Regulation, such as (EU) 2018/1139[41]. 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). Likewise, Defence

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

[41] 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)

equipment is subject to change protocols including approval by the relevant Member State Ministries of Defence.

It is clear that although acid surface treatments are available on the market, it is necessary to draw the distinction as to whether or not they are available to the applicant. For reasons discussed above, it is often the case that availability is constrained or limited by the need to achieve regulatory approval of the alternative. Restricted availability coupled with incompatible configurations of substrate, component design, or treatment system, requires further development and time to implement acid surface treatments described above for the purposes of passivation of stainless steel.

3.6 The substitution plan

3.6.1 Introduction

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

3.6.1.2 Substitution plans within individual members

Each ADCR member has a substitution plan to remove Cr(VI) in passivation of stainless steel that is uniquely reflective of their individual situation. Additionally, an individual member often has multiple substitution plans for passivation of stainless steel, running in parallel work streams. The reason for different substitution plans within one member is that they are segmented by factors such as type of substrate, type of component, and type of alternative. These different substitution plans are progressed simultaneously although they typically have differences in timing of milestones and anticipated achievement of each TRL/MRL level, based on various factors such as the technical difficulty of introducing the alternative and prioritisation of certain types of component or substrate.

3.6.1.3 Interplay with pre-treatments and post treatments

Development of substitution plans for alternatives to Cr(VI) for passivation of stainless steel are fundamentally related to and impacted by its compatibility with any pre-treatment and/or post-treatment for example a subsequent layer, where applicable. In the case where members are using Cr(VI) in the pre-treatment, they develop the Cr(VI)-free pre-treatments in parallel with the Cr(VI)-free passivation of stainless steel. The progression and success of the development of alternatives to Cr(VI) in passivation of stainless steel depends on the successful development of pre-treatment alternatives. Any unexpected technical failures in the development of the pre-treatment will impact the planned timing of the substitution plan for the passivation of stainless steel.

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

3.6.2 Substitution plan for ADCR in passivation of stainless steel

3.6.2.1 Substitution plans

Citric acid, nitric acid, and nitric/hydrofluoric acid mixtures have been progressed by members to replace Cr(VI) in passivation of stainless steel.

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

The data in the figure show the expected progress of 16 distinct substitution plans for Cr(VI) in passivation of stainless steel, 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 passivation of stainless steel for the ADCR consortium as a whole.

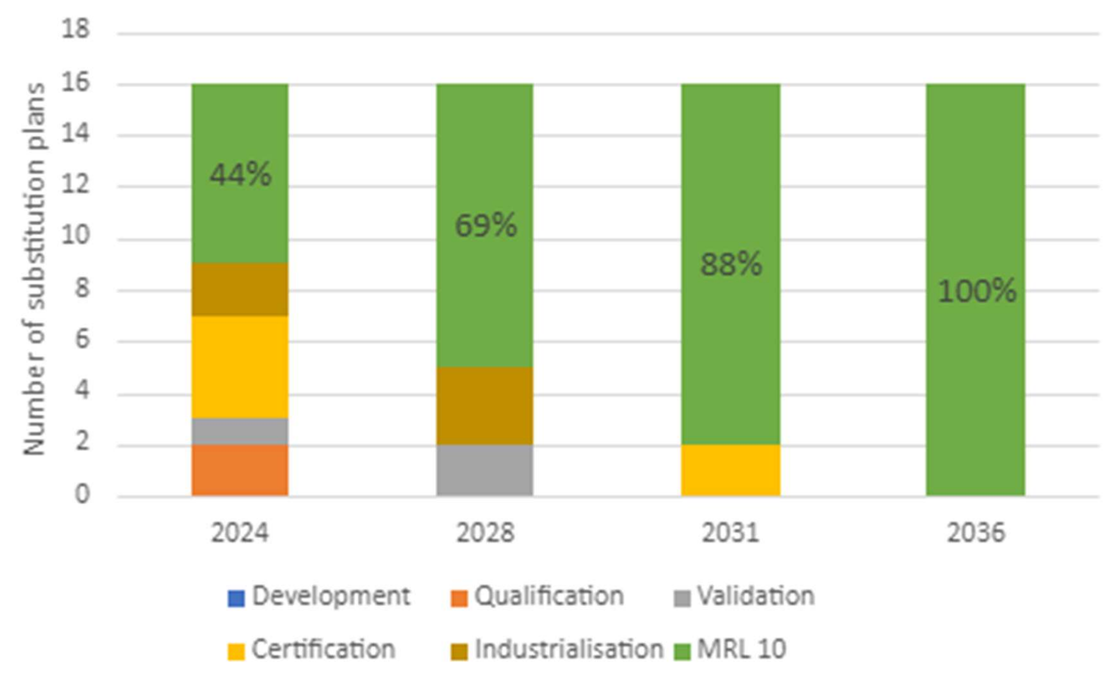

Figure 3-9: Expected progression of substitution plans for the use of Cr(VI) in passivation of stainless steel, by year

The vertical axis refers to number of substitution plans (some members have multiple substitution plans for passivation of stainless steel). The percentage value shown on each of the green bars indicates the proportion of substitution plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which there is expected to be a significant reduction in Cr(VI) usage.

Source: RPA analysis, ADCR members

The above summary shows:

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

The dates at which each substitution plan is expected to achieve each stage are estimates provided by the members, and there are uncertainties due to, for example, unexpected technical failures which may only reveal themselves at more advanced stages of testing. Consequently, the expected progress of substitution plans, especially in the outer years 2031 and 2036 where there is more uncertainty, may be slower (or faster) than estimated today, as presented in **Figure 3-9.** The actual status of the substitution plans 12 years from now could be different to our expectations today.

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

Many of the challenges with implementing nitric acid or citric acid as alternatives to Cr(VI) in passivation of stainless steel have been overcome by ADCR members, and consequently these alternatives are in use for some components in some situations which has led to a reduction in the use of Cr(VI). Challenges still remain which limit members' progression of the substitution plans beyond the stages indicted in **Figure 3-9**. Technical challenges include unproven efficacy of the biocide needed for citric acid, and nitric acid is too aggressive for use with some alloys. Process challenges include the need in some cases for multiple treatment baths, and the need to gain approval from a large and diverse range of customers. In the case of nitric/hydrofluoric acid mixtures, hydrofluoric acid is in the scope of the Seveso III Directive (96/82/EC) and as such can trigger obligations which carry with them significant impacts (such as infrastructure requirements). These requirements can be prohibitive and can inhibit the use of nitric/hydrofluoric acid mixtures as an alternative to Cr(VI) for passivation of stainless steel.

The timeframes associated with the activities presented in **Figure 3-9** result from the requirements of the substitution process which are presented in section 3.1.2.. To be noted also is that approval of suppliers cannot always occur in unison; qualification may need to cascade down the supply chain depending upon the number of tiers and actors involved. As resources are not available to action this simultaneously across all suppliers, the timescale for supplier qualification may be extended. Modifications may be required to the supply chain to allow for the installation of new equipment in some cases, although this can be mitigated by sourcing from existing established suppliers familiar with the requirements of qualification protocols.

3.6.2.2 Requested Review Period

It can be seen in **Figure 3-9** that despite ongoing and concerted efforts of the members to develop alternatives to Cr(VI) in passivation of stainless steel, it has not proved possible to replace Cr(VI) by the end of the Review Periods granted in the parent Authorisations (which end in 2024). It is clear from the chart that in 2031 (equivalent to seven years beyond the expiry date for the existing applications), while many substitution plans are expected to have successfully progressed to MRL 10 and the consortium is expected to have reduced its Cr(VI) use, a significant proportion are not expected to have achieved MRL 10 and are expected to be predominantly at the certification stage. For these substitution plans there is still expected to be a need for the use of Cr(VI).

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

4 Continued Use Scenario

4.1 Introduction

Section 3 provided an analysis of the alternatives with respect to the technical feasibility, economic feasibility, availability and suitability of alternatives. The assessment highlights the importance of Cr(VI) for corrosion protection and the other key functions delivered by passivation, in its application to stainless steel, particularly after machining. Although some of the companies supporting this use have implemented alternatives at the industrial level (e.g. nitric acid and hydrofluoric acid) for some components, this is not across all components or products.

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

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

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

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

The Continued Use Scenario can be summarised as follows:

Continued use of chromates in passivation 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 2030	-> 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 including acid surface treatments and their adoption across supply chains
->Modification of designs as substitutes, including acid surface treatments 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 passivation, including projected tonnages over the requested review period;
- The risks associated with the continued use of the chromates.

4.2 Market analysis of downstream uses

4.2.1 Introduction

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

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

- continuity of supply of critical products containing hexavalent chromium.

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

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

4.2.2 Overview of the European aerospace and defence sector

In 2020, the European A&D industry comprised over 3,000 companies of all sizes and employed over 880,000 highly skilled employees (with these figures including the UK[42]). 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"[43]. **Figure 4-1** provides details of turnover and employment for the industry in 2020, based on the A&D Industries Association of Europe (ASD) publication "2021 Facts & Figures".[44] These figures are lower

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

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

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

than the comparable figures for 2019, at around 405,000 jobs and €130 billion in revenues[45], with these leading to exports amounting to around €109 billion.

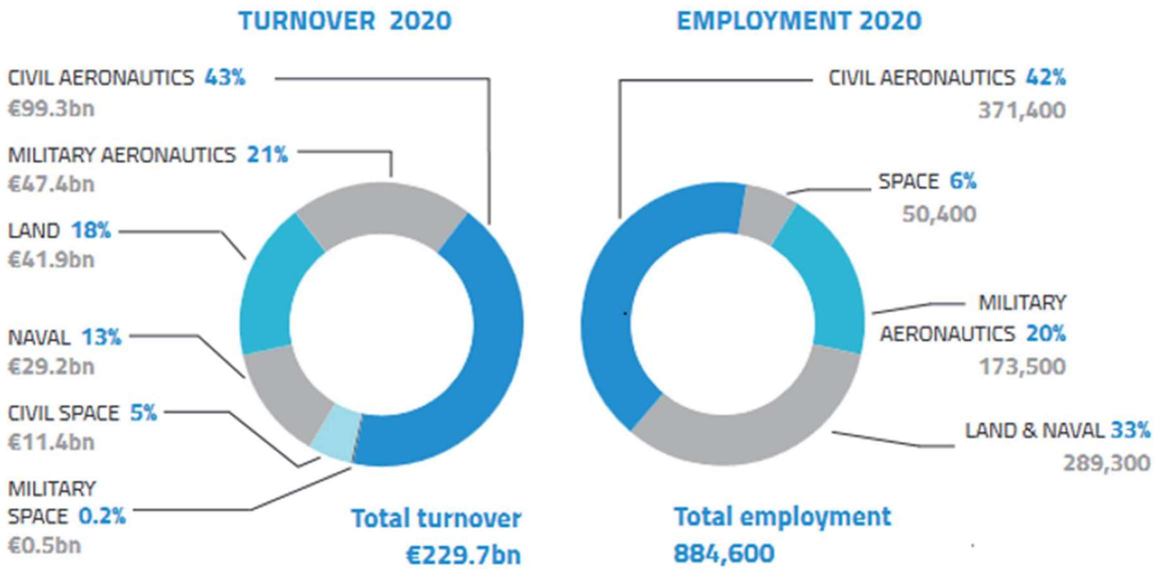

Figure 4-1: Turnover and Employment for the European A&D Industry in 2020 (snip taken from ASD, 2021)

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

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

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

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

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

- Aircraft and other products remain in services over long time periods. For example, the Boeing 747 first entered service in 1970, and continues to be flown and produced in 2022 (although it will now go out of production but remain in service). Given the need to ensure on-going

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

airworthiness and due to certification requirements, there will continue to be a “legacy” demand for the use of chromates in the production of components for maintenance of existing aircraft and equipment, as well as for models that are still in production long periods after the first aircraft or military products were placed on the market;

- A&D technologies take many years to mature. Product development is a five- to ten-year process, and it can take 15 years (or more) before the results of research projects are applied in the market. As part of the development and roll-out of new A&D products, OEMs have to be ready to demonstrate fully developed technologies, or they risk losing contracts that may have a lasting effect on business.[46]

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

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

4.2.3 Economic characteristics of Companies undertaking Passivation of Stainless Steel

4.2.3.1 Profile of downstream users

As noted in Section 2, passivation of stainless steel is a common use of CT and SD within the aerospace sector. As a treatment, it is carried out by in-house by some of the OEMs, as well as being carried out by BtP suppliers, and to a lesser degree DtB suppliers and MROs.

Passivation is relevant to production, repair, maintenance and overhaul of a range of different components, with examples (non-exhaustive) identified through consultation being as follows:

- Main landing gear;
- Nose landing gear;
- Access and freight doors;
- Lightning strike shielding;
- Gallery and lavatory;
- Pyrotechnic equipment;
- Interstage skirts, fuselage;
- Cockpit frames;

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

- Engine intake areas; and
- Tail rotor assembly;
- Propeller systems; and
- Amphibious craft propulsion systems.

SEA questionnaire responses were provided by 37 A&D companies undertaking passivation of stainless steel (40 when considering the EEA and UK separately), with these companies operating across 40 sites in the EEA and 18 sites in the UK (58 out of a total of 90 sites operated by these respondents).

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

Table 4-1: Numbers of SEA respondents undertaking Passivation

Role	Number of companies/sites undertaking Passivation*		Company Size[47]	
	EEA	UK	EEA	UK
Build to print	12/16	12/13	3 small 5 med 4 large	7 small 3 med 2 large
Design and build	5/5	2/2	1 small 2 medium 2 large	1 medium 1 large
MRO only	3/7	2/2	3 large	1 small 1 large
OEM	3/12	1/1	3 large	1 large
Total *	23/40	17/18		

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

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

4.2.3.2 Economic characteristics

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

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

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

Turnover is calculated as the weighted average by company size, as this is the most appropriate means of reflecting the level of turnover across the EEA (including UK) linked to the passivation of stainless steel and taking into account the size distribution of the companies[48] that are involved in such activities. GVA per employee, numbers of employees, and average personnel costs are given as the sector average and not per company size for several of the NACE codes, so it was not possible to calculate weighted averages for these. Note that the count total is by company and not by site.

Data on Gross Operating Surplus[49] (GOS) as a percentage of turnover (the GOS rate) is also used here to provide an indication of the profits associated with the turnover generated by these sites. This is based on a figure of 11% which is an average across the various NACE codes weighted by the number of companies declaring each NACE code.

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

[49] 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).

Table 4-2: Economic characteristics of "typical" companies by NACE in sectors involved in Passivation of stainless steel (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	25	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	4	57.20	65,000	43,200	9.7%
C2599 - Manufacture of other fabricated metal products n.e.c.	8	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%
C2732 - Manufacture of other electronic and electric wires and cables	0	34.39	76,000	51,700	4.8%
C2815 - Manufacture of bearings, gears, gearing and driving elements	5	284.64	72,000	44,500	7.9%
C3030 - Manufacture of air and spacecraft and related machinery	8	1,214.65	98,000	76,400	11.2%
C3040 - Manufacture of military fighting vehicles	5	1,214.65	99,000	64,800	9.8%
C3316 - Repair and maintenance of aircraft and spacecraft	7	71.33	85,000	56,400	8.4%
Other	2	NA	NA	NA	NA
Total count	65				
Note: The count total is by number of NACE code identifications by company and not by sites, with 37 companies providing data					

As can be seen from **Table 4-3**, the 58 sites for which data were collected via the SEA questionnaire represent an estimated €19 billion in turnover and €2 billion in GOS as a proxy for profits. Across all 90 sites (70 in the EEA and 20 in the UK) expected to be undertaking passivation in the EEA and UK, these figures rise to around €26 billion in turnover and €2.8 billion in GOS.

Table 4-3: Key turnover and profit data for market undertaking passivation (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
40 EEA Sites	16,510	1,733
18 UK sites	2,382	250
Extrapolation to all sites involved in chromate-based passivation in the EEA or UK		
70 EEA sites	23,160	2,431
20 UK sites	3,665	385

Source: Based on SEA questionnaire responses, combined with Eurostat data
Note: See Section 2.3.3.6 for basis of extrapolation to the 90 sites in the EEA and UK combined

4.2.3.3 Economic importance of Passivation of Stainless Steel to revenues

Passivation of stainless steel will only account for a percentage of the calculated revenues, GVA and jobs associated with the given in the above table. To understand its importance to the activities of individual companies, a series of questions were asked regarding other processes carried out, production costs, and the share of revenues generated from the use of chromates in passivation.

As the supply chains covered by this SEA vary from manufacturers of small components to producers of much larger components (e.g. components for landing gear versus doors and/or skirts), the responses vary significantly across companies. Of key importance is that for the design owners passivation of stainless steel continues to be a critical surface treatment, the loss of which would result in loss of a significant level of turnover due to the inability to meet airworthiness requirements, even though as a process it accounts for only a very small percentage of production costs.

Given the importance of passivation to protecting stainless steel components, there is no direct linkage between the share of production costs linked to passivation and revenues; the loss of passivation would have a far greater impact on revenues and the financial viability of the companies involved than suggested by its share production costs. The loss would also be greater than the share of production costs accounted for passivation.

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 40 companies, 45% state that passivation makes up less than 5% of all production costs, however 24% stated that passivation of stainless steel makes up between 76% to 100% of production costs. More generally, 60% of all companies stated that chromate-based activities make up more than 75% of their revenue.

Table 4-4 provides a summary of responses on the revenues generated by passivation of stainless steel. As can be seen from this table, 27 of the 40 companies indicated that over 50% of their revenues were linked to passivation of stainless steel. Of note is the fact that three of these were OEMs, whose main sources of revenues will be the sale of large assemblies or of finished aircraft/hardware.

Table 4-4: Percentage revenues generated by passivation of stainless steel

	<10%	10% - 25%	25% - 50%	50% - 75%	>75%	No response
Build-to-print	2	2	1	3	13	0
Design-to-build	0	0	0	2	6	0
MROs	0	0	1	2	0	0
OEMs	0	0	0	0	3	1
*These responses cover multiple sites and only reflect those companies carrying out the activities						

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

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

OEMs

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

With respect to capital investments relating to passivation of stainless steel, the following investments have taken place:

- Improvements in the passivation line, PPE and ventilation systems equating to €765,000;
- General R&D into chromates, costing more than €1 million over the last 7 years;
- Support engineering for new passivation equipment implementation, at a cost of €4 million;
- Alignment of chromate replacement efforts across companies involved in a defence partnership together with the customers; and
- Investment in a new facility to the cost of €3.65 million.

Design-to-build suppliers

Two of the DtB companies noted that they had invested in new equipment to support their passivation of stainless steel. These investments ranged from 80,000 to 800,000 a site and were first made in 2018.

One company also indicated that they moved from the use of CT solids to liquids to reduce the potential for worker exposures. This required new dosage equipment and additionally involved the installation of bath covers to reduce fumes/aerosols. Together these costs totalled €25,000 and the investments were made in 2019 and 2020.

DtB companies also require NADCAP certification, with one spending €400,000 in 2018 on certification of their existing passivation processes; this certification will expire after 10 years.

Build-to-print suppliers

Six of the BtP suppliers carried out investments into their chromate using process, some as early as 2007. Types of investment include passivation lines with new extraction systems, tanks and rectifiers. Investments ranged from €22,000 a site to €1 million a site. Some of these investments have expected lifetimes of 25 years.

One company stated that they have made investments into a chromate-free process as well, where this has been certified by their customer. This included equipment such as tanks, pumps, filtration and chiller units. The investment was made in 2013, to a cost of €80,000, and is expected to last for 15 years.

Additionally, investments were made into R&D to improve passivation processes, including for improvements in health and safety. Companies have invested in more efficient LEV as well as their health and safety systems more generally. These investments have ranged in value from between €35,000 and €50,000 a site and were carried out between 2017 and 2021.

Some BtPs have also participated in R&D on alternatives. This has included investments ranging from €5,000 to €250,000 per site, with some BtPs noting that they worked alongside their OEMs for R&D purposes. Again, these investments were carried out from 2017 to 2022.

It should also be noted that some of these BtP suppliers will have to be NADCAP accredited and will be subject to International Standards Organisation (ISO) audits of their processes using the chromates, in order to secure and hold accreditations/certifications for the customer and industry approvals. This expenditure varies by company size, with related costs quoted as varying from e.g. €10,000 to €60,000 per annum; and one company reporting costs of €200,000 over the period 2017 to 2021.

MROs

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

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

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

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

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

4.2.4 End markets in civil aviation and defence

4.2.4.1 Importance to end markets

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

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

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

The economic importance of ensuring that aircraft retain their airworthiness is illustrated by the figures quoted above for the number of air passengers transported in the European Union in 2019 (over 1 billion), as well as the net profits of the airlines in 2019 at US$ 6.5 billion (€5.8 billion, £5.1 billion).

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

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

4.2.4.3 Civilian aircraft

Demand for new civilian aircraft is expected to grow into the future. Projected global compound annual growth rates (CAGR) for different aircraft classes for the period 2020-2031 are given in the figure below[50], with this suggesting CAGR from 2020 to 2031 of around 2.5%.

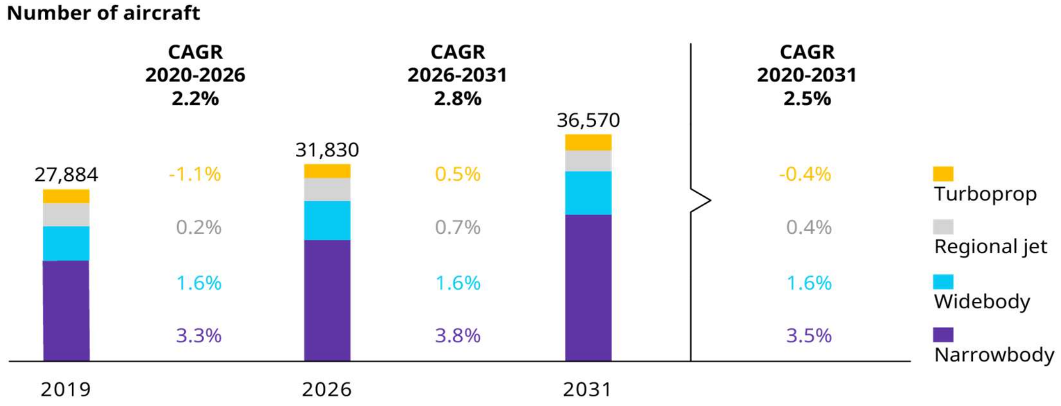

Figure 4–2: Global fleet forecast by aircraft class, 2020-2031
Source: Oliver Wyman analysis

Market reports issued by Airbus and Boeing indicate that future growth is expected to extend beyond 2031. Airbus' Global Market Forecast for 2022-2041 predicts that passenger air traffic will grow at 3.6% CAGR and freight traffic will grow at 3.2% CAGR globally. By 2041, there will be some 46,900 aircraft in service, with this including an estimated 39,500 new passenger and freighter aircraft (and the retirement of some of the older aircraft. This includes delivery of new aircraft for the European market, as well as the Asian and Chinese markets.[51]

Boeing's 2022 Commercial Market Outlook[52] indicates a similar level of increase, noting that the global fleet will increase by around 80% through to 2041 with the forecast value of new airplane deliveries at around US $7.2 trillion (based on a slightly higher growth in traffic at around 3.8% CAGR).

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

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

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

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

seating categories (100+ seater passenger aircraft and 10 tonnes + freighters) are given in **Table 4-5** below.

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

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

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

When considering these figures, it is important to recognise that the European aerospace sector is a global exporter of aircraft, and A&D products make a significant contribution to the overall balance of trade. For example, France and Germany alone had export markets totalling over US$ 57 billion (€50.4 billion, £44.3 billion) in 2020, while the UK export market was around US$13.2 billion (€11.7 billion, £10.3 billion) in 2020.[53]

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

4.2.4.4 The MRO market

Not only would the manufacture of new aircraft in the EEA and UK be impacted but anticipated growth in the aftermarket parts segment would also be affected. The aircraft spare components/final products market encompasses the market for both new and used rotable[54] components available as spares for aircraft and other products. This market was projected to grow with a CAGR of over 4% over the period from 2022-2027, although this rate may now be lower due to Covid-19. Growth is due to

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

[54] A component which is removed and replaced at pre-determined intervals measured in elapsed flight hours and/or flight cycles after which the removed item is sent for overhaul and will be subsequently re-used.

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

The MRO market was significantly affected by COVID-19 in 2020 but saw a gradual increase in demand as travel restrictions were lifted in 2021 and is expected to see positive growth over the next five to 10 years. Globally, the market is expected to have a CAGR of over 3% over the period from 2022-2027, as illustrated in the figure below.[55, 56]

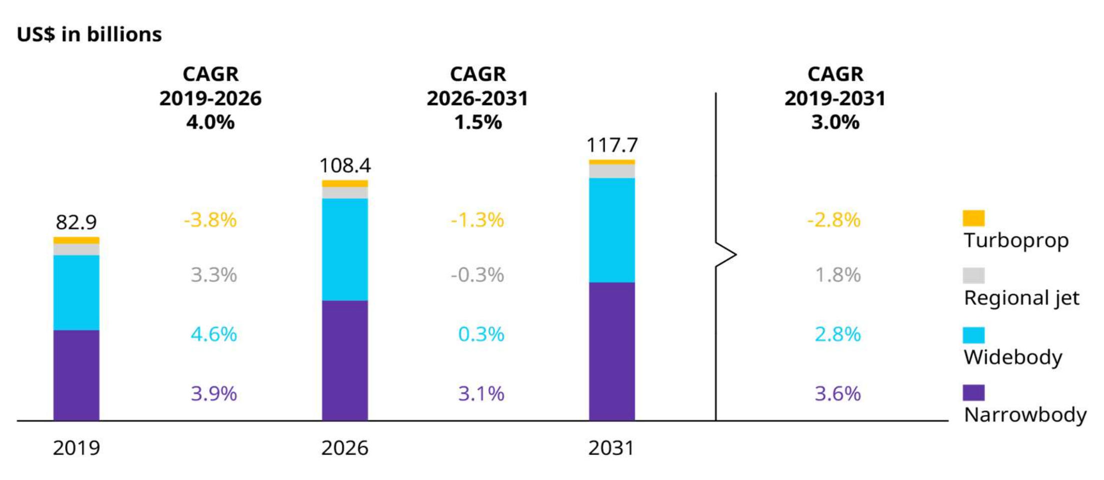

Figure 4–3: MRO market forecast by aircraft class, 2019-2031
Source: Oliver Wyman analysis

This growth is due to three factors: 1) Airlines are risk averse and try to maintain their fleets in an optimum condition, so as to delay the need to procure new aircraft, owing to the high investment costs of such aircraft - with COVID-19 severely impacting revenues and profit margins, more airlines are expected to resort to MROs to maintain fleet efficiency; 2) Airlines face very stringent MRO requirements so are not able to postpone MRO requirements; and 3) Increases in fleet sizes over the next five years will also lead to a continued growth in demand for maintenance and repair activities.

4.2.4.5 The defence market

The war in Ukraine has led to several EEA countries and the UK to revisit their defence expenditure. Several countries that are NATO members and which previously did not meet the target of spending 2% of GDP on defence are now committed to meeting that target. This compares to Eurostat figures for total general government expenditure on defence in 202 of around 1.3% of GDP for the EU[57]. The increase in investment will equate to hundreds of billions of Euros (e.g. Germany alone has pledged €100 billion in defence spending).

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

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

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

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

of 3% of GDP by 2030[58]. This equates to an increase in spending of around £157 billion between 2022 and 2030.

Such investment, which will include new spending on existing technologies, may also result in a continued reliance on the use of the chromates for passivation of stainless steel in the short to medium term until alternatives are certified for use in the manufacture of the relevant components and final products.

With respect to currently in-service products, the global military aviation maintenance, repair, and overhaul market registered a value of US $38 billion (€32 billion, £28 billion) in 2021, and it is expected to register a compound annual growth rate (CAGR) of over 2.5% during the forecast period 2022-2031. The European segment of this market is the fastest growing segment. The global civilian aircraft MRO market has a market size of US $70 billion (€59 billion, £51 billion) in 2021 and is growing even faster at a CAGR of over 4.6%.[59]

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 100 kg Cr(VI) per year per site using multiple chromates, with tonnages for individual sites as follows:

- 0 to 120 kg chromium trioxide used per year, translating to a maximum of 62 kg Cr(VI);
- 0 to 250 kg sodium dichromate used per year, translating to a maximum of 100 kg Cr(VI);

The majority of sites use sodium dichromate, but some sites may use both chromates.

4.3.2 Consultation for the SEA

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

Based on the maximums found in the CSR work and the upper bound figures quoted in the SEA responses the upper bound tonnages of the chromates used by the estimated 70 EEA and 20 UK sites

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[58] https://www.bloomberg.com/news/articles/2022-09-25/defence-spending-to-increase-by-at-least-52bn-in-response-to-russian-aggression or https://rusi.org/explore-our-research/publications/occasional-papers/famine-feast-implications-3-uk-defence-budget

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

for the passivation of stainless steel. These are upper bound figures for 2024 (assuming no decline from 2022 levels):

- EEA tonnage for 70 sites in ADCR supply chain: up to 8.4 tonnes per annum CT and up to 17.5 tonnes per annum SD;
- UK tonnage for 20 sites in ADCR supply chain: up to 2.4 tonnes per annum CT and up to 5 tonnes per annum SD.

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

4.3.3 Article 66 notifications data

Under Article 66 of REACH, downstream users covered by an authorisation up their supply chain must notify ECHA of their use. As of 31 December 2021, ECHA had received 382 notifications relating to the REACH Authorisations listed above covering 508 sites across the EU-27 (and Norway).

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

The distribution of notifications by substance and authorisation is summarised below[60].

Table 4-6: 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

Since there are more sites than notifications, it is assumed that some notifications cover more than one site. 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 cover many more processes than passivation of stainless steel. Indeed, only five of the notifications received by ECHA include specific reference to passivation on stainless steel. The associated quantities are low – generally less than 0.1 tonne per year. This confirms that the figures given above reflect upper bound estimates.

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

4.3.4 Projected future use of the chromates

4.3.4.1 Introduction

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

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

4.3.4.2 OEMs

Three of the OEMs (covering multiple sites) stated that their use of chromates had remained steady since 2014 as they worked to qualify, validate and certify alternatives; in contrast, one reported a 40% decrease at 75% of its sites. One OEM noted that their chromate consumption had only increased due to an increase in production.

Short term, all OEMs state that consumption will stay the same up to 2024 but, by 2032, most OEMs expect to there to be decreases in consumption as substitutes are certified and implemented throughout their supply chains; use should therefore cease by 2036. However, substitution by the value chain will not likely occur in unison and therefore full substitution along the supply chain will take longer. As these companies do not account for the total volumes of the chromates used in passivation, it is not possible to give an overall percentage reduction in volumes consumed on a year-by-year basis across the market.

Two of the OEMs already carry out passivation of stainless steel using non-chromate based alternatives, where these are technically feasible under current certifications.

4.3.4.3 Design-to-build

With respect to COVID, Four DtB companies indicated that although utilisation rates fell during the pandemic, with two expecting activity levels and chromates usage to return to normal and two expecting usage to remain between 10-40% below 2019 levels. Utilisation rates were commonly between 75% and 100% prior to COVID, reducing to 33% to 70% as a result of the pandemic. The other three companies indicated there had been no significant change in usage during the period from 2014 to 2021.

By 2030, three of the DtB companies are expecting to see decreases in chromates consumption of between 30 - 40%, with further reductions up to around 60% after 2030. In contrast, the other companies either could not predict how use might change or indicated that consumption could increase by up to 10% (compared to 2021 levels) as production levels return to normal.

Importantly, four of the seven companies also undertake passivation of stainless steel using non-chromate alternatives, where this is technically feasible under current certifications.

4.3.4.4 Build-to-Print

Of 16 BtP companies providing detailed information for their sites, seven indicated that they have seen decreases in chromate usage over the last seven years, by between 10% and 60%. The remaining nine companies have not seen significant changes in their levels of consumption, as the use of substitutes to CT and SD in the passivation of stainless steel have not yet been certified by the design owners that are their customers.

In terms of expected future usage, nine of the BtP companies either did not answer or did not know how their usage of chromates was likely to change between 2022 and 2030 (and beyond). Five companies indicated that chromate use was expected to decrease, however the majority were unclear on the extent of the decrease. Three companies indicated they were likely to see a 20-30% increase by 2024, however, they were unsure how usage would change after 2024. Four of the companies expect usage to remain steady over the short term, with decreases then occurring after 2030. All BtP companies noted that they used chromates in order to meet certification requirements.

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

4.3.4.5 MROs

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

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

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

4.3.4.6 Summary

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

- "*Products in the aviation industry are designed, manufactured and maintained for use phases of several decades. In terms of civil aircrafts, such a use phase typically comprises 30-40 years. Even if new products - placed on the market in the short / medium term - might succeed in dispensing with the use of CrO_3/Cr (VI) containing products; Products already placed on the market (or until the expiration of the current review periods) still need to be maintained and repaired by applying binding maintenance specifications (which the user is legally obliged to comply with). These specification entail - among others - processes and materials initially qualified (sometimes decades ago), which form a substantial part of the type certification.*".

- *"Such a long review period is required to allow sufficient time to develop alternatives to CT in passivation of stainless steel and to test them before qualification, certification and implementation.".*

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

The companies acting as design owners (OEMs and DtB) indicated that they expect on-going reductions in consumption of CT and SD for passivation purposes over the period from 2024 to 2031. If substitution proceeds as currently planned, use should cease by 2036 assuming that there are no setbacks. It is important to note that this gradual phase-out in usage will also impact on use by DtBs not acting as design owners, BtPs and MROs.

Industrial implementation will usually follow a stepwise approach to minimise 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 two chromates covered by this combined AoA/SEA were included into Annex XIV of Regulation (EC) No 1907/2006 due to their intrinsic properties (mutagenic, carcinogenic, toxic for reproduction; depending on the chromate).

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

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

The hazard evaluation follows recommendations given by RAC (ECHA, 2015)[61]:

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

4.4.1.2 Overview of exposure scenarios

All A&D sites that perform passivation of stainless steel within the ADCR supply chains are specialised industrial sites being active in the EEA or the UK. They have rigorous internal, health, safety and environment (HSE) organisational plans. A mix of technical, organisational and personal-protection-based and organisational measures are in place to reduce workplace exposures. The sites adhere to best practices to reduce workplace exposures and environmental emissions to as low as technically and practically feasible and use automated processes to the maximum extent possible. The feasibility and the degree of automation can vary between different sites and depend, among other factors, on the size of the site and the frequency of passivation activities. See the CSR for further details of measures in place.

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

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

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

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

Table 4-7: Overview of exposure scenarios and their contributing scenarios

ES number	ES number	ES number
ES1-IW1	Passivation of stainless steel – use at industrial site	
Environmental contributing scenario(s)		

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

Table 4-7: Overview of exposure scenarios and their contributing scenarios

ES number	ES number	ES number
ECS 1	Passivation of stainless steel – 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 5, PROC 9, PROC 10, 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 passivation. The calculated exposure levels and associated excess cancer risks are presented below (for further information on their derivation see the CSR).

4.4.2.1 Worker assessment

Excess lifetime cancer risks

The findings of the CSR with respect to worker exposures, are summarised in **Table 4-8**, which presents the excess lung cancer risks to workers involved in passivation treatment related activities. The risks are calculated using a combination of measured inhalation data and modelling for different SEGs (Similar Exposure Groups). The SEGs include:

- WCS1: Line operators for passivation of stainless steel are usually involved in numerous activities related to the passivation process. Most of their working time they spend in a hall where the passivation tanks are located and where the immersion process takes place, either on activities with direct or indirect Cr(VI) exposure;
- WCS2: Storage area workers who decant liquids and measure solids, clean containers, handle solid wastes, undertake bath make-up and cleaning of baths as part of bath renewal;
- WCS3: Laboratory technicians may be involved in activities related to passivation with potential for Cr(VI)-exposure, such as undertaking sampling laboratory analysis of treatment bath solutions;
- WCS4: Maintenance and/or cleaning workers who maintain pipes, pumps, sensors, scrubbers, electrical systems installed in treatment baths, and LEV systems; and
- WCS5: Incidentally exposed workers, who include those workers spending part of their time in the work area where treatment baths are located but do not carry out the tasks with direct exposure themselves.

Table 4-8 sets out the excess lifetime cancer risk for workers involved in each of the above tasks.

Table 4-8: Excess lifetime cancer risk by SEG

#	SEG	Number of workers and number of shifts	Excess lifetime lung cancer risk [1/υg/m^3]
WCS1	Line operators	1-2 per shift, on the line for 50% of shift; 4 a day on average	1.38E-03
WCS2	Storage area workers	1-2 per shift; 4 a day on average; up to 3 shifts	6.96E-05
WCS3	Laboratory technicians	1-4 per site	NA
WCS4	Maintenance and/or cleaning workers	1-7 per shift; up to 3 shifts; 3 a day on average	3.84E-04
WCS5	Incidentally exposed workers	0-5 per shift; up to 3 shifts; average 6 per site	1.00E-03

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

4.4.2.2 Humans via the environment

Excess lifetime cancer risks

The assessment of risks for humans via the environment presented in the CSR has been carried out for the general population at the local level only. No regional assessment has been carried out as it can be assumed that Cr(VI) from any source will be reduced to Cr(III) in most environmental situations and therefore the effects of Cr(VI) as such are likely to be limited to the area around the source, as described in the EU Risk Assessment Report for chromates (ECB, 2005). The approach to not perform a regional assessment for human Cr(VI) exposure via the environment as part of AfAs for chromate uses was also supported in compiled RAC and SEAC (Socio-economic Analysis Committee) opinions, as described for example in the Opinion on an Application for Authorisation for Use of sodium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites and sealings of anodic films (ID 0043-02). This reference states that regional exposure of the general population is not considered relevant by RAC .

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

Table 4-9: Excess lifetime cancer risk estimates for humans via the environment (general population, local assessment)

Inhalation			Oral			Combined
Local Cr(VI) PEC in air [µg/m3]	**Excess lung cancer risk [1/(µg/m3)] a**	**Inhalation risk**	**Oral exposure [µg Cr(VI)/kg x d]**	**Excess cancer risk for tumours of the small intestine [1/(µg/kg bw/day)] b**	**Oral risk**	**Combined risk**
3.84E-05	2.90E-02	1.11E-06	3.02E-05	8.00E-04	2.42E-08	1.12E-06

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

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

4.4.3 Populations at risk

4.4.3.1 Worker assessment

Numbers of workers exposed based on Article 66 data

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

Taking a simple total of the figures for the number of staff exposed would result in an over-estimate given that some of the Authorisations cover multiple types of surface treatment. These suggest that around 1,200 staff across the EEA are covered by Article 66 notifications are exposed during passivation activities.

No similar data are publicly available for the UK.

Table 4-10: Number of workers exposed - Article 66 Notifications data

Substance	Authorisation number	Use(s)	Staff Exposed across all uses
Chromium trioxide	REACH/20/18/14 to REACH/20/18/20	Passivation of non-Al metallic coatings, Passivation of stainless steel, slurry coating, chemical conversion coating, anodising, anodise sealing, pre-treatment, chromate rinsing, inorganic finish stripping	1107

Table 4-10: Number of workers exposed - Article 66 Notifications data			
Substance	**Authorisation number**	**Use(s)**	**Staff Exposed across all uses**
Sodium dichromate	REACH/20/4/1	Passivation of non-Al metallic coatings, Passivation of stainless steel, Chemical conversion coating, Anodise sealing, Pre-treatments, inorganic finish stripping	51
	REACH/20/5/3 and REACH/20/5/5	Passivation of non-Al metallic coatings, Passivation of stainless steel, Chemical conversion coating, Anodise sealing, Pre-treatments, inorganic finish stripping	77

Number of workers based on SEA questionnaire data

Responses to the SEA questionnaire indicated that 435 workers (full time equivalent) are directly involved in passivation of stainless steel across the 58 sites for which data were provided. This is broken down in **Table 4-11** below by role in the supply chain, and as extrapolated out to the 70 EEA and 20 UK sites.

Table 4-11: Employees linked to chromate-based passivation activities across all EEA and UK sites					
Number of workers at sites	**Number of sites EEA**	**Number of sites UK**	**No of employees EEA**	**No of employees UK**	**Total**
Number of workers 58 sites involved in passivation of stainless steel					
Build-to-print	16	13	31	41	72
Build to design	5	2	12	8	20
MRO only	7	2	205	29	234
ADCR Members	12	1	101	8	109
Total 58 sites	40	18	349	86	435
Number of workers at 70 EEA sites and 20 UK sites involved in passivation of stainless steel					
Build-to-print	30	13	58	41	99
Build to design	12	3	29	12	41
MRO only	12	2	351	29	380
ADCR Members	16	2	135	16	151
Total 90 sites	70	20	573	98	671

In total, this translates to a potential 671 exposed workers across the 70 EEA sites and 98 across the 20 UK sites, or between two to nine per site. These figures are lower than the CSR assumptions on the number of workers exposed but are consistent with the Article 66 notifications if it is assumed that these workers may also undertake other chromate-based surface treatments.

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

Table 4-12: Number of employees undertaking passivation across the EEA and UK

Worker Contributing Scenarios		Average No. Exposed from CSR	EEA sites	UK sites
WCS1	Line operators	4	280	80
WCS2	Storage area workers	4	280	80
WCS3	Laboratory technicians	2	140	40
WCS4	Maintenance and/or cleaning workers	3	210	60
WCS5	Incidentally exposed workers	6	420	120
Total		**19**	**1,330**	**380**

4.4.3.2 Humans via the Environment

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

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

A 1000m radius is adopted here to estimate the exposed population as, for most sites, the HvE results are driven by emissions to air. Oral exposure risks are typically much lower and are only higher for one of the seven passivation sites used as the basis for the CSR; in these cases, inhalation risks were lower than average. As a result, adopting the EUSES default assumption related to the capacity of local sewage treatment plants would over-estimate the number of inhabitants that may be exposed due to emissions from each site.

The resulting estimates of the number of people exposed within the general population are given in **Table 4-13** for the EEA and UK. The allocation of sites is based on information collected from the SEA questionnaires and from ADCR members on the location of their supply chains. The estimated total number of humans exposed via the environment in the EEA is around 36,400, with the UK figure being under 27,000 (with the UK figure appearing disproportionately high due to its high population density).

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

Table 4-13: General public (local assessment) exposed population from passivation			
Countries with DUs	No. Sites per country	Population density per km^2	Exposed local population within 1000m radius
France	9	118	3336
Germany	10	232	7288
Italy	10	200	6283
Spain	6	92	1734
Poland	6	123	2318
Czech Republic	5	135	2121
Sweden	5	23	361
Finland	5	16	251
Netherlands	4	421	5290
Belgium	5	376	5906
Denmark	1	135	424
Norway	1	14	44
Austria	3	109	1027
Total EEA	**70**		**36,386**
UK	**20**	**424**	**26,641**

4.4.4 Residual health risks

4.4.4.1 Introduction

Under the Applied-for-Use Scenario, use of chromates in passivation will continue up to the end of the current review period for a total of 12 years.

In December 2013, the Risk Assessment Committee (RAC) agreed lifetime (i.e. for 40 years and 70 years of exposure) mortality risk estimates associated with carcinogenicity for workers and humans via the environment exposed to Cr(VI) substances[62]. It assumes a linear relationship for both lung and intestinal cancer.

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

4.4.4.2 Morbidity vs mortality

Excess cancer cases need to be split between fatal and nonfatal ones. To this end, estimates of fatality and survival rates associated with lung and colorectum[63] cancer cases were derived from the Cancer Today database, see **Table 4-14** below.

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[62] 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).

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

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

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

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

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

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

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

In a similar fashion, the figures from Cancer Today reported in **Table 4-14** above are applied to the estimates to calculate the total number of additional fatal and non-fatal intestinal cancer cases[64].

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

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

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

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

Total excess cancer risk cases are based on the excess lifetime risk estimates derived in the CSR for the different worker contributing scenarios (WCS as presented in **Table 4-8**). These risk estimates reflect the additional safety measures that have been implemented due to the conditions placed on continued use by the initial authorisations.. The number of excess cancer cases is calculated by multiplying the number of workers assumed to be exposed in each task by the value of the excess cancer risk given above adjusted for the requested review periods, i.e. over 12 years. This value is then multiplied by the number of workers exposed in each WCS to calculate the total excess cancer cases arising from the continued use of chromates in passivation. **Table 4-15** and **Table 4-16** provide a summary of the results across all WCS for EEA and UK workers.

Note that WCS3 related to laboratory technicians is not considered here as the handling of substances in laboratories for quality control purposes under controlled conditions and in amounts below 1 tonne per annum falls under the REACH Art. 56(3) exemption[65]. Furthermore, the sampling activities that may be carried out by lab technicians are covered under other WCS.

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

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

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

WCS	Number of persons exposed	LUNG CANCER - Excess lifetime cancer risk	Excess number of lifetime cancer cases	LUNG CANCER - Number of excess lifetime fatal cancer cases	LUNG CANCER - Number of excess lifetime non-fatal cancer cases
WCS1	280	1.38E-03	**0.39**	**0.31**	**0.08**
WCS2	280	6.96E-05	**0.02**	**0.02**	**0.00**
WCS4	210	3.84E-04	**0.08**	**0.06**	**0.02**
WCS5	420	1.00E-03	**0.42**	**0.33**	**0.09**
		Years - Lifetime	**40.00**	**0.72**	**0.19**
		Years - Review period	**12.00**	**0.21**	**0.06**
		Years - Annual	**1.00**	**0.02**	**0.00**

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

WCS	Number of persons exposed	LUNG CANCER - Excess lifetime cancer risk	Excess number of lifetime cancer cases	LUNG CANCER - Number of excess lifetime fatal cancer cases	LUNG CANCER - Number of excess lifetime non-fatal cancer cases
WCS1	80	1.38E-03	**0.11**	**0.09**	**0.02**
WCS2	80	6.96E-05	**0.01**	**0.00**	**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**	**0.20**	**0.05**
		Years - Review period	**12.00**	**0.06**	**0.02**
		Years - Annual	**1.00**	**0.01**	**0.00**

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

The total number of people exposed as humans via the environment as given in **Table 4-13** 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 4-17**. The basis for estimating the number of people exposed per country is the percentages of Article 66 notifications made to ECHA per country, as described in Section 4.2.

Table 4-17: Number of people in the general public exposed (local assessment) across the EEA and UK

Countries with DUs	No. Sites per country	Population Density per km2	Exposed local population	Combined excess lifetime cancer risk	Excess number of lifetime cancer cases	Number of excess lifetime fatal cancer cases	Number of excess lifetime non-fatal cancer cases
France	9	118	3336	1.86E-06	6.21E-03	4.90E-03	1.30E-03
Germany	10	232	7288	1.86E-06	1.36E-02	1.07E-02	2.85E-03
Italy	10	200	6283	1.86E-06	1.17E-02	9.23E-03	2.45E-03
Spain	6	92	1734	1.86E-06	3.23E-03	2.55E-03	6.77E-04
Poland	6	123	2318	1.86E-06	4.31E-03	3.41E-03	9.06E-04
Czech Republic	5	135	2121	1.86E-06	3.94E-03	3.12E-03	8.28E-04
Sweden	5	23	361	1.86E-06	6.72E-04	5.31E-04	1.41E-04
Finland	5	16	251	1.86E-06	4.67E-04	3.69E-04	9.82E-05
Netherlands	4	421	5290	1.86E-06	9.84E-03	7.77E-03	2.07E-03
Belgium	5	376	5906	1.86E-06	1.10E-02	8.68E-03	2.31E-03
Denmark	1	135	424	1.86E-06	7.89E-04	6.23E-04	1.66E-04
Norway	1	14	44	1.86E-06	8.18E-05	6.46E-05	1.72E-05
Austria	3	109	1027	1.86E-06	1.91E-03	1.51E-03	4.01E-04
Total	**70**		**36386**	**1.86E-06**	**0.07**	**5.35E-02**	**1.42E-02**
			Years – Lifetime cases		**70.00**	**5.35E-02**	**7.71E-03**
			Years - Review period		**12.00**	**9.17E-03**	**2.44E-03**
			Years - Annual		**1.00**	**7.64E-04**	**2.03E-04**
UK	**20**	**424**	**26641**	**1.86E-06**	**4.96E-02**	**3.91E-02**	**1.04E-02**
			Years – Lifetime cases		**70.00**	**3.91E-02**	**1.04E-02**
			Years - Review period		**12.00**	**6.71E-03**	**1.78E-03**
			Years - Annual		**1.00**	**5.59E-04**	**1.49E-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 time-frame that goes from 2024 (inclusive of the end of 2024) to the end of 2036 (i.e. a 12 year review period) has been adopted and a 4% discount rate has been employed for calculating net present values[66]. It has been assumed that the levels of exposure to Cr(VI) for workers and members of the general population remains constant throughout the length of the review period, even though this is a very conservative assumption. In fact, downstream users will gradually reduce the amount of Cr(VI) consumed as the transition to the alternative proceeds. Combined with the investment in risk management measures put in place by the sites to protect workers as a result of the conditions placed on continued use by the initial authorisations, this should ensure that excess lifetime cancer risks reduce over the review period.

The economic valuation of the health impacts takes into account two important welfare components, the costs associated with mortality and morbidity. The basis of our calculations is the study led by the Charles University in Prague[67] 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[68]. 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[69]. This suggests that the aforementioned figures should be multiplied by a factor of 1.12. Thus, the following values are employed in the analysis below:

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

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

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

[67] 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.

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

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

Table 4-18: Alternative estimates of medical treatment costs			
Study	**Year for prices**	**Average direct costs in original units (per annum)**	**Direct costs in € 2021**
Lung cancer[70]			
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)[71]			
Luo et al (2010)	2000 (assumed)	US$29,196	€36,230
Lang et al (2009)	2006	US$28,626	€31,740
York Health Economics Consortium (2007)	2004	£8,808	€12,180
York Health Economics Consortium (2007)	2004	£12,037	€16,410

The average cost across the four lung cancer studies is €17,314 per annum (2021 prices). The average cost figures reported for intestinal cancer are based on figures produced for colon, rectal and colorectal cancer in the US and UK. The US figures are high compared to the UK data; as a result, the average across the two UK studies is taken here, with this being around €14,853 per case in 2021 prices, taking into account price inflation.

These average medical costs are annual figures and apply to survivors over the period of time that they continue to be treated. With respect to lung cancer morbidity cases, we have taken a percentage survival of 32% after one year since diagnosis, 10% after 5 years, 5% after 10 years[72]. With respect to intestinal cancer morbidity cases, we have taken a percentage survival of 76% after one year since diagnosis, 59% after five years, 57% after 10 years. Based on these time periods, the NPV of average future medical costs per lung cancer case is estimated at €30,110 in 2021 prices, using a 4% future discount rate. The NPV of average future medical costs per intestinal cancer case is estimated at €82,620 in 2021 prices. It is noted that a large percentage of people survive intestinal cancer after a period of 10 years and any stream of health care costs incurred after that is not incorporated in our calculations. However, such costs are not likely to be relevant considering that those surviving after such a long period of time can either be considered as definitely cured or probably only in need of a small degree of medical attention.

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[70] Leal, J., 2012. Lung cancer UK price tag eclipses the cost of any other cancer, presentation by Health Economics Research Centre, University of Oxford to the NCIR Cancer Conference, Wednesday, 7 November. s.l.:s.n. Braud, L. & al, 2003. Direct treatment costs for patients with lung cancer from first recurrence to death in France. Pharmacoeconomics, 21(9), pp. 671-679. Dedes, K. J. & al, 2004. Management and costs of treating lung cancer patients in a university hospital. Pharmacoeconomics, 22(7), pp. 435-444.

[71] Luo, Z. & al, 2010. Colon cancer treatment costs for Medicare and dually eligible beneficiaries. Health Care Finance Review, 31(1), pp. 33-50. Lang, K. & al, 2009. Lifetime and Treatment-Phase Costs Associated with Colorectal Cancer: Evidence from SEER-Medicare Data. Clinical Gastroenterology and Hepatology, Volume 7, pp. 198-204. York Health Economics Consortium, 2007. Bowel Cancer Services: Costs and Benefits, Final Report to the Department of Health, April 2007, York: University of York.

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

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

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

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

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

Table 4-19 applies the economic value of the associated health impacts to these additional statistical cases of cancer to generate the total economic damage costs of the excess lung cancer cases. Under the Continued Use scenario, the present value costs are **€313,000 for the EEA and €90,000 for the UK**, based on the assumption that chromate-based passivation continues at the current level of use over the entire review period; this will lead to an overestimate of the impacts as the sector transitions to the alternatives over the 12 year period.

Table 4-19: Present value and annualised economic value of mortality and morbidity effects to workers (discounted over 12 years @4% per year, 20 year lag, figures rounded)

	EEA Workers		UK Workers	
	Mortality	Morbidity	Mortality	Morbidity
Total number of lung cancer cases	2.15E-01	5.71E-02	6.14E-02	1.63E-02
Annual number of lung cancer cases	1.79E-02	4.76E-03	5.12E-03	1.36E-03
Present Value (PV, 2024)	€ 304,010	€ 9,483	€ 86,860	€ 2,709
Total PV costs	**€ 313,493**		**€ 89,569**	
Total annualised cost	**€ 72,373**		**€ 20,678**	

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

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

Table 4-20 applies the economic value of the associated health impacts to the additional statistical cases of cancer for the general population (humans via the environment) to generate the total economic damage costs of the excess cancer cases. Under the Continued Use scenario, the present value costs are roughly **€13,400 for the EEA and €10,000 for the UK**, based on the assumption that passivation continues over the entire review period at 2024 tonnages; as indicated above, this reflects an overestimate of the levels of exposures as use declines with a transition to the alternatives over the 12 year period.

Table 4-20: Present value and annualised economic value of mortality and morbidity effects to the general population, local assessment (discounted over 12 years @4% per year, 20 year lag, figures rounded)				
	EEA General Population		UK General Population	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cancer cases	9.17E-03	1.78E-03	6.71E-03	1.78E-03
Annual number of cancer cases	7.64E-04	2.03E-04	5.59E-04	1.49E-04
Present Value (PV, 2024)	€ 12,969	€ 442	€ 9,496	€ 324
Total PV costs	**€ 13,411**		**€ 9,819**	
Total annualised cost	**€ 3,096**		**€ 2,267**	

***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

Passivation of stainless steel with chromates results in no hexavalent chromium being present on the end components or products. As a result, workers in downstream life cycle stages are not exposed to Cr(VI) through passivation of stainless steel.

4.4.7 Environmental impacts

In accordance with RAC's conclusions (see e.g., the RAC/SEAC *"Opinion on an Application for Authorisation for Use of sodium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites and sealings of anodic films"*[73]), no regional assessment has been carried out as it can be assumed that Cr(VI) from any source will be reduced to Cr(III) in most environmental situations and therefore the effects of Cr(VI) as such are likely to be limited to the area around the source, as described in the EU Risk Assessment Report for chromates (see the CSR for further details). Therefore, combined exposures from various sources on the regional scale are not considered further.

4.4.8 Summary of human health impacts

Table 4-21 provides a summary of the economic value of the human health impacts across the worker and local populations. When considering these figures, it should be remembered that they relate to use of the chromates in passivation activities across the sector at an estimated 70 EEA sites and 20 UK sites covered by this review report.

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[73] RAC/SEAC, consolidated version, 2016; https://echa.europa.eu/documents/10162/658d42f4-93ac-b472-c721-ad5f0c22823c

Table 4-21: Combined assessment of health impacts to workers and general population value of mortality and morbidity effects to workers (discounted over 12 years @4% per year,20 year lag, figures rounded)

	EEA		UK	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cancer cases	2.24E-01	5.89E-02	6.81E-02	1.81E-02
Annual number of cancer cases	1.87E-02	4.96E-03	5.67E-03	1.51E-03
Present Value (PV, 2024)	3.17E+05	9.92E+03	9.64E+04	3.03E+03
Total PV costs	**€ 326,904**		**€ 99,389**	
Total annualised cost	**€ 75,469**		**€ 22,945**	

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

5 Socio-Economic Analysis of Non-Use

5.1 The Non Use Scenario

5.1.1 Summary of consequences of non-use

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

Additionally, essential attributes are provided by chromate based passivation treatments, which must be considered when assessing alternatives. This includes chemical resistance and fatigue strength, which, alongside the key functionalities, provide safety and reliability of components.

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

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

⇩

Due to certification and airworthiness requirements, downstream users would be forced to undertake chromate based passivation activities outside the EEA/UK or shift to suppliers outside of the EEA/UK

⇩

OEMs would shift manufacturing outside the EEA/UK due to the need for passivation 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 passivation of stainless steel only (and especially so for touch-up repairs)

⇩

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

⇩

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

⇩

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

⇩

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

⇩

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

⇩

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

As indicated in the above diagram, because passivation must be applied promptly to protect against corrosion and, depending on the follow-on process to ensure the next process step is successful, there would be significant subsequent effects for other parts of the aerospace and defence supply chains. The most likely outcome would be the relocation of large portion of the value chain (production, repair and maintenance) outside of the EEA/UK, as summarised below.

5.1.2 Identification of plausible non-use scenarios

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

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

Moving to a poorer performing alternative was ruled out based on the unacceptability of such an option to the OEMs due to safety and airworthiness requirements, as detailed further below. Follow-up questions were asked to establish why producing components overseas and shipping them back to the EEA/UK was not feasible, with this then ruled out based on the answers received regarding the logistic difficulties and economic infeasibility. These were considered to be non-plausible scenarios and are discussed in Section 5.1.3 below.

Table 5-1 below presents the choices presented in the SEA questionnaire and a count of the number of companies selecting each (37 out of the 39 companies in total provided responses, covering the 49 sites).

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

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

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

	OEM	Build-to-print only	Design-to-build only	MROs – only
/The decision is up to our customer		10	1	1
We may have to cease all operations as the company will no longer be viable	1	3	1	3
We will focus on other aerospace uses or on non-A&D uses		3	1	
We will shift our work outside the EEA/UK	2	2	1	
We will stop undertaking use of the chromate(s) until we have certified alternative	1	3	3	1
Number of responses (companies)	4	21*	7	5

*One response left blank and one responded for EEA and UK sites

5.1.2.1 OEMs

In discussions, the OEMs all stressed that the aim is the replacement of the use of the chromates in passivation of stainless steel to an alternative that enables the components to be qualified and certified alternative. In some cases, a qualified alternative has been identified, but more time is required to implement the alternative across the entire supply chain (particularly where a significant number of suppliers may be involved in passivation of stainless steel of similar components, e.g. bolts and fasteners).

With respect to the plausibility of the different non-use scenarios identified above, the following are clear from consultation with the OEMs across the 13 sites for which data was provided in the SEA questionnaire responses:

- **We will shift our work involving Chromates to another Country outside the EEA.** This is the most plausible scenario for two of the OEMs directly involved in passivation of stainless steel. Given the reliance on the use of chromate-based passivation of stainless steel in supply chains, it is also the most likely response for those OEMs companies who rely on suppliers carrying out passivation of stainless steel. This would be accompanied by losses in turnover of between 30 – 100% at the sites operated by these OEMs. The ability of one of these OEMs to shift its manufacturing relevant to passivation of stainless steel outside the EEA/UK may be restricted, however, as it manufactures final products for the defence sector. Additionally, due to the susceptibility of freshly-machined stainless steel to corrosion, shifting the passivation process will in many cases result in shifting the preceding machining processes.

- **We will stop using the chromates until we have certified alternatives:** Some of the OEMs will be able to move to substitutes within a seven year period, assuming that their current progression of alternatives does not face any set-backs in the final qualification, validation and certification stages. For others, substitution and especially the industrialisation phase of moving to alternatives will not be completed within a seven year time-frame across all components. The current “road map” for substitution and industrialisation cannot be sped up, and some margin is needed to allow for any delays or likely failures. Thus, under the non-use scenario, the potential for seven year production stoppages would not be economically feasible for the relevant sites, with turnover losses of between 30 - 100% identified.

- **We may have to cease all operations as the Company will no longer be viable.** If shifting work to countries outside the EEA is unacceptable due to the costs or timeframe involved in setting up the required manufacturing sites and supporting infrastructure, then a cessation of all operations may be the ultimate outcome for at least one of the OEMs with multiple sites in both the EEA and UK.

As a result, the OEMs indicated that if the viable alternatives are not qualified and implemented (or able to be implemented by the end of the current review period (i.e. September 2024) for chromium trioxide and sodium dichromate, then their **most plausible response under the non-use scenario would be to relocate all or some of their manufacturing activities outside of the EEA or UK** (it may also not be realistic given the efforts and expenditure involved in such relocation, which may be more likely to result in the complete closure of OEMs or divisions within them, with consequent impacts for the EEA/UK economies).

The extent to which the OEMs would move all or only some of their manufacturing outside the EEA/UK depends on the integrated "system" of activities undertaken at individual sites. Passivation of stainless steel is only carried out across a subset of sites, but it may be critical to certain divisions and to the operations of suppliers to those sites. As noted in Section 2, the larger ADCR members may be supported by up to seven to 10 suppliers undertaking passivation of stainless steel regionally (with this figure used in generating the number of sites in total assumed to be carrying out passivation in the EEA in particular). In terms of impacts on individual companies, the estimated loss of production and turnover ranges from around 30% to 100% of current levels at individual sites, with production expected to stop completely at sites where passivation is a core activity. As noted above, these impacts would be experienced by sites involved in civil aviation and/or defence manufacturing.

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

Particular difficulties would be faced by companies in the defence sector. Possibilities for relocating some activities outside the EEA/UK are limited due to the difficulties related to achieving specific customer requirements, national security considerations, work share agreements, and financial restrictions. As a result, it is likely that there would need to be requests for "defence exemptions" so that those activities that contractually have to be maintained in their current location could continue within the EEA/UK.

5.1.2.2 Design-to-build

The majority of DtB companies identified that they would cease use of the chromates until they had a certified alternative for production of components. Half of these companies stated that the development, testing, qualification and certification of alternatives for production of components will be very costly and that the final products they manufacture have long lifetimes and require high costs to be re-qualified. Two companies identified that they could relocate chromate operations outside the EU.

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

Estimated turnover losses range between 15% for companies that are not as reliant on their chromate-based operations to 100% for companies that would be required to cease all operations. Three (of seven) companies stated that they would have turnover losses below 50%, with a further three indicating losses of greater than 50%, and the remaining company unable to provide an estimate.

Of note is the fact that three DtBs have identified candidate alternatives and are currently in the process of gaining qualifications and certifications. One of these is still being tested; it meets performance requirements for some components but not all components. In the other two cases, qualification and certification will not have been achieved by 2024 (potentially not by 2028) and additional time will then be required for implementation.

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).

5.1.2.3 Build-to-print

BtP companies rely on their customers to define the production methods that they must use. As a result, half of these companies responded that the impacts of the non-use scenario were uncertain for them. For the other half of companies, the most likely response under the non-use scenario varies from ceasing operations or shifting work outside of the EEA/UK to stopping only passivation and the relevant A&D activities.

One company highlighted that the effects for their company would be massive, resulting in a loss of over 55% of turnover with this potentially impacting on the viability of the company even after a significant level of redundancies. They would also have to withdraw from NADCAP, as this would no longer be financially viable. It is of note that this company carries out passivation of stainless steel using both the chromates and chromate-free alternatives, where the latter have been certified for production of components.

More generally, 12 of the 22 companies currently run chromate-free passivation processes alongside their chromate-based lines. Once an alternative is qualified, validated and certified for use in the production of components by their customers, they would therefore be able to work with them to adapt to new production requirements. Respondents noted that their priority is to help find a substitution solution, but if customers are not able to find a feasible alternative then a subset of the companies indicated that they would either cease all operations or they would be forced to move outside of the EEA to, e.g. Morocco.

Only a subset of companies was able to provide estimates for turnover losses, with these ranging from 5% (for companies where the “decision is up to our customer”), to 100% for companies that would have to cease all operations. Four (of 22) companies identified turnover losses of 80 - 100%, three identified losses from 40 - 60%, and four identified losses from 5 - 30%. Ten companies stated that they were unsure of turnover losses, and one did not respond.

5.1.2.4 MROs

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

When components enter under the services of an MRO, the required maintenance effort, including which surface treatment processes may be required, is not directly foreseeable. Very often, the level of work required only becomes clear after disassembling the component. The surface treatment steps required for any given component is dependent on its condition and can differ for each maintenance event. As a result, not every component will pass through all potential surface treatment processes. Even where they do, levels of throughput are also dependent on the size and complexity of the component - processing times can range from five minutes to several days. Within these process flows, even if passivation 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 passivation of stainless steel to the requirements set out in Maintenance Manuals may make repair and overhaul services unviable for MROs. There is no scope for them to operate outside the requirements detailed in the OEMs’ service manuals, which are based on the qualified and approved uses of substances and mixtures for passivation. Where these requirements mandate the use of chromium trioxide or sodium dichromate, then the MRO must use the chromate as instructed unless the manuals also list a qualified alternative.

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

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

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

As noted by one of the MROs:

> "*The effect of a refused authorization is enhanced due to tie-in business - business models that rely on the implementation of the upstream Cr(VI)/CrO_3 and downstream process steps. The remaining business would not be viable anymore, operations would have to be ceased*".

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

5.1.3 Non-plausible scenarios ruled out of consideration

Move to a poorer performing alternative

Moving to a poorer performing alternative would not be acceptable to the OEMs, either from a Design Organisation Approval (DOA) perspective as approved by EASA[74], MoDs and the European Space Agency (ESA), or from an engineering perspective taking airworthiness safety requirements into consideration.

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

- The highly likely risk of EASA (airworthiness authorities) and MoDs not accepting a downgrade in performance;
- Increased maintenance operations, leading to an increase in the downtime of aircraft and military equipment, increased costs of maintenance, less flying hours, etc.; and
- Increased risks to passengers, cargo operators and operators of military equipment.

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

Additionally, as discussed in Section 3, corrosion resistance (or any of the other key functionalities), cannot be considered in isolation. For example, achieving corrosion resistance should not impact the adhesion of any subsequent layer, or at least be comparable to the benchmark Cr(VI) solution. A poorer performing alternative may provide one of the key functionalities, but not provide another key functionality or attribute that leads to increased maintenance.

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

- Substantial increase in inspections – both visual checks and non-destructive evaluations, such as ultra-sound crack tests, etc. Some inspections are very difficult or hazardous to perform (e.g. inside fuselage/wing structures). All aircraft using less effective materials in repair/overhaul and/or unproven materials across the operating lifetime of an aircraft would be subject. A very conservative inspection frequency would be set to ensure safety until adequate in-service performance experience is obtained.

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[74] 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.

- Increased overhaul frequency or replacement of life-limited components. Possible early retirement of aircraft due to compromised integrity of non-replaceable structural parts.
- Whole fleets may be grounded until a repair/replacement plan is in place for the whole aircraft fleet (e.g. grounding Boeing 787 fleet due to battery problems).
- Due to similarity of technologies and aircraft uses, a fleet grounding event in such a scenario could impact many or all aircraft fleets.
- An increased number of aircraft required by each airline would be needed to compensate for inspection/overhaul downtime and early retirement.
- Defence systems would have similar impacts adversely affecting the continuity of national security.

Aerospace components are portions of major systems (fuselage; wings; engines etc.) and the components in these systems are designed to withstand similar criteria between overhauls. For example, a system is designed to achieve 25,000 cycles between overhauls and a new component is only rated for 5,000 cycles because of a Cr(VI)-free coating. By default, the entire system would now be de-rated to 5,000 cycles. Take a compressor blade that is located in the middle of an engine. If that blade can only survive for a portion of the life of an engine due to limitations of a new coating, the engine would require disassembly to access the blades. This means taking the engine off the wing, sending it to a repair centre, disassembling the engine and replacing the components at much shorter intervals than needed for the remainder of the engine, thus adding inherent inspection, maintenance, and repair costs to the manufacturers, operators, and end use customers who will also be impacted by increased out of service times.

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

Without adequate experience and proven success, and therefore possible unknown or hidden properties, the performance of a chromate-free system cannot be highly rated. Consequentially, a significant reduction to the maintenance interval would be required, potentially cut in half. For cases with no long-term experiences or correlation to in-service behaviour, which is normally the case, a further reduction to the maintenance interval would be required. This would result in investment in additional spare A&D products to be used while products being repaired are out of service.

As a result, OEMs rule out moving to poorer performing alternative as a plausible scenario, as the risks are unacceptable. The primary objective of these companies is to move to an alternative. This objective cannot be achieved, however, without sufficient testing and flight (or other) data surrounding the use of alternatives. Without such data, the necessary approvals cannot be gained as the safety risk becomes too great, whether related to civil aviation or military aircraft. The benefits provided by passivation is crucial to the manufacture of the relevant stainless steel aircraft components in the EEA/UK; if there are no qualified alternatives certified for the use on components then such manufacturing work would cease.

Overseas production followed by maintaining EEA/UK inventories

To be competitive, companies have to keep inventory as low as possible (“just-in-time” delivery). Maintaining inventory clearly involves substantial capital costs (as elaborated below) and ties up cash.

Stockpiling is also clearly not feasible for the repair and maintenance side of the business because the main aim of repair is to make components serviceable rather than replace them by spare components (which would run counter to the sectors drive towards increased sustainability).

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

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

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

- The costs of building adequate warehouse facilities in the EEA and the UK would be prohibitive and would not be economically feasible. In the UK, an industrial warehouse without climate control (which would be required for the storage of some A&D inventory) costs around €1000 per m^2 to construct (a conservative estimate). Its assumed here that warehouses that would act as a hub for storing inventory would be around 10,000 m2 as a minimum, given the range of parts that would need to be stored. This implies a total build cost of around £10 million as a minimum, not taking into account the costs of land purchase, site preparation, design, construction, etc. which could easily add a further 25% even after taking into account any potential economies of scale in pricing due to the large size of the warehouse.[75] If such facilities are required at around 100 sites across the EEA and UK (to cover civilian and military requirements for storage of passivated and other components affected by a refused authorisation), then warehousing costs alone would lead to €1 billion in expenditure. These costs would be on top of the losses in profits that would occur from the need to subcontract manufacture to companies located outside the EEA/UK and the consequent profit losses and increased costs of shipping, etc.

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

- Existing facilities are not sized to store the amount of multi-year inventories required. Companies will need to build/invest in additional secure, high-quality warehouses to store the inventory. However, it is important to recognise that this scenario is not feasible at all for

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

many components, such as airframes, because these parts are not removed from the aircraft; these parts only allow MRO activities in-situ. Therefore, the entire aircraft would need to be transported to a non-EEA country for repair. If the plane is not airworthy, the effort and cost relating to transportation alone (e.g. from Belgium to Egypt) would be overwhelming.

- Being dependent upon inventories and non-European suppliers (and in turn vulnerable to local economic and political issues affecting non-EEA countries or the UK), and thus unable to reliably fulfil MRO activities, will lead to inevitable delays and potential cancellation of flights, fines due to longer turn-around times and aircraft on ground scenarios.

- Companies make design modifications for single components as part of their normal course of business (for reasons other than chromate substitution). In these cases, all existing inventory would need to be written off for a loss. Furthermore, companies would not be able to produce the modified components in the EEA/UK anymore (if passivation is still required). Consequently, it is clearly not possible to rely on a long-term stock of spare parts that would fit all situations.

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

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

It is not possible to estimate these impacts quantitatively due to their multi-fold nature (i.e., increased cost of land and construction for warehousing, worker costs to secure and maintain inventory, increased delays and 'aircraft on the ground,' writing-off stock) and there is no precedent to rely on, as this NUS is entirely contrary to current industry practice.

The result would be that the cost of operating in the EEA/UK would increase considerably and become economically infeasible. In a very competitive industry, this would result in a migration of the entire industry (the inter-dependency of the industry is explained below and elsewhere in the SEA) to non-EEA/UK locations. As production moves outside the EEA/UK, related activities such as R&D will also re-focus to these countries. It can also be expected that future investment in associated industries and technologies will be most efficiently located alongside these activities.

Given the above, this scenario was not considered plausible by the OEMs and MROs due to the need for components to be passivated quickly after machining. It was confirmed though that such an approach may be feasible for a small range of components for civilian aircraft and for a limited number of parts for military aircraft and equipment. However, as an overall strategy, it would not be feasible.

5.1.4 Conclusion on the most likely non-use scenario

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

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

1. EEA and UK suppliers of the chromates would be impacted by the loss of sales, with the market relocating outside the EEA/UK. In the short term at least, i.e. two to four years, this would result in a loss of revenues and profits from sales in the EEA/UK. Over the longer term, some of the market may return to the EEA/UK but it is also likely that a significant proportion will have relocated more permanently.

2. OEMs directly involved in passivation of stainless steel would move a significant proportion of their manufacturing operations outside the EEA/UK, with the consequent loss of significant levels of turnover and employment. They will be moving those manufacturing activities reliant on the use of passivation where there is no qualified alternative or where implementation across suppliers after qualification and certification have been achieved is expected to require several years after the end of the current review period. The losses to the EEA/UK would range from around 30% - 50% of manufacturing turnover for some sites, rising to 65% - 100% of manufacturing turnover at others. On average it is assumed losses at affected sites would be around 60% of manufacturing turnover, with associated losses in jobs.

3. OEMs who do not carry out passivation of stainless steel themselves may still move some of their manufacturing operations outside the EEA/UK due to the desire to have certain treatment and production activities co-located within a region (i.e. to form clusters). This would facilitate the integration of manufacturing activities and associated maintenance and repair activities. As a result, there would be losses in turnover and employment associated with these companies also relocating. An alternative option would be increasing the capacities of existing non-EEA/UK suppliers that are already qualified by OEMs.

4. As OEMs shift their own manufacturing activities outside the EEA/UK, they will have to carry out technical and industrial qualification of new suppliers or of EEA/UK suppliers moving to the new location, to ensure suppliers have the capability to deliver the stringent airworthiness and certification requirements. This would then be followed by a ramping up of production in order to meet the manufacturing rate objectives.

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

6. A significant proportion of the existing BtP companies involved in passivation of stainless steel – 80% based on SEA responses – do not supply other sectors and are reliant on the A&D sector;

furthermore, the types of products that they manufacture are specific to the aerospace sector. This applies to those who indicated they "don't know" what the most plausible scenario would be for them and those that would cease trading or move outside the EEA/UK. There will also be significant loss of turnover for those that indicated they would cease passivation until a certified alternative was available or that they would shift to other activities. Given the spread of losses reported in responses to the SEA questionnaire and interdependency of these companies with decisions made by the OEMs, it has been assumed that turnover losses across the BtP suppliers of around 50% would occur.

7. MRO sites that carry out passivation as part of their services will also be severely hit and the larger operators indicated that they will either cease trading or move operations outside the EEA, due to the need to maintain vertical integration across the surface treatment processes that they are able to carry out. On this basis, it is estimated that between 60% of turnover at affected sites would occur.

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

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

10. Taken together there would be significant economic impacts from the loss of manufacturing and maintenance to both the EEA and UK economies, together with the loss of highly skilled jobs (and potentially a highly skilled labour force) and the benefits derived from the R&D carried out by a high-tech sector.

The justification for this NUS takes into account that OEMs and DtBs will not have all components with certified alternatives which have been fully implemented across their supply chains by September 2024. Many will require a further 12 years to have fully implemented alternatives across all components/final products and EEA/UK supply chains. The regulatory requirements placed on the sector mean that unless components have certified alternatives there is no substitute which can be considered "generally available"[76].

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

The impacted operations and socio-economic impacts to industry under the non-use scenario will therefore go far beyond production of just the specific stainless steel components that require passivation. In the first box, a component reliant on passivation would be impacted. If this can no longer be produced according to type certification, then manufacture of a sub-assembly is impacted.

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[76] 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)]

This then impacts on manufacture of an assembly and places the manufacture of the entire aircraft in jeopardy. As a result, it is not possible to relocate single Cr(VI) based activities on their own in most cases, as they are an integral part in the production chain and cannot be separated from previous or following process steps.

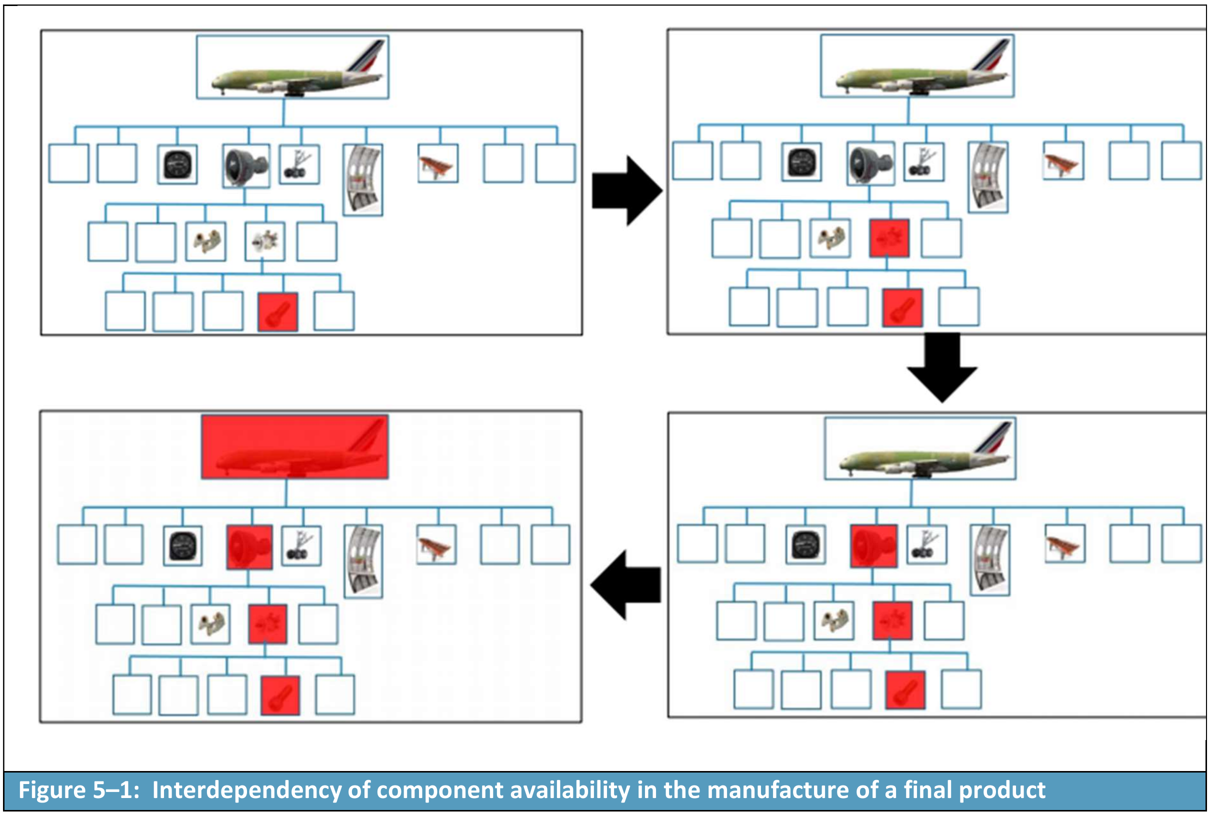

Figure 5–1: Interdependency of component availability in the manufacture of a final product

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

Finally, although this is considered the most plausible scenario, OEMs note that the obstacles that would have to be overcome may make it overly optimistic. The infrastructure of the sector is based in part around manufacturing clusters or hubs (see also **Figure 5-3**), with smaller suppliers located around the sites operated by the larger OEMs. Not all of these smaller sites, including those of critical suppliers, would be able to shift their activities outside the EEA/UK, leading to OEMs having to create entirely new supply chains outside the EEA/UK. This scenario also implies a huge economic investment would be carried out by the OEMs as well as their EEA/UK suppliers. This level of investment is unlikely to be feasible and in the meantime, the OEMs would have to cease manufacturing activities in the EEA/UK until the new industrial facilities were in place and ready to operate outside the EEA/UK.

5.2 Economic impacts associated with non-use

5.2.1 Economic impacts on applicants

Under the non-use scenario, all applicants and the formulators of the passivation products would be impacted by the loss of sales of the two chromates or of imported formulations containing the chromates for use in passivation. At the specific supplier level, these impacts may vary in their significance, as the importance of the different chromates used in passivation formulations to their revenues varies across the suppliers (as does the level of supply of chromates for use in other treatment processes).

In the short term (i.e. first 2 years under the non-use scenario), the losses will be in the order of Euro /Pound sterling tens of millions per annum to the applicants and their downstream formulators.

Over time, as consumption of the chromates reduces in line with companies' substitution plans, sales and hence revenues will continue to decrease. However, the formulators producing the chromate-based passivation formulations are also the same companies that will be providing formulations based on the alternatives. As a result, sales of alternative formulations once they are certified and implemented across value chains would be expected to offset profit losses from declining demand for the chromate-based formulations.

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

5.2.2 Economic impacts on A&D companies

5.2.2.1 Introduction

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

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

5.2.2.2 Approach to assessing economic impacts

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

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

1. **Estimates based on loss of jobs**: The first approach takes as its starting point the number of jobs that would be lost at the sites of SEA questionnaire respondents, based on their most likely response to the Non-Use Scenario. This includes loss of jobs directly linked to use of the chromates and losses in jobs at the site reliant upon the continuation of their use, i.e. jobs in related manufacturing and assembly activities. Importantly, it excludes losses in employment at local sub-contractors providing support services. The numbers of jobs lost are multiplied by the average Gross Value Added - GVA - per job (taking into 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 of these approaches provide proxy estimates of profit losses based on current levels of employment and turnover. They do not account for foregone future turnover under the continued use scenario due to the inability of the EEA/UK aerospace sector to respond to growth in the global demand for air traffic or to increased military and defence spending as a result of either a cessation in manufacturing activities or their relocating outside the EEA/UK.

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

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

The SEA questionnaire collected data on the number of employees who would lose their jobs under the NUS. This includes both those whose job directly involves use of the chromates and those whose jobs would be affected due to a cessation of production activities or due to companies moving outside the EU. The resulting figures collected for the 58 sites are presented in **Table 5-2** below.

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

- For the 58 sites providing responses to the SEA questionnaire: 8,375 jobs (around 7,029 in the EEA and 1,346 in the UK) involving workers directly involved in passivation and linked manufacturing activities across product lines or due to the cessation of MRO services activities;

- Extrapolated out to the total 90 sites expected to be carrying out passivation across the EEA: 13,950 jobs (around 11,600 in the EEA and 2,350 in the UK) due to the cessation of passivation and linked manufacturing activities across product lines or to the cessation of MRO services, including as a result of companies moving operations outside the EU.

Table 5-2: SEA survey responses and extrapolations on numbers of jobs lost under the Non-Use Scenario						
	No. Company Responses		Direct job losses – workers undertaking processes linked to passivation		Additional direct job losses – due to a cessation of manufacturing/MRO activities	
From SEA Survey	EEA	UK	EEA	UK	EEA	UK
Build to print (29 sites)	16	13	208	234	272	85
Design to build (7 sites)	5	2	363	15	327	0
MROs (9 sites)	7	2	740	12	2,474	0
OEMs (13 sites)	12	1	885	700	1,760	300
Total 58 sites	**40**	**18**	2,196	961	4,833	385
Job losses - Extrapolation of job losses under the Non-Use Scenario to the estimated 90 sites undertaking passivation treatments						
Build to print (43 sites)	23	13	390	234	510	85
Design to build (15 sites)	12	4	871	23	785	0
MROs (14 sites)	12	2	1,269	12	4,241	0
OEMs (18 sites)	23	2	1,180	1,400	2,347	600
Total sites (90)	**70**	**20**	3,710	1,669	7,883	685
Total EEA direct and indirect across 70 sites			**11,592**			
Total UK direct and indirect across 20 sites			**2,354**			

It is important to note, that these losses do not equate to 100% of the jobs at these sites, as there would not be a full cessation of activities at all sites. This can be clearly seen by the UK figures which assume no additional direct job losses. Although these figures may appear high, they should be seen within the context of the roughly 890,000 employees (2019[77]) within the European aerospace sector, taking into account the critical importance of the chromates in passivation.

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

The estimated losses in GVA equate to:

- €968 million per annum across the EEA and €218 million per annum for the UK, extrapolated out to the 70 EEA and 20 UK downstream user sites.

For comparison, turnover for the EU A&D industry is around €259 billion[78] per annum, while that for the UK A&D sector is around €57 billion (£50 billion) in 2020[79]. Thus, although these figures appear high, they are considered to be underestimates by the ADCR members (particularly the OEMs) given the potential for much larger segments of the sector to move outside the EEA /UK should chromate-based passivation 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:

- €421 million per annum across the EEA and almost €127 million per annum for the UK, extrapolated out to the 70 EEA and 20 UK downstream user sites.

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

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

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

Table 5-3: GVA losses per annum under the Non-use Scenario

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 (29 sites)	59,500*	59,500*	12.38	13.93	16.19	5.06
Design to build (7 sites)	59,500*	59,500*	21.61	0.89	19.47	0
MROs (9 sites)	85,000	85,000	62.90	1.02	210.29	0
OEMs (13 sites)	98,500	98,500	87.17	68.95	173.36	29.55
Total 58 sites			184.07	84.79	419.31	34.61
		Total EEA	**€ 603 million per annum**			
		Total UK	**€ 119 million per annum**			
GVA losses - Extrapolation to the estimated 90 sites undertaking passivation treatments						
Build to print (43 sites)	59,500*	59,500*	23.22	13.93	30.36	5.06
Design to build (15 sites)	59,500*	59,500*	51.87	1.34	46.72	-
MROs (14 sites)	85,000	85,000	107.83	1.02	360.50	-
OEMs (18 sites)	98,500	98,500	116.23	137.90	231.15	59.10
Total sites (90)			299.14	154.19	668.73	64.16
		Total EEA	**€ 968 million per annum**			
		Total UK	**€ 218 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 (29 sites)	28.6	19.0	18.7	12.4	9.9	6.6
Design to build (7 sites)	41.1	0.9	26.8	0.6	14.3	0.3
MROs (9 sites)	273.2	1.0	181.3	0.7	91.9	0.3
OEMs (13 sites)	260.5	98.5	186.7	70.6	73.8	27.9
Total 58 sites	**603.4**	**119.4**	**413.5**	**84.3**	**189.9**	**35.1**
Operating surplus losses - Extrapolation to the estimated 70 EEA and 20 UK sites undertaking passivation treatments						
Build to print (43 sites)	53.6	19.0	35.0	12.4	18.6	6.6
Design to build (15 sites)	98.6	1.3	64.3	0.9	34.2	0.5
MROs (14 sites)	468.3	1.0	310.7	0.7	157.6	0.3
OEMs (18 sites)	347.4	197.0	137.0	77.7	210.3	119.3
Total sites (90)	**967.9**	**218.4**	**547.1**	**91.7**	**420.8**	**126.7**

*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 that a refused authorisation would have on turnover/revenues. Fewer companies responded to this question, although the responses provided by the OEMs (as the end customer) and MROs enable estimates of the likely percentages of turnover lost by role to be developed. These estimates take into account the number of companies indicating that they also carry out activities other than chromate-based passivation for the A&D sector, as well as surface treatment and other processes for other sectors. They also account for potential loss in turnover from subsequent manufacturing and assembly activities.

Estimates of lost revenues per site are based on Eurostat data by NACE code with weighted averages used for BtP and DtB companies, and NACE code specific data for OEMs and MROs. Note that the weighted averages exclude micro-enterprises as few suppliers within the sector will fall into this size category. Gross operating surplus losses are then calculated by applying GOS rate data for the different NACE codes from Eurostat for 2019. The resulting losses are given in **Table 5-5**.

Table 5-5: Turnover and GOS losses under the Non-Use Scenario – (avg. 10.6% losses across all roles)

	Turnover lost per annum € millions		GOS losses per annum € millions per annum	
	EEA	UK	EEA	UK
Build to print (29 sites)	547	444	71	57
Design to build (7 sites)	137	55	18	7
MROs (9 sites)	300	86	25	7
OEMs (13 sites)	8,745	729	918	77
Total 58 sites	9,728	1,313	1,032	148
Extrapolation of turnover and GOS losses to the estimated 90 sites undertaking passivation treatments				
Build to print (43 sites)	1,025	444	132	57
Design to build (15 sites)	328	82	42	11
MROs (14 sites)	514	86	43	7
OEMs (18 sites)	11,661	1,458	1,224	153
Total sites (90)	13,527	2,069	1,442	228

*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 chromate-based passivation to both of these sets of companies.

- GVA based approach estimates of lost operating surplus:
  - Losses of €421 million per annum for the EEA
  - Losses of €127 million per annum for the UK

- Turnover based approach of lost operating surplus:
  - Losses of €1,442 million per annum for the EEA
  - Losses of €228 million per annum for the UK

These two sets of figures are used in this SEA to provide lower and upper bound estimates of losses in producer surplus, with the ratios between the two sets of estimates for the different roles shown in **Table 5-6**. It is important to note that these losses apply to commercial enterprises only. No data was provided by any of the military organisations reliant upon the continued use of chromate-based passivation which could be used in this analysis. These organisations simply stated that they would have to cease undertaking MRO related activities in their home country, resulting in severe impacts on their military forces.

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

	Total job losses		% Turnover lost		Ratio of lost profits based on turnover to lost operating surplus based on jobs (Based on €billions lost)	
	EEA	UK	EEA	UK	EEA	UK
Build to print (43 sites)	480	319	50%	50%	7.12	8.70
Design to build (15 sites)	690	15	40%	40%	1.24	22.78
MROs (14 sites)	3,214	12	60%	60%	0.27	20.95
OEMs (18 sites)	2,645	1,000	60%	60%	5.82	1.28
Total sites (90)	7,029	1,346	€13.5 billion	€2 billion	3.43	1.80

5.2.2.6 Offsetting profit losses and impacts on rival firms

The losses in operating surplus given above would result not only from a cessation of manufacturing activities, but also from the premature retirement of existing capital equipment. Some of this capital equipment would be replaced in any event as part of substitution, over the next four to 12 years, with any such investment in new equipment would be focused on facilitating substitution (while the capital equipment associated with the continued use of the chromates over the next seven to 12 years would not be expected to be replaced).

As there are no suitable alternatives which are generally available, following SEAC's latest guidance, consideration has been given to the need to offset the profit losses for downstream users against the potential resale or scrappage value of the sector's tangible EEA and UK assets. However, given the potential scale of the impacts of a refused authorisation for the sector as a whole, any possible market for redundant equipment is likely to be overwhelmed by the number of sites ceasing activities, including related processes. As a result, it is not possible to estimate the potential scrappage value of equipment (e.g. immersion baths), especially as its current use for chromate-based treatments may further reduce its value.

Because this is a sectoral application and the ability to shift to alternatives is driven by qualification and validation by OEMs and obtaining certification approval by airworthiness authorities, the issue of potential losses incurred by rival firms undertaking passivation using alternatives is not relevant. The OEMs determine whether or not there are alternatives that can be used, not individual downstream users. Furthermore, as previously indicated, the ADCR is a sectoral consortium and downstream user members include competitors, which may also act as suppliers to each other, while the larger companies share many of the same BtP and DtB suppliers (an estimated 15-25% overlap in suppliers exists across some OEMs). Relationships between the OEMs and BtP and DtB are developed over time and often reflect long-term commitments given the need for OEMs and DtB companies to certify their suppliers in the manufacturing of components. As a result, rival suppliers cannot readily step in and replace their production activity.

The economic losses are therefore based on consideration of losses in operating surplus/profits only. These have been estimated over three time periods in line with SEAC's new guidance for those cases where there are not suitable alternatives available in general. Discounted losses over one, two, four, seven and 12 years are given in **Table 5-7**.

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

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

	Lost EBITDA/Profit € millions		GVA-based Operating Surplus Losses € millions	
	EU	UK	EU	UK
1 year profit losses (2025)	1,442	228	421	127
2 year profit losses (2026)	2,720	430.43	794	239
4 year profit losses (2028)	5,236	828.45	1,527	460
7 year profit losses (2031)	8,657	1,369.80	2,525	760
12 year profit losses (2036)	13,536	2,142	3,949	1,189

5.2.2.7 Other impacts on Aerospace and Defence Companies

Under the Non-use Scenario there would be an enormous impact on the A&D sector in the EEA/UK, leading to a second wave of negative impacts on the EEA market. These impacts have not been quantified here but would include as a minimum:

- Cancelled future orders and loss of contracts for new products if supplies are significantly interrupted;
- Customer penalties for late/missed delivery of products;
- Extended durations of maintenance, repair and overhaul operations for products in service leading to e.g. "aircraft on the ground" (AoG) and other out-of-service final products, with consequent penalties and additional impacts on turnover;
- Increased logistical costs; and

- Reputational damages due to late delivery or cancelled orders.

As indicated in Section 3.5, there is the potential for the adoption of alternatives such as hydrofluoric acid (HF) to trigger additional regulatory requirements at the site level under the Seveso III Directive (96/82/EC). If the implementation of an alternative caused a site to face new obligations under Seveso III, the cost implications could be significant. Seveso III restricts the proximity of affected sites to local residential areas. If major changes in the layout of the site to accommodate requirements for the storage and on-site transportation of a substance are not geographically or economically possible, site relocation may need to be considered. In many cases relocating a site due to the obligations of Seveso III may render the adoption of, for example, HF as an alternative too expensive and/or impractical.

5.2.3 Economic impacts on competitors

5.2.3.1 Competitors in the EEA/UK

This combined AoA/SEA has been prepared so as to enable the continued use of the CT and SD in passivation across the entirety of the EEA and UK A&D sectors. It is non-exclusive in this respect. It has been funded by the major (global) OEMs and DtB manufacturers in the EEA and the UK, with additional support provided by their suppliers and by Ministries of Defence, so as to ensure functioning supply chains for their operations.

As a result, there should be no economic impacts on competitors, especially as the major global OEMs and DtBs act as the major design owners which determine the ability of all suppliers to move to an alternative. As design owners they validate, qualify and certify components and products with new alternatives and gain new approvals (e.g. approvals from EASA, ESA or MoDs). Once these design owners have certified new alternatives in the manufacture of components, these alternatives will be implemented throughout their value chain.

5.2.3.2 Competitors outside the EEA/UK

Under the NUS, it is likely that some of the major OEMs and DtB suppliers would move outside the EEA/UK, creating new supply chains involving BtP and MROs. This would be to the detriment of existing EEA/UK suppliers but to the advantage of competitors outside the EEA/UK. These competitors would gain a competitive advantage due to their ability to continue to use chromate-based passivation treatments and due to their proximity to the OEMs and DtB, thus minimising logistic and transport issues.

5.2.4 Wider socio-economic impacts

5.2.4.1 Impacts on air transport

Under the Non-Use Scenario there would be significant impacts on the ability of MROs to undertake repairs and to follow normal maintenance and overhaul schedules. As indicated previously, MROs are legally bound to adhere to the requirements set out in the OEMs' manuals under airworthiness and military safety requirements. Where maintenance or overhaul activities would require chromate-based passivation, they would have to be performed outside the EEA/UK until the OEMs have gained approvals and certifications for the use of alternatives on components and have adapted the manuals setting out maintenance and overhaul instructions.

If an aircraft needs unscheduled repairs (i.e. flightline or "on-wing" repairs), it will be grounded at the airport until these take place due to airworthiness constraints. This would result in AOGs and could result in an aircraft having to be disassembled and transported outside the EEA/UK for repairs, with dramatic financial and environmental impacts.

Should MRO facilities be relocated outside the EEA/UK, airlines will also experience additional delays to routine aircraft maintenance due to transport requirements and capacity constraints at MRO facilities outside the EU. Indeed, it may take some time to build up capacity to accommodate additional demand from EU-based operators, potentially resulting in a large number of aircraft being grounded until maintenance checks can be completed.

As a result, airlines would need to have additional spare components/engines/planes to account for the added time that aircraft would be out of commission due to extended MRO times. Airports may also have to build up large inventories of spare components to replace products that currently can be repaired, with this going against the desire to ensure sustainability within the sector.

The need to have maintenance carried out outside the EEA/UK would also lead to additional operational costs being incurred through increased fuel use. Small planes (e.g. business jets) that do not have the fuel capacity or airworthiness approvals for long haul flights would need to make multiple stops enroute to non-EEA MRO facilities and back to the EEA/UK. The impacts for larger aircraft would also be significant. For example, flying from Western Europe to Turkey or Morocco adds approximately 3,000 km each way and for a Boeing 737 this would take slightly less than four hours. For an airline which has 50 aircraft requiring an annual "D check" (heavy maintenance inspection of the majority of components, carried out every 6-10 years), this would involve 400 hours of flight time (return trip) or 20 days of foregone revenue, equivalent to €1.4 million. Scaling this up to the EEA passenger aircraft fleet, which stands at approximately 6,700, suggests lost revenues in the tens of millions per annum just due to the need to have around 700 aircraft which require a "D check" each year. Using the above estimate for a fleet of 50 aircraft, this would amount to €20 million in revenue lost by European airlines for "D checks" alone. This figure excludes the costs of fuel and personnel, as well as the fact that additional flights bring forward maintenance interval requirements and impact on the total lifespan of an aircraft

In addition, based on a leasing cost for a large passenger jet of around $500,000/month in 2021 (€421,500, £362,250)[80], the leasing costs alone of a plane being out of service would be roughly €14,000/£12,100 per day. On top of this will be the additional losses in revenues from not being able to transport passengers or cargo. For example, an Airbus A320 carries from 300 to 410 paying customers on one long-haul flight per day. If tickets cost on average €650 (£560) per customer (assuming 350 customers), the revenue lost due to being 'out of action' for one day amounts to €227,500 (£195,500). As a result, the cost of extending the period over which a plane is out of service for repair or maintenance reasons may lead to significant new costs for airlines, delays for passengers and in the transport of cargo, as well as subsequent effects for GDP and jobs due to planes being out of service for longer.

ICAO reported[81] a -49 to -50% decline in world total passengers in 2021 compared to 2019. In 2020, figures for Europe show a -58% decline in passenger capacity, -769 million passengers and a revenue loss of -100 billion USD. In addition, COVID-19 caused a 74% decrease in passenger demand for

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

[81] https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf

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 below. Similar growth is expected in air freight transport. If this growth path were to be achieved, by 2036 the air transport industry would contribute 15.5 million in direct jobs and $1.5 trillion of GDP to the world economy. Once the impacts of global tourism are taken into account, these numbers could rise to 97.8 million jobs and $5.7 trillion in GDP.

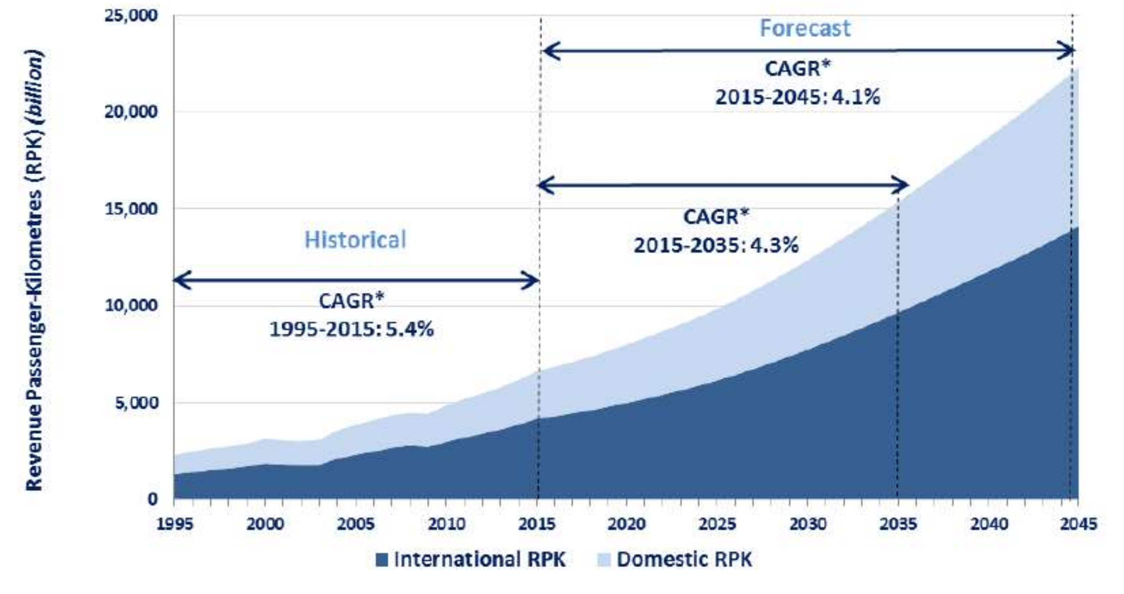

Figure 5–2: Forecast compound annual growth rates – Revenue Passenger-kilometres

Post Covid-19, projections are for a lower rate of increase in air traffic, with Airbus suggesting a growth rate between 2019 and 2040 of around 3.9% CAGR.[82] The impact of COVID has resulted in an expected 2-year lag in growth, but the forecast remains unchanged with passenger numbers expecting to increase in line with the forecasts. This growth rate is relevant to global air traffic, with Europe expected to realise a lower compound annual growth rate of about 3.3% for total traffic[83] (covering inter-regional and intra-regional/domestic) for the period between 2018 to 2038.

This level of growth in EEA air traffic, together with the jobs and contributions to GDP that it would bring, could be impacted under the NUS. Impacts on the ability of MROs to undertake repairs and carry out maintenance where this would require the use of chromate-based passivation to ensure the continued airworthiness of aircraft could impact on the realisation of such growth. No quantitative estimate of the level of impact can be provided, but it is clear that the closure of EU-based MRO operations in particular could impact on the availability of aircraft and hence passenger and freight transport until substitution has taken place as expected over the review period (unless airlines responded by buying more planes or stockpiling of components, which would inevitably give rise to increases due to the costs of holding spares and/or bringing spare planes on-line).

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

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

5.2.4.2 Defence-related impacts

Defence related impacts under the NUS would have two dimensions: impacts on military forces; and impacts on companies acting as suppliers to military forces.

Two national Ministries of Defence have provided information regarding their use of passivation of stainless steel, with SEA responses also provided by defence suppliers. In addition, MROs providing services to MODs have also provided information to ensure that they are able to continue to maintain and repair military final products into the future. The implications of having to cease these activities are significant. Military final products which could not be maintained to appropriate safety standards would have to be removed from service. Not only would this impact on the availability of key equipment in the case of a military emergency, but it would also affect the mission readiness of operational forces in particular.

It is also worth noting that Governments are likely to be reluctant to send military final products to MRO facilities located in non-EU countries, although the US, Canada and Turkey are NATO members, and as such may be suitable candidates to service European military aircraft. There would be impacts on mission readiness if repairs cannot be done locally. This could, in fact, be far more impactful than the economic impacts linked to the defence sector

As a result, it is likely that under the NUS, companies manufacturing components for and servicing military products would have to apply for defence exemptions; although for some companies, the turnover generated by military contracts alone may not be sufficient to maintain current production levels and it may not be economically feasible to operate dual manufacturing lines for military and civilian customers.

Companies in the European defence sector represent a turnover of nearly €100 billion and make a major contribution to the wider economy. The sector directly employs more than 500,000 people of which more than 50% are highly skilled. The industry also generates an estimated further 1.2 million jobs indirectly. In addition, investments in the defence sector have a significant economic multiplier effect in terms of the creation of spin-offs and technology transfers to other sectors, as well as the creation of jobs. For example, according to an external evaluation of the European Union's Seventh Framework Programme, through short-term leverage effect and long-term multiplier effects each euro spent by the Seventh Framework Programme (FP7) generated approximately an additional €11 billion of estimated direct and indirect economic effects through innovations, new technologies and products.[84]

Indeed, the European Commission announced in July 2022 that it plans to grant a total EU funding of almost **€1.2 billion** supporting **61 collaborative defence research and development projects** selected following the first ever calls for proposals under the European Defence Fund (EDF).[85] The aim will be to support high-end defence capability projects such as the next generation of fighter aircrafts, tanks and ships, as well as critical defence technologies such as military cloud, Artificial Intelligence, semiconductors, space, cyber or medical counter-measures. It will also spearhead disruptive technologies, notably in quantum technologies and new materials and tap into promising SMEs and

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[84] https://www.evropskyvyzkum.cz/cs/storage/bf5134fec407f6e005288c0e2631ad232c38c013?uid=bf5134fec407f6e005288c0e2631ad232c38c013

[85] https://ec.europa.eu/commission/presscorner/detail/en/IP_22_4595

start-ups. Some of these gains may not be realised if the main EEA defence OEMs have to divert resources into shifting part of their manufacturing base outside of the EEA.

However, under the NUS, companies manufacturing components for defence and servicing military aircraft and other derivative defence products would most likely apply for defence exemptions; although for some companies, the turnover generated by military contracts alone may not be sufficient to maintain current production levels and it may not be economically feasible to operate dual manufacturing lines for military and civilian customers. If some production moved out of the EEA/UK under the NUS, as indicated by some OEMs as their most likely response, then the above multiplier effects would be lost.

If Governments did allow the manufacture and servicing of military aircraft and other defence products to move out of the EEA/UK under the NUS, then some proportion of such multiplier effects would be lost to the EEA/UK economy. In addition, the ability of the EEA/UK to benefit from some of the innovations and technological advances in products ahead of other countries could be lost, if the shift in manufacturing remains permanent and extends to new products.

5.2.5 Summary of economic impacts

Table 5-8 provides a summary of the economic impacts under the Non-Use scenario.

Table 5-8: Summary of economic impacts under the Non-Use scenario (12 years, @ 4%)

Economic operator	Quantitative	Qualitative
Applicants	- See formulation SEA	Not assessed

A&D companies	- Annualised lost profits:
	  ○ EEA: €421 – 1,442 million
	  ○ UK: €127 – 228 million
	- 12 year lost profits:
	  ○ EEA: €3,950 – 13,536 million
	  ○ UK: €1,189 – 2,142 million
		Relocation costs, disruption to manufacturing base and future contracts, impacts on supply chain coherence, impacts on future growth in the EEA and UK sectors, loss of skilled workforce, impacts on R&D (and potential to deliver new more sustainable technologies)

Competitors	Not anticipated due to sectoral coverage of the application	Not anticipated due to sectoral coverage of the application
Customers and wider economic effects	Not assessed	- Impacts on airlines, air passengers, customers, cargo, and emergency services, and thus society as a whole - Impacts on military forces' operation capacity and mission readiness - Lost employment multiplier effects due to impacts on civil aviation and loss of defence sector spending - Loss of spin-off effects – innovation and new technologies

5.3 Environmental impacts under non-use

As well as leading to increases in operating costs and lost revenues to airlines, the increased distances that airlines would need to fly planes in order for them to undergo normal maintenance and overhaul schedules would lead to significant increases in fuel consumption and hence CO_2 emissions.

The most plausible non-use scenario in the event of a refused Authorisation - even if it may not be practical and would involve huge levels of investment - would be to shift passivation of stainless steel to another country (outside the EEA or UK).

Under this scenario, as noted above, the environmental impacts would be real and the effects enormous. If manufacturing activities using chromates and not using chromates are separated on both sides of the European border, huge logistics and transport related requirements would have to be introduced with dramatic impacts on the aerospace and defence sectors' environmental footprint.

For MRO activities, each time an aircraft would need a repair requiring the use of chromate-based passivation, it would force the manufacturer to go to a non-European site. In the case of a major repair, aircraft that could not fly would become stranded or, less likely, would have to be dis-assembled for transport to a non-European site. Some stranded final products would become obsolete prematurely, due to the lack of the components needed for their maintenance and repair.

This would go against the principles underlying the Circular Economy and the sustainable use of raw materials, by limiting the ability of the sector to repair and re-use components and assemblies.

Today, the civil aviation industry strives to develop new technologies to reduce the amount of CO2 emissions by 15 - 20% on each generation of in-service aircraft (make aircraft movements emission-free).

Even despite the impact that the COVID-19 pandemic had on air traffic and the whole civil aviation industry, aviation is expected to double in the next 20 years. Consequently, a refused authorisation renewal would lead to aircraft manufacturing and MRO activities involving chromate uses to move outside the EEA. In addition to the socio-economic consequences this would have, the drastic increase in CO_2 emissions, would outweigh all the benefits achieved by aviation efforts to reduce fuel consumption and CO2 emissions of in-service aircrafts.

5.4 Social impacts under non-use

5.4.1 Direct and indirect job losses

5.4.1.1 Estimated level of job losses

The main social costs expected under the NUS are the redundancies that would be expected to result from the cessation of production activities (all or some) and the closure and relocation of sites. As indicated in the assessment of economic costs, the estimated reduction in job losses is based on responses to the SEA questionnaires covering 58 sites in total. Direct job losses will impact on workers at the site involved in passivation and linked pre-treatment and post-treatment processes as well those involved in subsequent production steps and related activities (e.g. lab workers, etc.). These are all referred to here as direct job losses (for avoidance with confusion of multiplier effects).

While redundant workers are expected to face a period of unemployment, in line with ECHA's guidance it is assumed that such a period would be only temporary. However, the length of the average duration of unemployment varies greatly across European countries, as do the costs associated with it.

It should be noted that the ECHA methodology has been followed here despite the fact that the impacts across the A&D sector may make it difficult for workers to find another job, especially as there may be a skill mis-match 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 passivation of stainless steel, as well as to maintenance and repairs of such parts at a subset of MRO facilities. No consideration is given to job losses at those companies providing services that are contracted to provide cleaning and other services to the BtPs, DtBs, MROs and ORMs.

As context, the civil aeronautics industry alone employees around 405,000 people in the EU, with the defence sector employing more than 500,000 and supporting a further 1.2 million[86]. The figures in **Table 5-9** indicate that approximately 75,000 of these A&D company jobs could be in jeopardy under

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[86] https://www.eudsp.eu/event_images/Downloads/Defence%20Careers%20brochure_1.pdf

the NUS. Added to these are over 27,000 jobs at MROs (of which there are 80,000 in the EEA and 13,000 in the UK), and over 36,000 jobs at suppliers falling under the other relevant NACE codes.

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 (43 sites)	900	319
Design to build (15 sites)	1,656	23
MROs (14 sites)	5,510	12
OEMs (18 sites)	3,527	2,000
Total sites (90)	**11,592**	**2,354**

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[87]).

Costs of unemployment are calculated by adding up lost output which is equivalent to the pre-displacement gross salary throughout the period out of work, search costs, rehiring costs for employers and scarring effects, and deducting the value of leisure time.

Dubourg (2016) estimated different ratios of the social cost per job loss over the annual pre-displacement wage for European countries and the EU-28 as a whole that varies according to the mean duration of unemployment. These vary by country, with the mean duration of unemployment weighted by the number of employees for each country relevant to A&D sector productions sites varying from seven months to 1.6 years.

These figures are combined with the ratio of social costs per job loss provided in Dubourg (2016) and annual wages to calculate the social costs per lost job. Data were collected in the SEA questionnaire on the average salary for workers involved in the use of the chromates. The typical range given is from €30k to 50k, rising to an average maximum of around €76k, across all of the companies and locations. For the purposes of these calculations, a figure of €40k has been adopted and applied across all locations and job losses. This figure is based on the NACE code data provided by companies but may underestimate the average salary given that A&D jobs are higher paid than those in other industries.

The resulting estimates of the social costs of unemployment are given in **Table 5-10** based on consideration of the geographic distribution Article 66 notifications, the location of SEA respondents, and the location of suppliers in the ADCR members' supply chains, as well as MROs. The estimated social costs under the NUS are around €1.18 for the EEA and €236 million for the UK due to the cessation of the passivation of stainless steel and linked manufacturing activities.

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[87] Dubourg, R (2016): Valuing the social costs of job losses in applications for authorisation. Available at: https://echa.europa.eu/documents/10162/13555/unemployment_report_en.pdf/e0e5b4c2-66e9-4bb8-b125-29a460720554

Table 5-10: 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	1,507	191,082,528
Poland	1,043	98,068,320
Italy	1,739	210,742,560
Germany	1,623	168,779,520
Spain	1,043	116,847,360
Czech Republic	811	88,933,824
Netherlands	696	65,378,880
Sweden	811	72,380,448
Norway	116	12,612,096
Belgium	811	98,346,528
Finland	811	56,476,224
Austria	464	44,698,752
Denmark	116	8,114,400
Total EEA	**11,592**	**1,179,648,288**
United Kingdom	**2,354**	**236,153,280**
Total	**13,946**	**1,468,614,720**

5.4.2 Wider indirect and induced job losses

5.4.2.1 Aerospace and defence related multiplier effects

Employment in one sector is often the input to employment in another sector, so that fluctuations in employment of the latter will inevitably affect the former. It is clear that, under the NUS, there could be significant wider impacts on jobs given the likelihood that some of the largest players in the EEA/UK A&D sector would relocate their activities elsewhere with a partial or full cessation of manufacturing in the EEA/UK.

A UK Country Report on the “Economic Benefits from Air Transport in the UK” produced by Oxford Economics (2014) indicates the following with respect to the aerospace sector’s contribution to UK employment in 2012:

- Indirect employment effects: 139,000 jobs implying a multiplier effect of 1.36 indirect jobs for every direct job;

- Induced employment effects: 86,000 jobs implying an additional multiplier effect of 0.84 induced jobs for every direct job.

Indirect employment effects will to a degree be captured by the estimates of lost jobs presented in **Table 5-9** given that it includes the loss of jobs at suppliers to the aerospace OEMs. The figures exclude other service providers to these companies whose services would no longer be required. Induced effects are not captured by the above estimates and an employment multiplier of 0.84 suggests that they may be significant given the predicted numbers of jobs that would be lost across the key countries in which aerospace-related manufacturing takes place.

The loss of jobs within those companies that serve the defence industry would have their own multiplier effects. The external evaluation of FP7 referenced above[88] quotes an employment multiplier of between 2.2 to 2.4, with this covering both indirect and induced employment effects. The sector is identified as bringing a major contribution to the wider economy.

To successfully compete at a global level, the European and UK A&D industries have formed regional and industry clusters that includes local and national government partners. The clusters are part of the European Aerospace Cluster Partnership[89](EACP) which focuses on the exchange of experiences concerning both cluster policy and the implementation of effective solutions needed to address various challenges faced by the partners. It has members located in 44 aerospace clusters across 18 countries, thus covering the entire A&D value chain in Europe. **Figure 5-3** below is a "snip" taken from the EACP website highlighting the location of these different hubs across Europe, to provide an indication of where effects may be experienced at the regional level.

Under the non-use scenario, the economic impact on each region could have severe consequences. For example, Aerospace Wales consists of over 180 members which employ 23,000 employees with a turnover of over £6.5 billion in Wales, while the Andalucía Aerospace Cluster has over 37 members, 16,000 employees with over €2.5 billion turnover (See Annex 2). Both of these clusters are an essential part of the local economy.

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[88] 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

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

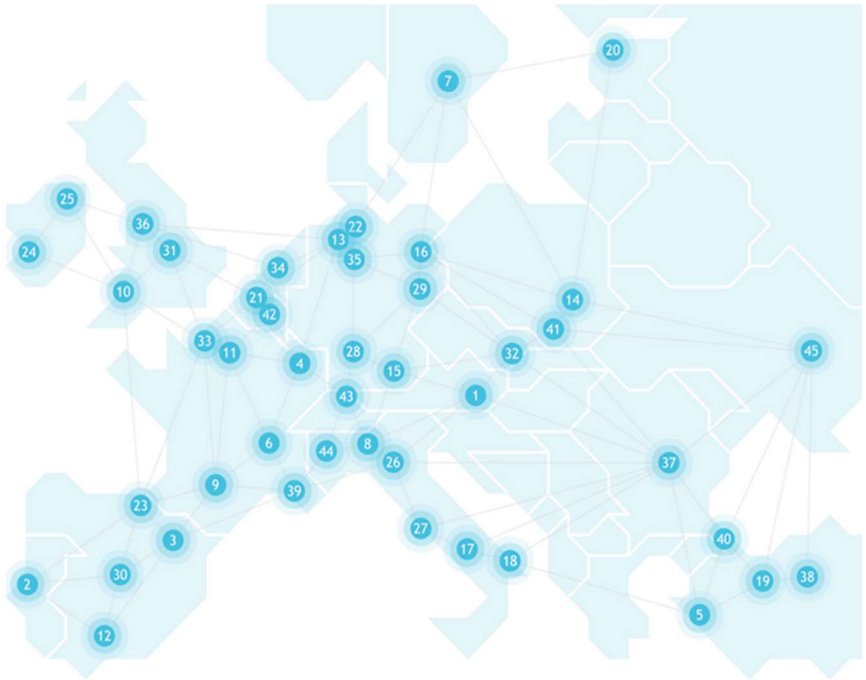

Figure 5-3: Aerospace clusters across Europe

5.4.2.2 Air transport multiplier effects

A 2019 "Aviation Benefits Report"[90] 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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[90] Published by the ACI, CANSO, IATA, ICAO and the ICCAIA, available at: https://www.icao.int/sustainability/Documents/AVIATION-BENEFITS-2019-web.pdf

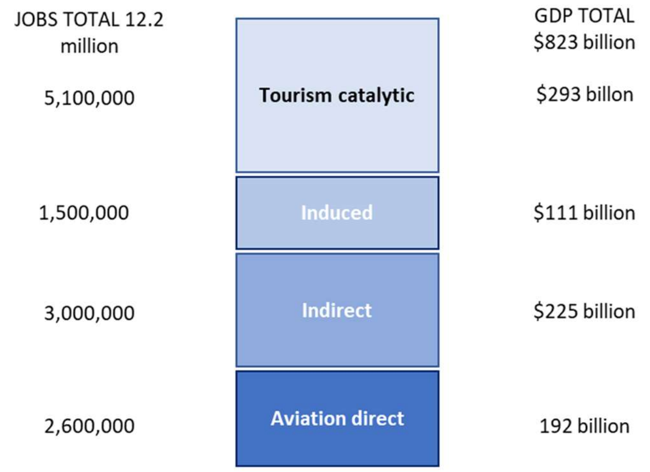

Figure 5-4: Aviation related multiplier effects
Source: Based on: *https://www.icao.int/sustainability/Documents/AVIATION-BENEFITS-2019-web.pdf*

The potential employment losses associated with a decline in European aviation can be seen by reference to the impacts of COVID-19[91]. A "COVID-19 Analysis Fact Sheet" produced by Aviation Benefits Beyond Borders reports the following:

- A reduction from 2.7 direct aviation jobs in Europe supported pre-COVID to 2.1 million jobs post-COVID (i.e. at the end of 2021); and

- 13.5 million jobs in supported employment pre-COVID in Europe to 8.1 million at the end of 2021.

Although one would not expect the losses in supported employment (i.e. indirect, induced, and catalytic effects) to be as great due to the loss of passivation of stainless steel alone, it is clear that a disruption to civil aviation could have significant employment impacts.

5.4.3 Summary of social impacts

In summary, the social impacts that would arise under the NUS include the following:

- Direct job losses:
    - Around 11,590 jobs in the EEA due to the loss of stainless steel passivation and linked assembly and/or manufacturing activities, and
    - Over 2,350 jobs in the UK due to the loss of stainless steel passivation and linked assembly and/or manufacturing activities;

- Social costs of unemployment:
    - €1,180 million for the EEA associated with direct job losses and
    - €236 million for the UK associated with direct job losses;

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

- Indirect and induced unemployment at the regional and national level due to direct job losses; and

- Direct, indirect, and induced job losses in air transport due to disruption of passenger and cargo services.

5.5 Combined impact assessment

Table 5-11 sets out a summary of the societal costs associated with the Non-Use scenario. Figures are provided as annualised values, with costs also presented as a PV over a two-year period as per ECHA's latest guidance; note that restricting losses to only those occurring over the first two years of non-use will significantly underestimate the profit losses to the A&D companies as well as the applicants. Most A&D companies would incur losses for at least a four-year period, with over 60% incurring losses for seven years and 25-30% for the full 12-year period as design owners work continues towards development, testing, qualification, validation, certification, and industrialisation of alternatives.

Table 5-11: Summary of societal costs associated with the Non-Use Scenario

Description of major impacts	Monetised/quantitatively assessed/qualitatively assessed impacts	
1. Monetised impacts	**PV @ 4%, 2 years**	**€ annualised values**
Lost producer surplus[1]: Impacts on applicants - Lost profits EEA - Lost profits UK Impacts on A&D companies[1]: - Lost profits EEA - Lost profits UK	Applicants: See formulation SEA A&D companies EEA: €794 – 2,720 million (£682 – 2,339 million) UK: €239 – 430 million (£205 – 370 million)	Applicants: See formulation SEA A&D companies EEA: €420 – 1,442 million (£362 – 1,240 million) UK: €127 – 228 million (£109 – 196 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: €1,180 million (£1,014 million) UK: €236 million (£203 million)	EEA: €590 million (£507 million) UK: €118 million (£102 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: €1,973 – 3,900 million (£1,670 - 3,354 million) UK: €475– 667 million (£409 – 573 million)	EEA: €1,010 million– 2,032 million (£869 – 1,748 million) UK: €245 – 346 million (£210 – 298 million)
2. Additional qualitatively assessed impacts		
Impacts on A&D sector	Impacts on R&D by the A&D sector, impacts on supply chain, impacts on technological innovation	
Civilian airlines	Wider economic impacts on civil aviation, including loss of multiplier effects, impacts on airline operations, impacts on passengers including flight cancellations, ticket prices, etc.	
Ministries of Defence	Impacts on the operational availability of aircraft and equipment, premature retirement of aircraft and equipment, impacts on mission readiness	
Other sectors in the EEA	Loss of jobs due to indirect and induced effects; loss of turnover due to changes in demand for goods and services and associated multiplier effects. Loss of jobs in other sectors reliant on aeroderivative uses of the chromates, such as the energy sector (e.g. use of passivation on turbine blades and engine components including wind turbines) Impacts on emergency services and their ability to respond to incidents Impacts on cargo transport	
1) Lower bound figures represent lost EBITDA estimates, upper bound lost operating surpluses. 2) Estimated using the approach set out by Dubourg		

6 Conclusion

6.1 Steps taken to identify potential alternatives

Potential alternatives to Cr(VI) for passivation of stainless steel should be "generally available"[92].

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 passivation of stainless steel are shown in **Figure 6-1**:

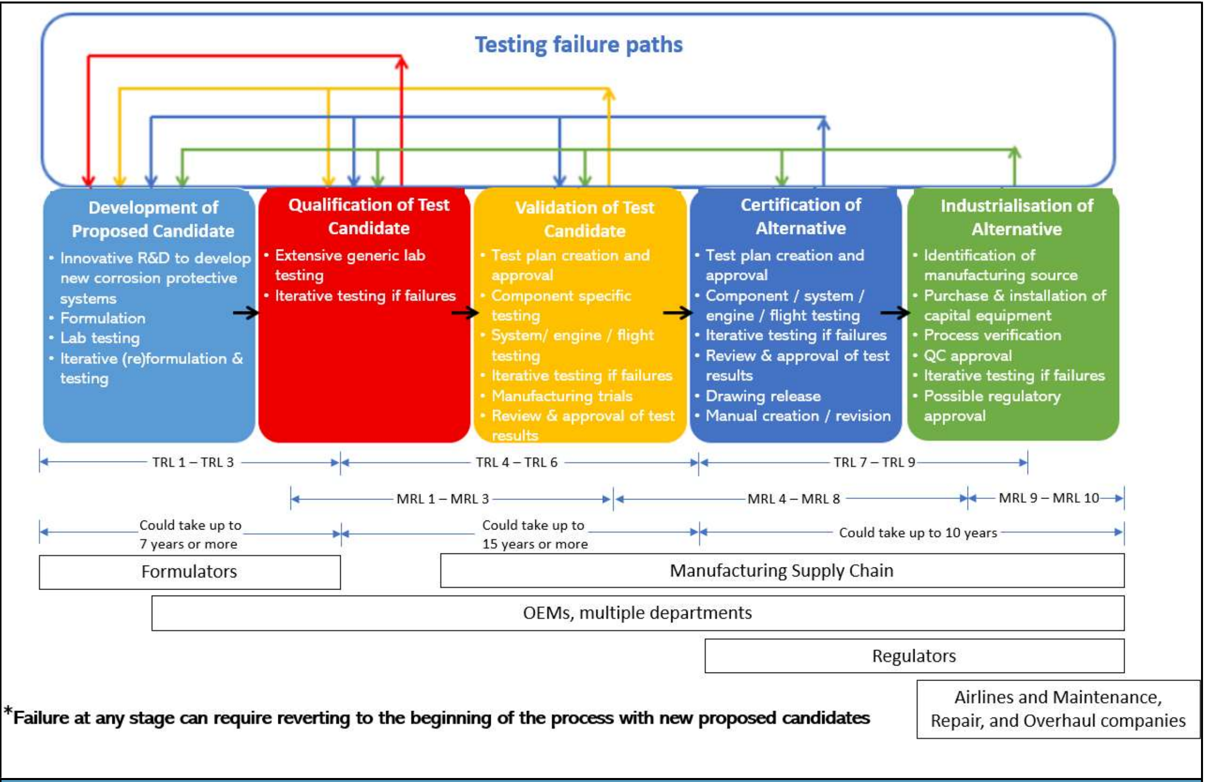

Figure 6-1: Schematic showing the key phases of the substitution process.
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note 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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[92] 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 passivation of stainless steel. Individual members often have multiple substitution plans within passivation of stainless steel, reflecting the complexity of different components to be treated, the various substrates, and the different performance resulting from test candidates in these different situations. While there have been successes, with some members having been able to implement alternatives to Cr(VI) in certain limited situations and for certain substrates, thereby reducing their Cr(VI) usage, many technical challenges remain.

As discussed in Section 3.6.2 and shown in **Figure 6-2** below, of the 16 distinct substitution plans for passivation of stainless steel assessed in this review report, 44% of them are expected to have achieved MRL 10 by September 2024. MRL 10 is the stage at which it is expected production will be in operation and there will be a significant reduction in Cr(VI) use for the components covered in that substitution plan.

The proportion of substitution plans that are expected to achieve MRL 10 is then expected to progressively increase to 69% in 2028, 88% in 2031, and 100% in 2036.

In 2031 (equivalent to seven years beyond the expiry date for the existing applications), while many substitution plans are expected to have successfully progressed to MRL 10 and the consortium is expected to have reduced its Cr(VI) use, a significant proportion are not expected to have achieved MRL 10 and are expected to be predominantly at the certification or industrialisation stages, with some substitution plans at earlier stages. For these substitution plans (which are from several member companies), there is still expected to be a need for the use of Cr(VI).

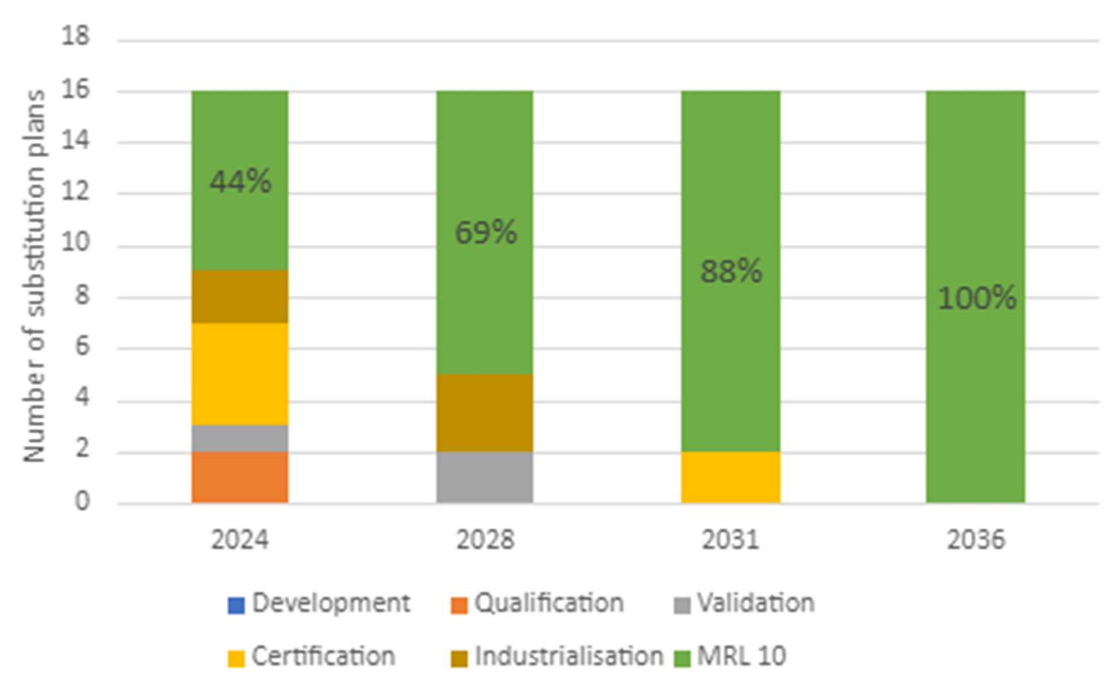

Figure 6-2: Expected progression of substitution plans for the use of Cr(VI) in passivation of stainless steel, by year

The vertical axis refers to number of substitution plans (some members have multiple substitution plans for passivation of stainless steel). The percentage value shown on each of the green bars indicates the proportion of substitution plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which there is expected to be a significant reduction in Cr(VI) usage.

Source: RPA analysis, ADCR members

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

6.3 Comparison of the benefits and risk

Table 6-1 summarises the socio-economic benefits of continued use of the chromates in passivation of stainless steel by companies in the A&D sector. Overall, net benefits of between ca. €1.97 to 3.9 billion for the EEA and €475 to 666 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 €327k and €99k 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 6,040 on the lower bound assumptions for the EEA and 4,780 on the lower bound assumptions for the UK.

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

Societal costs of non-use		Risks of continued use	
Monetised profit losses to applicants	Losses in profits from reduced sales of the chromate substances and associated formulations. Losses quantified in the Formulation SEA	Health risks to workers at formulation sites over the review period, taking into account the reduction in risks due to adherence to the conditions placed on the initial authorisations. These risks are quantified and monetised in the Formulation SEA	
Monetised profit losses to A&D companies	EEA: €794 – 2,720 million (£682 – 2,339 million) UK: €239 – 430 million (£205 – 370 million)	Monetised excess risks to directly and indirectly exposed workers (€ per year over 12 years)	EEA: €313k (£270k) UK: €90k (£77k)
Social costs of unemployment	EEA: €1,180 million (£1,014 million) UK: €236 million (£203 million)	Monetised excess risks to the general population (€ per year over 12 years)	EEA: €13k (£12k) UK: €10k (£8k)
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: €1,973 – 3,900 million (£1,670 – 3,354 million) - UK: €475 – 666 million (£408 – 573 million) • Ratio of annualised societal costs to risks: - EEA: 6,036:1 to 11,930:1 - UK: 4,780:1 to 6,707:1		

It should be appreciated that the social costs of non-Authorisation could be much greater than the monetised values reported above, due to the likely 'knock-on' effects for other sectors of the economy:

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

⬇

EEA/UK formulators would relocate to ensure that they could continue to supply their downstream customers until alternatives are certified across products; this could result in the temporary loss of key passivation formulations to downstream users as relocation of manufacturing would require re-certification of the formulations

⬇

Due to certification and airworthiness requirements, downstream users would be forced to undertake passivation activities outside the EEA/UK or shift to suppliers outside of the EEA/UK

↓

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

↓

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

↓

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

↓

MROs will have to shift at least some (if not most) of their activities outside the EEA/UK, as passivation 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 passivation activities significantly outweigh the residual risks from continued use.

Three further points are relevant. **Firstly, the use of chromium trioxide and sodium dichromate is required (and may be required beyond 12 years) to ensure the operational capabilities of the military and the ability to comply with international obligations as partner nations at the EEA level and in a wider field, e.g. with NATO.**

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

Finally, the non-use scenario would involve the relocation of economically and strategically important manufacturing processes. This would be in contradiction to the EU policy on "Strategic dependencies and capacities," which highlights the need to minimise such dependencies where they could have a significant impact on the EU's core interests, including the access to goods, services and technologies.[93] The need to support the A&D industry (as one of the 14 priority industrial ecosystems) is explicitly recognised within the update to the 2020 New Industrial Strategy.[94]

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

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

6.4 Information for the length of the review period

6.4.1 Introduction

In a 2013 document, the ECHA Committees outlined the criteria and considerations which could lead to a recommendation of a long review period (12 years) (ECHA, 2013):

1. *The applicant's investment cycle is demonstrably very long (i.e., the production is capital intensive) making it technically and economically meaningful to substitute only when a major investment or refurbishment takes place.*
2. The costs of using the alternatives are very high and very unlikely to change in the next decade as technical progress (as demonstrated in the application) is unlikely to bring any change. For example, this could be the case where a substance is used in very low tonnages for an essential use and the costs for developing an alternative are not justified by the commercial value.
3. *The applicant can demonstrate that research and development efforts already made, or just started, did not lead to the development of an alternative that could be available within the normal review period.*
4. *The possible alternatives would require specific legislative measures under the relevant legislative area in order to ensure safety of use (including acquiring the necessary certificates for using the alternative).*
5. The remaining risks are low, and the socio-economic benefits are high, and there is clear evidence that this situation is not likely to change in the next decade.

In the context of this review report, it is assumed that qualification and certification requirements combined with the need for approvals from EASA, the ESA and MoDs are consistent with the requirements under criterion 4 above.

Further discussion was held at the 25th Meeting of Competent Authorities for REACH and CLP (CARACAL) of 15 November 2017. A document endorsed by CARACAL suggests that "*in order to consider a review period longer than 12 years, in addition to the criteria for a 12-year review period established in the document "Setting the review period when RAC and SEAC give opinions on an application for authorisation", two additional conditions should jointly be met*:

6. *As evaluated by the RAC, the risk assessment for the use concerned should not contain any deficiencies or significant uncertainties related to the exposure to humans (directly or via the environment) or to the emissions to the environment that would have led the RAC to recommend additional conditions for the authorisation. In the case of applications for threshold substances, the appropriateness and effectiveness of the applied risk management measures and operational conditions should clearly demonstrate that risks are adequately controlled, and that the risk characterisation ratio is below the value of one. For applications for non-threshold substances, the applied risk management measures and operational conditions should be appropriate and effective in limiting the risks and it should be clearly demonstrated that the level of excess lifetime cancer risk is below $1x10^{-5}$ for workers and $1x10^{-6}$ for the general population. For substances for which the risk cannot be quantified, a review period longer than 12 years should normally not be considered, due to the uncertainties relating to the assessment of the risk.*

7. *As evaluated by the SEAC, the analysis of alternatives and the third party consultation on alternatives should demonstrate without any significant uncertainties that there are no suitable alternatives for any of the utilisations under the scope of the use applied for and that it is highly unlikely that suitable alternatives will be available and can be implemented for the use concerned within a given period (that is longer than 12 years)"* (CARACAL, 2017).

As far as the second criterion above is concerned, the same document provides some relevant examples, one of which (Example (d)) reads as follows:

> "(…) *the use of the substance has been authorised in accordance with other EU legislation (e.g. marketing authorisation, certification, type-approval), the substance being specifically referred to in the authorisation/certification granted and substitution, including the time needed for modification of the authorisation/certification/type-approval, would not be feasible within 12 years and would involve costs that would jeopardise the operations with regard to the use of the substance*".

6.4.2 Criterion 1: Demonstrably Long Investment Cycle

The aerospace and defence industry is driven by long design and investment cycles, as well as very long in-service time of their products, which are always required to meet the highest possible safety standards. As noted in Section 4.4, the average life of a civil aircraft is typically 20-35 years, while military products typically last from 40 to >90 years. Furthermore, the production of one type of aircraft or piece of equipment may span more than 50 years.

These long investment cycles and long product lives have been recognised in the FWC Sector 26 study on the Competitiveness of the EU aerospace industry[95]. They are a key driver underlying the difficulties facing the sector in substituting the use of the chromates in passivation across all affected components within final products. The long service life of aircraft and other products makes it difficult to undertake all of the tests required to qualify and certify a component with the substitute, due to the level of investment and costs that would be involved in such an activity for out of production A&D products; as it would require testing at multiple levels (components, sub-assemblies, assemblies, final aircraft/defence equipment).

The ADCR would like to emphasise the crucial role every single component within an A&D product plays with respect to its safety. For example, an aircraft is a complex system involving not only design of the aircraft itself, but also its use and maintenance history in varied climates and service. An aircraft engine is exposed to massive forces and extremely high stress levels due to high velocities and environmental impacts. Therefore, every single component needs to be designed and manufactured with serious attention and care.

In a complex system, change introduces new forms of failure. Any change will bring failures that can be anticipated – and some that are unanticipated. The components in an A&D product need to be adjusted to each other very precisely on the design as well as on the manufacturing level. When in the early design phase for completely new engines, for example, there is an opportunity to consider introducing a material change. Mostly such a material change will be a step improvement on a

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[95] 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.

previous design, in line with the principle of proven engineering. Very rarely is a substantial design change introduced into an existing product, as this would involve substantial cost and risk.

Even where such a small change is considered feasible in principle, the implications are significant and highly complex; time consuming, systematic TRL-style implementation is required to minimise the impact of unanticipated failures and the serious repercussions they might cause. Even when an OEM has been able to undertake the required testing and is in the process of gaining qualifications and certifications of components with a substitute, it may take up to seven years to implement the use of a substitute across the value chain due to the scale of investment required and the need for OEMs to undertake their own qualification of different suppliers.

In addition, MoDs rarely revise specifications for older equipment, which must nevertheless be maintained and repaired. MROs servicing military equipment therefore have to undertake any maintenance or repairs in line with the OEMs' original requirements. Similarly, MROs in the civil aviation field are only legally allowed to carry out maintenance and repairs in line with OEMs' requirements as set out in Maintenance Manuals. Long service lives therefore translate to on-going requirements for the use of the chromates in the production of spare parts and in the maintenance of those spare components and the final products and aircraft/equipment they are used in.

As such, a review period of at least 12 years is warranted and requested for the highly complex systems the ADCR is addressing in this Review Report. 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 passivation of stainless steel, however, the industry is committed to the goal of substitution. A 12-year review period will enable the implementation of the significant (additional) investment in R&D, qualification and certification of design/drawing changes and industrialisation required across the various OEMs.

6.4.3 Criterion 2: Cost of moving to substitutes

Cr(VI) coatings were validated/certified in the 1950s and 60s and extensive in-service performance has demonstrated the performance of chromated materials. This includes modifications to design practice and material selection based upon resolution of issues noted in service. Chromate-based passivation, due to its extensive performance history, represent the baseline that alternatives must match to demonstrate equivalence.

For example, modern commercial aircraft (including helicopters) in their entirety consist of between 500,000 to 6 million components, depending on the model. Depending on the materials of construction, 15-70% of the entire structure of an aircraft requires treatment using Cr(VI) at some point during the manufacturing process. Older models generally require a larger percentage of Cr(VI) surface treatments as the aerospace industry has worked diligently to incorporate new base materials and Cr(VI)-free protective coatings in newer models wherever it is safe to do so.

There are literally billions of flight hours' experience with components protected from corrosion by chromate-based passivation. Conversely, there is still limited experience with Cr(VI)-free alternatives on components. It is mandatory that components coated using a Cr(VI)-free alternative are demonstrably every bit as safe as they had been when coated using a Cr(VI) product. The performance of Cr(VI)-free products can sometimes be demonstrated at the laboratory step but then fails at industrial scale, as it is impossible to replicate all in-service conditions in a laboratory. As a result, the time taken to progress through the TRL process may be increased until it is possible for the performance of the alternative to be demonstrated as per safety requirements at the aircraft level when operating under real life conditions.

Flight safety is paramount and cannot be diminished in any way. Take, for example, a compressor blade that is located in the middle of an engine. If that blade can only survive for a portion of the life of an engine because of service life (and hence maintenance requirement) limitations due to a new coating, the engine would need to be disassembled to be able to access the blades. That means taking the engine off the wing, sending it to a Repair Center, disassembling the engine and replacing the components at much shorter intervals than previously needed for the remainder of the engine. This would add inherent maintenance time and costs to the manufacturers; operators; and eventually end-use customers.

Where possible, and for specific components and final products, some new designs have been able to utilize newly developed alloys that do not require a Cr(VI)-based coating (as typically used to provide corrosion protection on metallic legacy components). However, even in newer designs there may still be a need for the use of chromate-based passivation which cannot be replaced at present due to safety considerations.

These technical hurdles are a fundamental reason why the A&D industry requests a review period of at least 12 years.

6.4.4 Criteria 3 & 7: Results of R&D on alternatives and availability of alternatives over the longer term

Research into the substitution of the chromates has been on-going for several decades. Although use continues, it should be recognised that significant achievements have been made over this period in the substitution of the use of the chromates by alternative substances or technologies. This is illustrated by the achievements of one of the OEMs in reducing by 75% (reduction by weight) of their level of dependency on use of the chromates (see **Figure 6-3**).

This 75% reduction in the use of the chromates by weight reflects the massive efforts and investment in R&D aimed specifically at substitution of the chromates. Although these efforts have enabled substitution across a large range of components and products, this OEM will not be able to move to substitutes for chromate-based passivation (its single most important on-going use of the chromates) across all components and products for at least 12 years, and perhaps longer for those components and products which have to meet military requirements (including those pertaining to UK, EEA and US equipment).

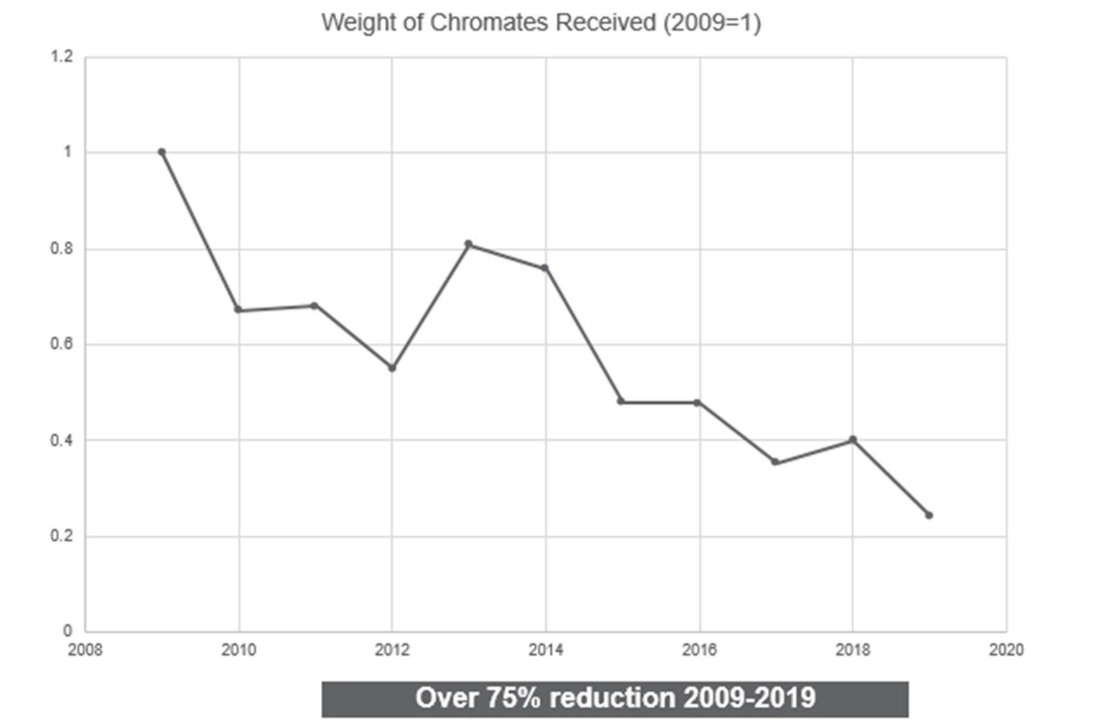

Figure 6-3: Reductions in chromate dependency over the period 2009 -2019

The European aerospace and defence security industry is heavily regulated to ensure passenger/operator safety. The consequence is that there are very long lead times and testing cycles before technologies developed from a research project can be implemented into real products. Technologies which are available on the market today are the result of extensive research, including research funded by grants and conducted over the last 25+ years. In 2020, the European A&D industries spent an estimated €18 billion in Research & Development (with an approximate 40:60 split between civil and military activities, and investment in R&D in the US roughly four times higher)[96].

A PricewaterhouseCoopers (PwC) study[97] refers to the high risks of investments in the aerospace industry: "Historically, step changes have been the norm in aircraft R&D. But recent development efforts have been so expensive that it is unclear whether the companies will earn the anticipated return on their investments. Furthermore, slips in the program schedule have worsened the economics."

Corrosion prevention systems are critical to aircraft safety. Testing in environmentally relevant conditions to assure performance necessarily requires long R&D cycles for alternative corrosion prevention processes. A key factor driving long timeframes for implementation of fully qualified components using alternatives by the aerospace and defence industry is the almost unique challenge of obtaining relevant long-term corrosion performance information. In the case of passivation, it

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

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

requires testing of changes in a process of corrosion protection, which includes changes in the primers (another step in the process) applied to a passivation treated component or product.

Aerospace companies cannot apply a less effective corrosion protection process as aviation substantiation procedures demand component performance using alternatives to be equal or better. If such performance is not achieved, then the alternatives cannot be used. The implications for repair, replacement and overhaul must also be understood before moving to an alternative. In particular, it must be recognised that the performance delivered by one component is dependent upon the performance of other components; thus, the performance delivered by a final product is dependent upon the components used. The number of configurations of components and final products is immense, and each configuration may differ from the next in terms of its behaviour with a Cr(VI) alternative.

As noted previously, there is a complex relationship between each component and its performance requirements within its own unique design parameters, which requires component certification for each individual substitution.

6.4.5 Criterion 4: Legislative measures for alternatives

As discussed in detail in section 3.1.2, the identification of a technically feasible Cr(VI)-free formulation is only the first stage of an extensive multi-phase substitution process leading to implementation of the alternative. This process, illustrated below, requires that all components, materials and processes incorporated into an A&D system must be qualified, validated, certified and industrialised before production can commence. Each phase must be undertaken to acquire the necessary certification to comply with airworthiness and other safety-driven requirements.

From start to finish, significantly more than 12 years is required to move from Phase 1 to Phase 5 (i.e. to identify, qualify, validate, certify and industrialise alternatives) for all critical A&D applications. The ADCR OEMs and DtBs as design owners are currently working through this process with the aim of implementing chromate-free passivation by 2036; their current substitution plans are designed to ensure they achieve TRL9 and MRL10 within the next 12 years or sooner. This includes gaining airworthiness certification or military safety approvals, both of which can take up to several years to ensure safety and reliability.

In addition, several of the ADCR members note that military procurement agencies prefer key components of defence equipment to be produced in the EEA, although there are also international agreements enabling manufacture in partner countries. In contrast to other industry sectors, shifting production to a non-EEA territory and import of finished surface treated components or products into the EEA is more complex, as it could create a dependence on a non-EEA supplier in a conflict situation.

They also note that the provision of defence exemptions, as allowed for in Article 2 (3) of the REACH regulation, is **not** a suitable instrument to ensure the continued availability of the chromates for passivation of stainless steel 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 passivation by several actors in several EU member states (i.e. it often relies on a transnational supply chain). In contrast, defence exemptions are valid at a national level and only for the issuing member state. Furthermore, the defence exemption process cannot be used as an alternative to the normal authorisation process unless this is necessary for confidentiality reasons and in the interest of defence. Thus, defence applications also need to be covered by the normal authorisation process.

Finally, the EEA defence sector requires only small quantities of chromates in passivation. On the basis of a defence exemption alone, the quantities demanded would not be sufficient for manufacturers, formulators and surface treatment companies to continue to offer their services and products. As a result, passivation of stainless steel components for use in for military aircraft and equipment would not continue in the EEA or UK if other civilian applications were not also possible. This can only be ensured by the granting of an authorisation.

6.4.6 Criterion 5 & 6: Comparison of socio-economic benefits and risks to the environment and effective control of the remaining risks

As demonstrated by the information collected by the SEA questionnaire, A&D companies have invested in monitoring and the installation of additional risk management measures in response to the conditions placed on the continued use of the chromates under the initial (parent) authorisations. This has resulted in reduced exposures for both workers and reduced emissions to the environment. As substitution progresses across components and assemblies and the associated value chains, consumption of the chromates will decrease, and exposures and emissions will reduce further over the requested 12 year review period. As a result, the excess lifetime risks derived in the CSR for both workers and humans via the environment will decrease over the review period. These risks will also be controlled through introduction in 2017 of the binding occupational exposure limit value on worker exposures to Cr(VI) at the EU level under the Carcinogens and Mutagens Directive[98].

The European aerospace and defence industry is a world-class leader in technology and innovation. They are an essential part of the European economy contributing to job creation (880,000 direct jobs in 2020[99]) and Europe's trade balance (55% of products developed and built in the EEA are exported).

Civil aeronautics alone accounted for around €99.3 billion in revenues, with military aeronautics accounting for a further €47.4 billion in turnover; overall taking into account other defence and space turnover, the sector had revenues of around €230 billion. Of the €99.3 billion in civil aeronautics turnover, €88.3 billion represented exports from the EU.

Both acknowledged market reports of Airbus and Boeing find a growing trend in the aerospace industry. Passenger air traffic is predicted to grow at 3.6% CAGR for 2022-2041 and freight traffic to grow at 3.2% CAGR globally, according to Airbus' Global Market Forecast. By 2041, there will be some 46,900 aircraft in service, with this including an estimated 39,500 new passenger and freighter aircraft (and the retirement of some of the older aircraft. This includes delivery of new aircraft for the European market, as well as the Asian and Chinese markets in particular.[100]

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[98] 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

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

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

Boeing's 2022 Commercial Market Outlook[101] indicates a similar level of increase, noting that the global fleet will increase by around 80% through to 2041 with the forecast value of new airplane deliveries at around US $7.2 trillion (based on a slightly higher growth in traffic at around 3.8% CAGR.

The socio-economic benefits of retaining the key manufacturing base of the EEA and UK A&D industries are clearly significant, given that they will be major beneficiaries of this growth in demand. As demonstrated in the socio-economic analysis presented here, even without accounting for such growth in demand under the Continued Use Scenario, the socio-economic benefits clearly outweigh the associated risks to human health at social costs to risk ratios of over 3,560 to one for the EEA and 1,426 to one for the UK.

6.5 Substitution effort taken by the applicant if an authorisation is granted

As the AoA shows, where alternatives have been proven as technically feasible – on a component-by-component basis – they have been or are in the process of being implemented. However, there are still many cases where components do not have technically feasible alternatives available. **Figure 3-3** highlights the actions that are being taken by A&D design owners to develop, qualify, validate, certify and industrialise alternatives for individual components.

This work will continue over the requested review period with the aim of phasing out all uses of chromate-based passivation. As illustrated in Section 4.4, on-going substitution is expected to result in significant decreases in the volumes of the two chromates used in passivation within the next seven years. However, technically feasible alternatives are still at the development phase (Phase 1 out of the 5 phases) for some components and final products, where alternatives have not been found to meet performance requirements.

6.6 Links to other Authorisation activities under REACH

This combined AoA/SEA is one of a series of applications for the re-authorisation of the use of chromium trioxide in surface treatments carried out by the A&D industry. This series of Review Reports has adopted a narrower definition of uses original Authorised under the CTAC, CCST and GCCA parent applications for authorisation. Please see the Explanatory Note for further details.

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

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

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

8) Passivation of non-Al metallic coatings
9) Inorganic finish stripping
10) Chromate rinsing after phosphating
11) Slurry coatings

7 References

Acciai, T. and Terni, S. (2007) *Pickling and Passivating Stainless Steel Materials and Applications Series, Volume 4 Euro Inox*. Available at: www.ugine-alz.comwww.bssa.org.ukCedinoxwww.cedinox.es (Accessed: 25 November 2020).

Airbus (2009) ‘FAST45 magazine’. Available at: http://www.airbus.com/en/services/publications/ (Accessed: 16 August 2022).

Airbus SAS (2022) *Laboratory Testing | Engineering & Design Services | Expand | Services | Airbus Aircraft*. Available at: https://aircraft.airbus.com/en/services/expand/engineering-design-services/laboratory-testing (Accessed: 15 August 2022).

Askari, M. *et al.* (2021) ‘Downhole corrosion inhibitors for oil and gas production – a review’, *Applied Surface Science Advances*, 6, p. 100128. Available at: https://doi.org/10.1016/J.APSADV.2021.100128.

Cao, P., Wells, D. and Short, M.P. (2017) ‘Anisotropic ion diffusion in α-Cr2O3: an atomistic simulation study’, *Physical Chemistry Chemical Physics*, 19(21), pp. 13658–13663. Available at: https://doi.org/10.1039/C7CP00838D.

CARACAL (2017) *REACH Authorisation - Criteria for longer review periods*.

CCST (2015) *Dichromium tris(chromate) AoA, use 2 (0045-02)*.

CCST Consortium (2015) *Sodium dichromate AoA, use 2 (0043-02)*. Available at: https://echa.europa.eu/documents/10162/1816486e-348f-42a9-bc88-02d52ddfd891 (Accessed: 28 July 2021).

Corrosionpedia (2022) *7 Things to Know About Flash Rust*. Available at: https://www.corrosionpedia.com/7-things-to-know-about-flash-rust/2/6695 (Accessed: 7 September 2022).

CTAC (2015) *Chromium trioxide AoA, use 4 (0032-04)*. Available at: https://echa.europa.eu/documents/10162/c82315c4-df7f-4e81-9412-eb90fcd92480 (Accessed: 26 August 2021).

Donlan, R.M. (2002) *Biofilms: Microbial Life on Surfaces*, *Emerging Infectious Diseases •*. Available at: http://www.microbelibrary.org/.

EASA (2012) *European Aviation Safety Agency GOOD PRACTICES Coordination between Design and Maintenance First Installation of a Change to a Product*.

ECHA (2013) *SETTING THE REVIEW PERIOD WHEN RAC AND SEAC GIVE OPINIONS ON AN APPLICATION FOR AUTHORISATION*.

Elsevier B.V. (2022) *ScienceDirect.com | Science, health and medical journals, full text articles and books.* Available at: https://www.sciencedirect.com/ (Accessed: 24 August 2022).

EPO (2020) *EPO - Espacenet: patent database with over 120 million documents*.

EU (2018) *Regulation (EU) 2018/1139 | EASA*. Available at: https://www.easa.europa.eu/document-library/regulations/regulation-eu-20181139 (Accessed: 2 September 2022).

GCCA (2017a) *Dichromium tris(chromate) AoA, use 1 (0116-01)*. Available at: https://www.echa.europa.eu/documents/10162/1a0be468-61e2-e452-bb57-f6e1375ccde0 (Accessed: 11 August 2022).

GCCA (2017b) *Dichromium tris(chromate) AoA, use 2 (0116-01)*.

Gharbi, O. *et al.* (2018) ‘Chromate replacement: what does the future hold?’, *npj Materials Degradation 2018 2:1*, 2(1), pp. 1–8. Available at: https://doi.org/10.1038/s41529-018-0034-5.

el Ibrahimi, B. *et al.* (2020) ‘Amino acids and their derivatives as corrosion inhibitors for metals and alloys’, *Arabian Journal of Chemistry*, 13(1), pp. 740–771. Available at: https://doi.org/10.1016/J.ARABJC.2017.07.013.

Information on Chemicals - ECHA (no date). Available at: https://echa.europa.eu/information-on-chemicals (Accessed: 24 August 2022).

Jaworowski, M. (2000) ‘Coatings for Low Temperature Corrosion Protection", Lecture Notes, Rensselaer Polytechnic Institute’.

Ma, L. *et al.* (2019) ‘Origin of nanoscale heterogeneity in the surface oxide film protecting stainless steel against corrosion’, *Nature* [Preprint]. Available at: https://doi.org/10.1038/s41529-019-0091-4.

Ma, L. *et al.* (2021) ‘Nanoscale early oxidation mechanisms of model FeCrNi austenitic stainless steel surfaces at room temperature’, *Corrosion Science* [Preprint]. Available at: https://doi.org/10.1016/j.corsci.2021.109653ï.

Malinovskis, P. *et al.* (2018) ‘Synthesis and characterization of multicomponent (CrNbTaTiW)C films for increased hardness and corrosion resistance’, *Materials & Design*, 149, pp. 51–62. Available at: https://doi.org/10.1016/J.MATDES.2018.03.068.

Marcus, P. (2017) ‘Philippe Marcus - ECS Olin Palladium Award Lecture - YouTube’, in. Available at: https://www.youtube.com/watch?v=WkdJoWy_bM4 (Accessed: 17 August 2022).

Noblis (2016) ‘Cadmium and Hexavalent Chromium Alternatives 5-Year Strategy and Roadmap, Contract # W9128F-12-D-0041’.

Rheinmetall – Systems & Products (no date). Available at: https://rheinmetall-defence.com/en/rheinmetall_defence/systems_and_products/index.php#Milit%C3%A4rischeFahrzeuge (Accessed: 17 August 2022).

Rowbotham, J. and Fielding, T. (2016) ‘Intended and unintended consequences of REACH’, *Aerospace Coatings*, pp. 26–27. Available at: www.coatingsgroup.com (Accessed: 30 March 2022).

Royal Academy of Engineering (2014) ‘Innovation in aerospace’, (June 2014), pp. 1–21. Available at: http://www.raeng.org.uk/publications/reports/innovation-in-aerospace.

Royal Navy (2021) *Osprey tiltrotor*. Available at: https://www.royalnavy.mod.uk/news-and-latest-activity/news/2021/april/01/20210401-osprey-mounts (Accessed: 17 August 2022).

Sarmento, V.H.V. *et al.* (2010) ‘Corrosion protection of stainless steel by polysiloxane hybrid coatings prepared using the sol–gel process’, *Surface and Coatings Technology*, 204(16–17), pp. 2689–2701. Available at: https://doi.org/10.1016/J.SURFCOAT.2010.02.022.

Soufeiani, L. *et al.* (2020) ‘Corrosion protection of steel elements in façade systems – A review’, *Journal of Building Engineering*, 32, p. 101759. Available at: https://doi.org/10.1016/J.JOBE.2020.101759.

Thyssenkrupp AG (2022) *Stainless Steel Composition What Is It? - thyssenkrupp Materials (UK)*. Available at: https://www.thyssenkrupp-materials.co.uk/stainless-steel-composition.html (Accessed: 3 August 2022).

TREND Programme - Research & Development in the Czech Republic (no date). Available at: http://www.czech-research.com/rd-funding/national-funds/relevant-programmes/trend-programme/ (Accessed: 27 August 2022).

Vezina, N. (no date) ‘Monitoring Passivation on Stainless Steel with Open Circuit Potential Technology Walter Surface Technologies Monitoring Passivation on Stainless Steel with Open Circuit Potential Technology’.

Wikipedia (2021) *Galling - Wikipedia*. Available at: https://en.wikipedia.org/wiki/Galling (Accessed: 4 September 2022).

Yuan, S. *et al.* (2020) ‘Recent developments in research of double glow plasma surface alloying technology: a brief review’, *Journal of Materials Research and Technology*, 9(3), pp. 6859–6882. Available at: https://doi.org/10.1016/J.JMRT.2020.03.123.

ZHANG, X. man *et al.* (2022) ‘Corrosion resistances of metallic materials in environments containing chloride ions: A review’, *Transactions of Nonferrous Metals Society of China (English Edition)*, 32(2), pp. 377–410. Available at: https://doi.org/10.1016/S1003-6326(22)65802-3.

Zunita, M. and Kevin, Y.J. (2022) ‘Ionic liquids as corrosion inhibitor: From research and development to commercialization’, *Results in Engineering*, 15, p. 100562. Available at: https://doi.org/10.1016/J.RINENG.2022.100562.

8 Annex 1: Standards applicable to passivation of stainless steel

Table 8-1 lists examples of standards and specifications reported by ADCR members applicable to the use passivation of stainless steel. 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 passivation of stainless steel key functions

Standard Reference	Standard Description	Key function/Standard type
(SAE)QQ-P-35, Type II	Passivation Treatments for Corrosion-Resistant Steel (Medium temperature nitric acid solution with sodium dichromate additive). Use on austenitic, ferritic, martensitic and precipitation hardening corrosion resistant steels	Corrosion resistance: Covers the different types of passivation treatments as well as recommendations, guidance and precautions for cleaning and descaling corrosion-resistant parts, components, equipment, and systems
SAE-AMS 2700, Type 1	Passivation of Corrosion Resistant Steels (Low Temperature Nitric acid with sodium dichromate)	Industry QC spec
SAE-AMS 2700, Type 2	Passivation of Corrosion Resistant Steels (Medium Temperature Nitric acid with sodium dichromate)	Industry QC spec
SAE-AMS 2700, Type 3	Passivation of Corrosion Resistant Steels (High Temperature Nitric acid with sodium dichromate)	Industry QC spec
SAE-AMS 2700, Type 4	Passivation of Corrosion Resistant Steels (40% Nitric acid for Free Machining Steels)	Industry QC spec
SAE-AMS 2700, Type 5	Passivation of Corrosion Resistant Steels (Anodic, for High Carbon Martensitic Steels)	Industry QC spec
BS EN 2516 C2	Passivation of Corrosion Resisting Steels and Decontamination of Nickel Base Alloy (Austenitic, precipitation hardening and duplex stainless steel)	Aerospace series. Passivation of corrosion resisting steels and decontamination of nickel base alloys is classified in these ICS categories: 1. 49.040 Coatings and related processes used in aerospace industry(a)
AMS2700F	Passivation of Corrosion Resistant Steels	Requirements for a process to assure removal of free iron or other less noble contaminants from the surfaces of corrosion resistant steel parts(b)
AMS03-2C method M	Cleaning and Preparation of Metal Surfaces	Processes for the cleaning of metal surfaces to remove any extraneous or undesirable material or deposits at any stage of manufacture, storage, or service and for the preparation of these surfaces for further treatment. Any necessary stress-relieving treatments are also included (c)

ASTM A967	Standard Specification for Chemical Passivation Treatments for Stainless Steel Parts	Chemical passivation treatments for stainless steel parts. The tests in this specification are intended to confirm the effectiveness of passivation, particularly with regard to the removal of free iron and other exogenous matter. This specification makes no recommendations regarding the suitability of any grade, treatment, or acceptance criteria for any particular application or class of applications(d)
ASTM A380	Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems	Standard recommendations and precautions for cleaning, descaling, and passivating of new stainless steel parts, assemblies, equipment, and installed systems. Consideration shall be given in the design of parts, equipment, and systems that will require cleaning to minimise the presence of areas in which dirt, or cleaning solutions might become trapped, and to provide for effective circulation and removal of cleaning solutions(e)
ASTM F519	Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating/Coating Processes and Service Environments	Describes mechanical test methods and defines acceptance criteria for coating and plating processes that can cause hydrogen embrittlement in steels(f)
ISO 2409	Paints and varnishes – Cross-cut test	Assessing the resistance of subsequent layers (paints and varnishes) to separation from substrates when a right angle lattice pattern is cut into the coating penetrating through to the substrate(g)
ISO 2812-1	Paints and varnishes — Determination of resistance to liquids. Immersion in liquids other than water	Chemical resistance(h)

Source:

a) BS EN 2516 C2
b) AMS2700F: Passivation of Corrosion Resistant Steels - SAE International
c) AMS03_2C: Cleaning and Preparation of Metal Surfaces - SAE International
d) Standard Specification for Chemical Passivation Treatments for Stainless Steel Parts (astm.org)
e) Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems (astm.org)
f) Standard Test Method for Mechanical Hydrogen Embrittlement Evaluation of Plating/Coating Processes and Service Environments (astm.org)
g) ISO - ISO 2409:2020 - Paints and varnishes — Cross-cut test
h) ISO - ISO 2812-1:2017 - Paints and varnishes — Determination of resistance to liquids — Part 1: Immersion in liquids other than water

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.

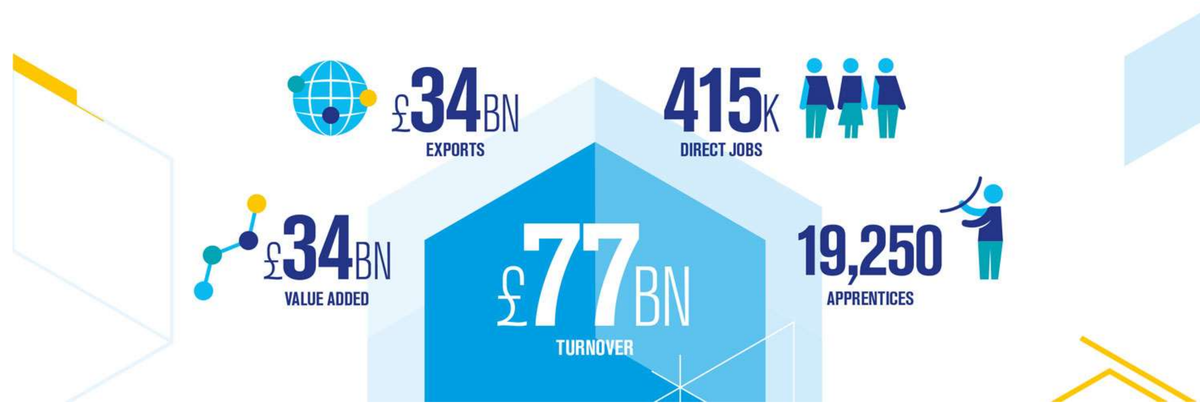

Figure 10-1: Contribution of UK aerospace, defence, security and space sectors to the economy in 2020[102]

The UK aerospace sector is considered by the government to be "hugely important to the UK economy"[103], 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)[104]. 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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[102] https://www.adsgroup.org.uk/wp-content/uploads/sites/21/2022/06/ADS-FF2022-Twit-header-72.jpg

[103] BEIS, Aerospace Sector Report, undated.

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

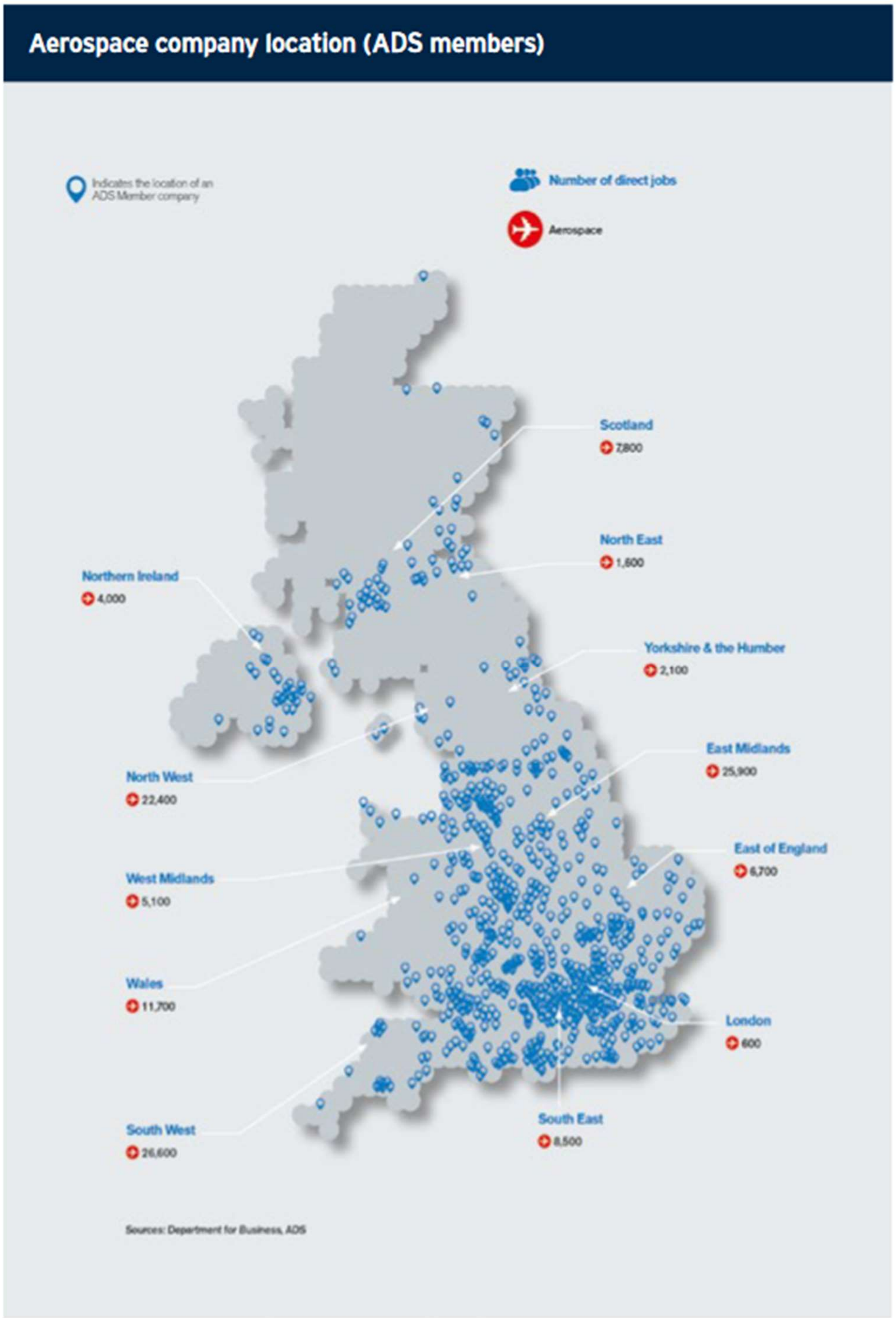

Figure 10-2: Location of aerospace manufacturing sites and associated jobs in the UK[105]

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

The National Aerospace Technology Exploitation Programme was created in 2017 to provide research and technology (R&T) funding with the aim of improving the competitiveness of the UK aerospace industry, as well as other supporting measures under the Industrial Strategy. The Government's investment in R&T is through the Aerospace Technologies Institute and is programmed at £1.95 billion in expenditure between 2013-2026.

This will help in maintaining the current expected market development in the UK, which would see a 2.3% per year growth in real terms, leading to direct added value of just over £14 billion in 2035 (compared to £9 billion in 2016). In 2016, the UK aerospace sector employed around 112,500 people, with each direct job in the aerospace industry creating at least one additional job within the aerospace supply chain. This gives around 225,000 people directly and indirectly employed by the aerospace sector in high-value design and high value manufacturing jobs. By maintaining its current direction of growth, the sector is expected to create up to a further 45,000 positions by 2035.

The value of the sectors is also significant in wider economic terms. Investment in aerospace research and technology leads to wider impacts beyond the sector. Every £100 million spent on R&T by the government crowds-in around £300 million of additional private sector investment. Furthermore, every £100 million invested benefits not only UK aerospace GVA by £20 million per year, but also the wider economy by £60 million per year through technology spillovers. These include automotive, marine, oil and gas, nuclear, electronics, composites, metals and other UK industrial sectors. In total, the return on government investment in the sector is estimated as delivering an additional £57 billion of gross value added for the UK aerospace sector and a further £57 billion to the wider UK economy between 2015 and 2035.

10.2 Defence

With respect to defence, the UK is the second largest defence exporter in the world, with its contribution to employment, turnover, and exports illustrated in **Figure 10-3**[106]. 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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[106] Sources: https://www.adsgroup.org.uk/industry-issues/facts-figures/facts-figures-2022/

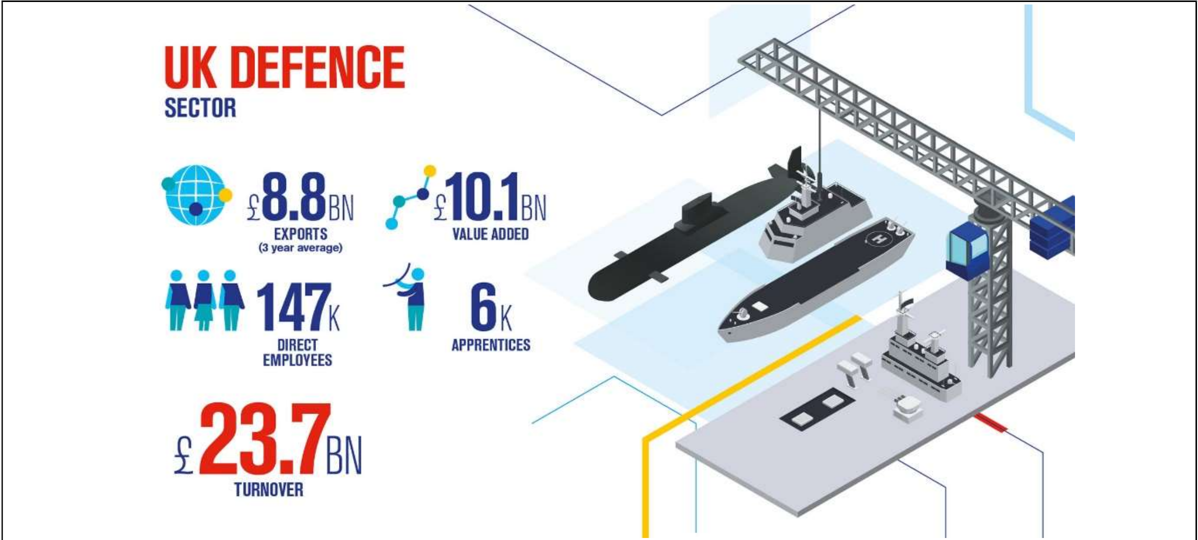

Figure 10-3: UK defence sector contribution to the economy in 2021