ANALYSIS OF ALTERNATIVES

and

SOCIO-ECONOMIC ANALYSIS

Complete version

Legal name of applicant(s):	PPG Industries (UK) Ltd
Date:	10 July 2024
Substances:	- Potassium hydroxyoctaoxodizincate dichromate
Use title:	Use of wash primers containing potassium hydroxyoctaoxodizincate dichromate in aerospace and defence industry and its supply chains
Use number:	1

Note

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

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Abbreviations

ADCR – Aerospace and Defence Chromates Reauthorisation

A&D – Aerospace and Defence

AfA – Application for Authorisation

AoA – Analysis of Alternatives

AoG – Aircraft on the Ground

BCR – Benefit to Cost Ratio

BtP – Build-to-Print manufacturer

BSI – British Standards Institution

CAA – Civil Aviation Authority

CAGR – Compound Annual Growth Rate

CCC – Chemical Conversion Coating

CCST – Chromium VI Compounds for Surface Treatment

CFC – Consumption of fixed capital

CMR – Carcinogen, Mutagen or toxic for Reproduction

Cr(VI) – Hexavalent chromium

CSR – Chemical Safety Report

CT – Chromium trioxide

CTAC – Chromium Trioxide Authorisation Consortium

DOA – Design Organisation Approval

DtB – Design-to-Build manufacturer

DtC – Dichromium tris(chromate)

EACP – European Aerospace Cluster Partnership

EASA – European Aviation Safety Agency

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

ECHA – European Chemicals Agency

EEA – European Economic Area

EHS – Environment, Health and Safety

ESA – European Space Agency

EU – European Union

GB – Great Britain

GCCA – Global Chromates Consortium for Authorisation

GDP – Gross Domestic Product

GOS – Gross Operating Surplus

GVA – Gross Value Added

HvE – Humans via the Environment

ICAO – International Civil Aviation Organisation

ISO – International Organization for Standardization

LEV – Local exhaust ventilation

MoD – Ministry of Defence

MRL – Manufacturing readiness level

MRO – Maintenance, Repair, and Overhaul

MSG-3 – Maintenance steering group 3

NACE – Nomenclature of Economic Activities

NATO – North Atlantic Treaty Organisation

NI – Northern Ireland

NPV – Net Present Value

NSS – Neutral salt spray

NUS – Non-use scenario

OELV – Occupational Exposure Limit Value

OEM – Original Equipment Manufacturer

ONS – Office for National Statistics

PCO – Pentazinc chromate octahydroxide

PHD – Potassium hydroxyoctaoxodizincatedichromate

PPE – Personal protective equipment

RAC – Risk Assessment Committee

R&D – Research and Development

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

SEG – Similar exposure groups

SIC – Standard Industrial Classification

SME – Small and medium-sized enterprises

SVHC – Substance of Very High Concern

T&E – Testing and Evaluation

TRL – Technology Readiness Level

TSA – Tartaric-sulphuric acid anodising

UK – United Kingdom

WCS – Worker Contributing Scenario

Glossary

Term	Description
Active Corrosion Inhibition	The ability of a corrosion protection system to spontaneously restore corrosion protection following damage to the original coating 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.
Adhesive failure	The state when the adhesive loses adhesion from one of the bonding surfaces. It is characterised by the absence of an adhesive on one of the material surfaces.
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 without destruction of designed use except welded and bonded parts, 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.

Term	Description
Bond strength	The amount of adhesion between bonded surfaces. It is measured by the stress needed to separate the bonded layers from each other.
Bonding primer	Bonding primers (sometimes referred to as adhesive bonding primers) provide corrosion resistance and promote and maintain adhesion between a substrate and an adhesive material.
Build-to-Print (BtP)	Companies that undertake specific processes, dictated by the Original Equipment Manufacturer (OEM), to build A&D components.
Certification	The procedure by which a party (Authorities or MOD/Space customer) gives written assurance that all components, equipment, hardware, services, or processes have satisfied the specific requirements. These are usually defined in the Certification requirements.
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.
Cohesive failure	A breakdown of intermolecular bonding forces in a given adhesive substance. This type of failure occurs in the bulk layer of the adhesive.
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 fatigue	Corrosion fatigue is fatigue in a corrosive environment. It is the mechanical degradation of a material under the joint action of corrosion and cyclic loading
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".
Dynamic performance	Dynamic performance is the requirement for a combination of chemical resistance and mechanical cycling at high and low temperatures.
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.

Term	Description
Formulation	A mixture of specific substances, in specific concentrations, in a specific form.
Formulator	Company that manufactures formulations (may also design and develop formulations).
Gross Domestic Product (GDP)	The standard measure of the value added created through the production of goods and services in a country during a certain period. As such, it also measures the income earned from that production, or the total amount spent on final goods and services (less imports).
Gross Operating Surplus	Equivalent to economic rent or value of capital services flows or benefit from the asset.
Gross Value Added	The value of output less the value of intermediate consumption; it is a measure of the contribution to GDP made by an individual producer, industry or sector.
Hardness	Ability of a material to withstand localised permanent deformation, typically by indentation. Hardness may also be used to describe a material's resistance to deformation due to other actions, such as cutting, abrasion, penetration and scratching.
Heat resilience	The ability of a coating or substrate to withstand repeated cycles of heating and cooling and exposure to corrosive conditions. Also known as cyclic heat-corrosion resistance.
Hot corrosion resistance	The ability of a coating or substrate to withstand attack by molten salts at temperatures in excess of 400°C.
Industrialisation	The final step of the substitution process, following Certification. After having passed qualification, validation, and certification, the next step is to industrialise the qualified material or process in all relevant activities and operations of production, maintenance, and the supply chain. Industrialisation may also be referred to as implementation.
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	A global accreditation programme for aerospace engineering, defence and related industries, administered by the Performance Review Institute (PRI).
Net Present Value	See Present Value; It is obtained by discounting future flows of net 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	Present Value is the current value of future flows of benefits or costs discounted at the appropriate discount rate.

Term	Description
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.
Processing temperature	The temperature at which a process, or part of a process (such as curing cycle) takes place.
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'.
Protective primer[1]	Those primers and speciality coatings, the use of which is authorised under Authorisation decisions C(2020)2076, C(2020)2089, C(2020)6231, and C(2020), excepting bonding primers and wash primers.
Qualification	1. Part of the substitution process following Development and preceding Validation to perform screening tests of test candidate(s) before determining if further validation testing is warranted. 2. The term qualification is also used during the industrialisation phase to describe the approval of suppliers to carry out suitable processes.
Requirement	A property that materials, components, equipment, or processes must fulfil, or actions that suppliers must undertake.
Resistivity	Property that quantifies how a given material opposes the flow of electric current. Resistivity is the inverse of conductivity.
Rework	The process of correcting defective, failed, or nonconforming components after inspection and before delivery to the customer.
Social Cost	All relevant impacts which may affect workers, consumers and the general public which 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 the 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 of materials, parts/components, assemblies, sub-systems, and systems.

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[1] *The use name 'Primer products other than wash or bonding primers' is condensed to the term 'protective primers'. This encompasses one or more of the various forms of this primer use; basic, structural, fuel tank and aluminised. 'Protective primers' are covered by another ADCR application, i.e. not in this application.'*

Term	Description
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	Value of avoiding a fatality. It is used in monetising cancer mortality risks in this document.
Verification	The process of establishing and confirming compliance with relevant procedures and requirements.
Wash primer	A thin coating applied usually prior to a primer or topcoat scheme. Where higher corrosion protection is required, in most cases, the wash primer has to be overcoated by a basic primer before the final coating is applied. Wash primers passivate the surface by neutralising metal (hydr)oxides and/or etching the surface.
Wear resistance	The ability of a surface to withstand degradation or loss due to frictional movement against other surfaces.
Sources: GCCA and ADCR consortia	

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 has developed several Review Reports and new applications on behalf of the applicants. These Review Reports or new applications cover all uses of chromates in primer products 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 civil and military aviation (including rotorcraft e.g. helicopters), ground-based defence/security and space industries, as well as aeroderivative products.

The aerospace and defence (A&D) industry has been working towards the substitution of Cr(VI) across various uses for the past 25-30 years. Although there have been successes and levels of use have decreased significantly, the specific use of hexavalent chromium compounds in wash primers[2] is still required for many components. This use 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 GB society and economy more generally.

1.2 Availability and suitability of alternatives

For the past several decades, ADCR members who are “design owners” (including Original Equipment Manufacturers (OEMs) and Design-to-Build (DtB) manufacturers) selling products used in civil and military aviation, space industries and others involved in producing, maintaining, or using military material for land, naval or aerospace use have been searching for alternatives to the use of the two chromates for wash primers as a specific use. At the current time, the remaining uses form a part of an overall system providing the following key functions (see also Section 3.1.1.1):

- Corrosion resistance (including ‘active corrosion inhibition’);
- Adhesion promotion;
- Chemical resistance;
- Temperature resistance;
- Layer thickness;
- Compatibility with substrate/other coatings; and

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[2] Review Reports are also being submitted by the ADCR covering three other uses of the chromates in formulation and other primer-types as more narrowly defined by the ADCR.

- Compatibility with processing temperatures

Other factors to consider include a variety of performance requirements in addition to the above key functions, see Section 3.2.1.1, which need to be taken into account when assessing test candidate alternatives.

Cr(VI)-based wash primers are corrosion inhibiting coatings of liquid consistency. These are applied most commonly to bare metal substrates (but also to substrates which have undergone prior surface treatment such as CCC or anodising) as a thin layer which etches the substrate and converts into solid, adherent and tough film that provides adhesion promotion. Corrosion of metal surfaces can be influenced by a broad variety of factors, such as temperature, salinity of the environment, industrial environment, and component location. A&D products operate in highly challenging, extreme environments over extended timeframes. Due to these challenges, alongside engineering-based solutions, the A&D industry must use numerous high-performance mixtures which have passed through an extensive approval process to demonstrate their suitability for use.

OEMs (as design owners), in particular, have responsibility for certification of alternatives and have conducted a full analysis of their requirements into the future, taking into account progress of research and development (R&D), testing, qualification, certification and industrialisation activities. Companies are at different stages in the implementation of alternatives. 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 the minimisation of supply chain disruption and associated business risks, a 12-year review period is requested. Business risks arise from the need for alternatives to be available and deployed across all components and suppliers to ensure continuity of manufacturing activities across the supply chain. A shorter period could cause uncertainty impacting on the functioning of the current market, given the complexity of supply chain relationships.

Maintenance, repair, and overhaul (MRO) activities face additional constraints when implementing test candidates. This is because they are mandated to continue using the chromate primers if this is specified in Maintenance Manuals provided by the OEMs. This means they are legally obliged to carry out their activities in line with these Maintenance Manuals given their importance in maintaining the airworthiness and reliability of final products. Consequently, MROs cannot implement or adopt test candidates until OEMs have updated their Maintenance Manuals.

A number of test candidates have been developed and evaluated over decades in an effort to substitute Cr(VI)-based corrosion inhibitors in wash primers for the A&D sector. Candidates shortlisted as potential alternatives to Cr(VI) in wash primers for the A&D sector, include magnesium-rich primers, phosphate, zinc or zirconate-based corrosion inhibitors and silane-based coatings, as well as blends of two or more of these chemistries in proprietary formulations. While the status of test candidates has progressed since the submission of the parent applications for authorisation (AfAs), none have yet been identified which would constitute a generally suitable and available alternative to Cr(VI) in wash primers for the A&D sector. Key reasons for failure of test candidates have been an unacceptable regression in performance compared to the incumbent Cr(VI)-based wash primer treatments, particularly in provision of corrosion resistance and adhesion promotion.

As a result of the different requirements outlined above, at the sectoral level, there will be an on-going progression of alternate development and substitution over the requested 12-year review period.

1.3 Socio-economic benefits from continued use

The continued use of chromates in wash primer coating specifically 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, emergency services. It will also ensure the continued functioning of the aerospace and defence supply chains in GB, conferring the wider economic growth and employment benefits that come with this.

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

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

- OEMs and MROs will be able to rely on the use of chromates by their GB suppliers and in their own production activities and for providing maintenance and repair services. The avoided profit losses[3] to these companies under the continued use scenario would equate to between £87 and 159 million, over a 2-year period (PV discounted at 3.5%). 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 GB and meet the performance requirements of the OEMs. The associated profit losses that would be avoided under the non-use scenario for these companies are calculated at £7 to 158 million over a 2-year period (PV discounted at 3.5%);

- 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 wash priming are estimated at £177 million. These benefits are associated with the protection of over 1,800 jobs in GB;

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

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

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

The level of disruption caused to A&D customers and society in not being able to continue priming activities would outweigh the monetary losses to these companies and its value chain including OEMs, DtBs, BtP suppliers, MROs, and MoDs.

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[3] Two different approaches have been used to calculate economic impacts to produce lower and upper bound estimates. Profit losses are discounted over two years at 3.5% per annum.

1.4 Residual risk to human health from continued use

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

Furthermore, significant technical achievements have been made in developing and qualifying alternatives for use on some components/final products, although there remain technical challenges for other components and final products. As a result, it is projected that based on current company specific development 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 25 GB sites where chromate-based wash primers are anticipated as being used, an estimated total of 1,800 workers may be exposed to Cr(VI).

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 wash priming is considered to take place, an estimated 202,633 people in GB are calculated as potentially being exposed to Cr(VI) due to chromate-based wash primer activities. Again, these figures are conservative due to the on-going substitution of wash primers with alternatives.

The predicted number of cancer cases per annum and the annualised economic value of these social costs for both workers and humans via the environment are[4]:

- 0.01 fatal cancers and 0.01 non-fatal cancers per year over the 12-year review period, at a total social cost of £ 47,000 to 67,000 per year;

1.5 Comparison of socio-economic benefits and residual risks

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

- 619 to 1 for the lower bound of profit losses and unemployment costs or 761 to 1 for the upper bound profit losses and unemployment costs;

The above estimates represent a significant underestimate of the actual benefits conferred by the continued use of pentazinc chromate octahydroxide (PCO) and potassium hydroxyoctaoxodizincatedichromate (PHD) in wash primers, as it only encompasses benefits that could be readily quantified and monetised. The true benefit-cost ratios must be assumed to also encompass:

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[4] Discounted over 12 years at 3.5% per annum, and assuming a 10 year lag in effects.

- 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 GB due to stranded aircraft on the ground (AoG), reductions in available aircraft, increased flight costs, etc.;

- The avoided impacts on society more generally due to impacts on air transport and the wider economic effects of the high levels of unemployment within a skilled workforce, combined with the indirect and induced effect from the loss of portions of the A&D sector from GB 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 GB for maintenance, repair and overhaul (whether civilian or military) and production activities.

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

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

- Occupational exposure monitoring requirements were placed on downstream users within the applicants supply chain as part of the granting of the parent authorisations. The A&D industry has responded to these requirements by increasing the level of monitoring carried out, including increases in expenditure on worker monitoring and adaptations to the way in which monitoring was previously carried out. In the Risk Characterisation parts of the Chemical Safety Report (CSR), each of the Worker Contributing Scenario (WCS) sections compare the ADCR applications larger database of occupational exposure monitoring studies with those from the parent applications.

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

- A Binding Occupational Exposure Limit Value (OELV) has been introduced under EU Directive 2004/37/EC that will become more stringent after January 17th, 2025. This Binding OELV was recommended by the Tripartite Advisory Committee on Safety and Health based on consensus and will provide an additional level of protection for workers undertaking Cr(VI)- based primer activities. The sector is working with formulators to reduce the volume of chromates used in priming activities and, as indicated in the test candidate development plan, companies are progressing towards the certification and implementation of substitutes across on-going uses.

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

- **The costs of moving to alternatives are high, not necessarily due to the cost of the alternative substances but due to the strict regulatory requirements that must be met to ensure airworthiness and safety.** These requirements mandate the need for testing, qualification, and certification of components using the alternative wash primers. This process must 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 a final product for extensive periods of time, which is not only costly but may also be infeasible (due to the age of the final product, lack of testing facilities, age of available test vehicles (engines, aircraft, defence equipment, etc.)). On a cumulative basis, the major OEMs and DtB companies that act as the design owners could not afford to undertake action across the range and number of components that still require the qualification, certification, and industrialisation of alternatives without sufficient time and resources. These activities themselves are costing the companies hundreds of millions of Euros across all uses of Cr(VI).

- **The strict regulatory requirements that must be met generate additional, complex requalification, recertification, and industrialisation activities,** to ensure the continued airworthiness of aircraft and the safety and reliability of defence equipment (including air, naval and land-based systems). These requirements mean that there is no simple or single drop-in replacement for chromates in wash primers, which can be considered to be "generally available" following the European Commission's definition[5]. 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

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[5] 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: https://echa.europa.eu/documents/10162/13637/ec_note_suitable_alternative_in_general.pdf/5d0f551b-92b5-3157-8fdf-f2507cf071c1

economically feasible for the sector as a whole to have achieved full substitution within the seven-year period of the original authorisation. Although some companies have been able to qualify and certify alternatives for some of their components, others are still in the early phases of testing and development work due to alternatives not providing the same level of performance as chromates. They will not be able to qualify and certify a proposed or test candidate for some components within a seven-year time frame. It is also of note that wash primers are used throughout the supply chain and by large numbers of smaller suppliers. As a result, sufficient time will be required to fully implement alternatives through the value chain once they have been certified.

- Even then**, it may not be feasible for MROs to move completely away from the use of chromates in wash primers 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 chromates is required to ensure the operational capabilities of the military and the ability to comply with international obligations as partner nations at the UK level, 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 GB.** The sector needs certainty to be able to continue operating in GB 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 GB.

- As highlighted above and demonstrated in Section 5 and 6, **the socio-economic benefits from the continued use of potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide in wash primers significantly outweigh the risks of continued use.** The European A&D sector is a major exporter of final products and is facing a growing market for both its civilian and defence products which it can only serve if it retains its current strong industrial and supply chain base in GB. It will not be able to respond to this increased market demand if the continued use of chromates in wash primers 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 GB A&D sector must ensure not only that it meets regulatory requirements in GB, 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 (ADCR) Consortium

This review report is based on a grouping approach and covers all the chromates used in wash primers by the ADCR consortium members and companies in their supply chain. Wash primers, sometimes referred to as etch primers, are an example of a 'pre-treatment' coating, and are applied directly to a metal surface to provide surface etching, corrosion resistance and adhesion promotion. In some cases, wash primers are applied on substrates which have undergone prior surface treatment.

The use of chromates in wash primers is limited to those situations where it plays a critical (and currently irreplaceable) role in ensuring components meet product performance, reliability, and safety standards. In particular, those relating to airworthiness set by Civil Aviation Authority (CAA). This is also true with respect to their use in defence, space, and in aerospace derivative products, which include non-aircraft defence systems, such as ground-based installations or naval systems. Such products and systems must also comply with numerous other requirements including those of the European Space Agency (ESA) and of national MoDs.

This is an upstream application submitted by importers and/or formulators of chromates and chromate-containing primer 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 consortium 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 incidents of supply chain disruption that has arisen due to the COVID-19 pandemic.

As a result, the analysis presented here is based on an extensive programme of work funded and carried out by the main OEMs and DtBs, and key suppliers where this includes small, medium, and other large actors within the sector. It is based on sector-specific data and detailed information obtained from the ADCR members (which includes OEMs, DtBs, BtPs, MROs, and MoDs) and collected from their A&D suppliers throughout the supply chain. In total, data was collected from companies covering over 45 A&D sites in GB, with data for 8 of those sites using wash primers used in developing this combined AoA/SEA.

2.1.2 Aims of the combined AoA and SEA document

The downstream users supporting the ADCR consortium have no qualified (from a technical perspective) and economically feasible alternatives which can be fully implemented across all products, components and MRO processes before the expiry of the original authorisations. They must continue to use potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide in wash primer application carried out within GB, as it is fundamental to preventing corrosion of A&D components and final products. It forms part of an overall surface treatment and coating system, aimed at ensuring the compulsory airworthiness requirements of aircraft and the safe and reliable operation of military equipment.

Although the A&D sector has been successful in implementing alternatives for some components with less demanding requirements, the aim of this application is to enable the continued use of potassium hydroxyoctaoxodizincate dichromate and pentazinc chromate octahydroxide in wash primers beyond the end of the existing review period which expires 22 January 2026, for the processes where suitable alternative identification, through to 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 potassium hydroxyoctaoxodizincate dichromate or pentazinc chromate octahydroxide, which does not compromise the functionality and reliability of the components to which wash primers are applied, and which could be validated by OEMs and gain certification/approval by the relevant aviation and military authorities across the globe (Section 3.1.2);

- That R&D that has been carried out by the OEMs, DtBs and their suppliers towards the identification of feasible and suitable alternatives to potassium hydroxyoctaoxodizincate dichromate and pentazinc chromate octahydroxide in wash primers. 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 (Section 3.4);

- The efforts currently in place to progress proposed candidate alternatives through Technology Readiness Levels (TRLs), Manufacturing Readiness Levels (MRLs) and final validation/certification of suppliers to enable final implementation. This includes the treatment of components for civilian and military aircraft and defence equipment that continue to be produced, as well as for maintenance, repair and overhaul of out-of-production civilian and military aircraft and other defence systems (Section 3.5);

- The socio-economic impacts that would arise for ADCR downstream users and their suppliers, downstream supply chains and, crucially, for GB more generally, if the applicants were not granted re-authorisations for the continued use of the chromates over an appropriately long review period (Section 5); and

- The overall balance of the benefits of continued use of the chromates and risks to human health from the carcinogenic and repro-toxic effects that may result from exposures to the chromates (Section 4).

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

2.2 The Parent Applications for Authorisation

The chromates identified from previous Applications for Authorisation (AfA), associated with this primer-type are:

• Potassium hydroxyoctaoxodizincatedichromate	EC 234-329-8	CAS 11103-86-9
• Pentazinc chromate octahydroxide	EC 256-418-0	CAS 49663-84-5

Both potassium hydroxyoctaoxodizincatedichromate (PHD; Entry No. 30) and pentazinc chromate octahydroxide (PCO; Entry No. 31) have been included in Annex XIV of Regulation (EC) No 1907/2006 under Article 57(a) as they are classified as carcinogenic (cat. 1A).

These two chromates were previously granted authorisations for use in wash primers across a range of applicants and substances. **Table 2-1** summarises the parent AfAs:

Table 2-1: Overview of initial parent applications for authorisation

Application ID	Substance	CAS #	EC #	Applicants	Use name
0047-02 27UKREACH/20/6/5	Potassium hydroxyoctaoxodizincatedichromate	11103-86-9	234-329-8	Various applicants (CCST consortium)	In primer and coatings (including as wash primers) for the aerospace sector in which any of the following key functionalities is required: corrosion resistance, adhesion of paint / compatibility with binder system, layer thickness, chemical resistance, temperature resistance (thermal shock resistance), compatibility with substrate and processing temperatures

2.3 Scope of the analysis

2.3.1 Brief overview of uses

2.3.1.1 Process description

Cr(VI)-based coatings are specified within the A&D sector primarily because they provide superior corrosion protection and active corrosion inhibition. They must also provide maximum adhesion both to the substrate and to subsequently applied primers/topcoat.

Wash primers, sometimes referred to as etch primers, are an example of a 'pre-treatment' coating; meaning an organic coating that contains at least 0.5% acids (by weight) and is applied directly to metal surfaces to provide surface etching, corrosion resistance and adhesion. Wash primers can be further characterised as a thin surface coating (4-13 µm) applied prior to the use of a primer or primer topcoat scheme, although on some parts layer thickness can be up to 20 µm. As most wash primers are not resistant to hydraulic fluids typically used in commercial aircraft, they must be overcoated with a hydraulic fluid resistant primer. However there are also some applications where wash primers are applied without subsequent primers or topcoats (e.g. dynamic parts on areas where some corrosion resistance in combination with low thickness is required) (CCST, 2015a).

In order to provide the desired functionality, the chromate must be available in sufficient quantity and mobility to reach an unprotected scratched area on the material in sufficient concentration to modify or prevent the corrosion process. The corrosion inhibitive particles of the chromates contained in wash primers are only effective in solution, however, are extremely effective at low loadings (i.e. concentrations).

Wash primers passivate the surface by neutralising metal (hydr)oxides and/or etching the surface. They increase the efficiency of the painting process (fast drying) and help to establish corrosion resistance for a component. Most wash primers are yellow to yellow-green because of the Cr(VI) content. The underlying surface or substrate may still be visible through the very thin wash primer layer (CCST, 2017).

For reference, substrates identified by the ADCR members as relevant to wash primers include:

- Aluminium and its alloys;
- Bronze;
- Copper alloys;
- Magnesium and its alloys;
- Steel and its alloys; and
- Titanium and its alloys.

In addition to the above, there is a technical feasibility criterion requirement for wash primers to be compatible with substrates. These may include composites used in proximity to the treated area which could be subject to overspray, for example.

2.3.1.2 Choice of chromate

Pentazinc chromate octahydroxide and potassium hydroxyoctaoxodizincatedichromate are both selected for use in wash primers as they have limited solubility in water, although the solubility of pentazinc chromate octahydroxide is considerably lower. Both chromated pigments are known to have almost identical compatibility with substrates and provide equivalent functionality in key criteria such as corrosion resistance and adhesion promotion. The choice of specific chromate is therefore due to historical reasons (i.e., the pigment which was initially qualified for use is still used, rather than qualifying another pigment), or commercial (i.e., the formulators use the pigment which is most economically feasible and available to their business).

2.3.1.3 Relationship to other ADCR applied for chromate uses

Prior to application of the wash primer, the substrate may undergo a surface-treatment, such as anodising or chemical conversion coating, for the primer to successfully adhere to it. However they are also used in cases where the normal deoxidise-anodise/conversion coating sequence is not possible (e.g. large components, maintenance) or in order to mitigate liquid hazardous waste production during conversion coating and rinse operations (CCST, 2015a). In some cases, wash primers may be applied to aluminium substrates which have undergone chromic acid anodising, sulfuric acid anodising, chemical conversion coating or abrasion. Steel substrates subjected to wash primer application may have undergone phosphating or cadmium plating. Other possible surface treatments prior to the application of wash primers also include fluoronitric acid pickling, passivation and non-chromated conversion coating. However, in repair cases, wash primers are typically applied directly to abraded surfaces. For example, touch-up on components following removal of old or damaged paint via sanding. The paint free surface is cleaned and degreased before applying the wash primer to the bare metal.

As reported in Section 1.3.1, most wash primers are applied prior to a primer and/or topcoat scheme although there are some situations where they are applied without any subsequent coating layers. An example is to provide corrosion protection on mechanical parts; assemblies, where tight geometric tolerances exist.

The multilayer coating system described above is illustrated in **Figure 2-1** below:

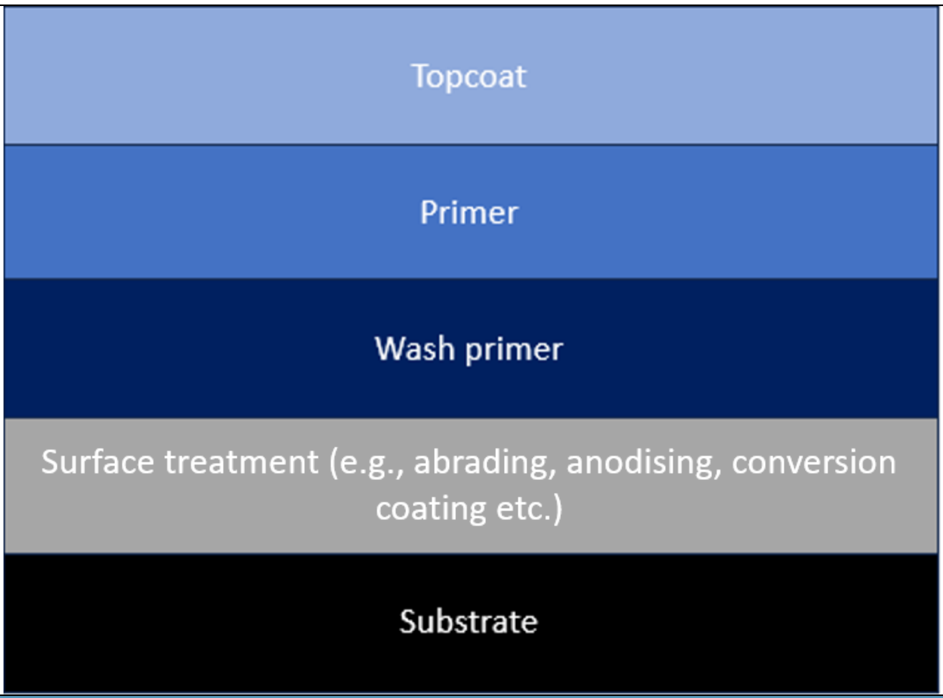

Figure 2-1: Example coating system for wash primers
Adapted from (CCST, 2017)

2.3.2 Temporal scope

Because of the lack of viable and qualified alternatives for the use of potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide in wash primers for aerospace and defence 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 for substitution 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 begin;
- When such impacts would be realised; and
- The minimum period over which the continued use of the chromates would be required by the A&D industry.

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			
Price year		2022 (values are expressed in 2022 prices)	
Start of discounting year		2026	
Impact baseline year		2026	
Scenario	**Impact type**	**Assessment period**	**Notes**
"Applied for Use"	Adverse impacts on human health	12 years, following a 10-year time lag	Based on the length of requested review period
"Non-use"	Loss of profit along the supply chain	12 years; profit estimates of 2 years are used as proxy for societal producer surplus loss	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 GB 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	12 years; note that some costs such as lost wages, search and recruitment costs do not incur for whole 12 years due to temporary nature of unemployment	Average period of unemployment in Dubourg, (2016)

2.3.3 The supply chain and the estimated number of sites

2.3.3.1 The ADCR Consortium

The ADCR is composed of 17 companies located in the EEA and the UK that act as suppliers to the A&D industry (importers, formulators, and distributors), and 45 companies which are active downstream users (OEMs, DtBs or BtPs) or are MRO providers (civilian or military) within the industry sector. Membership also includes Ministries of Defence (MoDs) due to concerns over the loss of the availability of the chromates for on-going maintenance and repair of military equipment.

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

Over half of the larger ADCR members (14 of 24) support the use of chromates in wash primers; this may be either for their own use or for use in their supply chains. The larger members in particular may be supporting the use of one or more of the chromates in protective primers to ensure it is available to their suppliers as well as for their own use. As can be seen from **Table 2-3**, the most supported substance is potassium hydroxyoctaoxodizincate dichromate (12 members).

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

	Potassium hydroxyoctaoxodizincate dichromate	Pentazinc chromate octahydroxide
No. of members	6	2

2.3.3.2 Downstream users of potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide for wash primers

Use of primer products 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[6] (DtB) – companies which design and build components;
- Build-to-Print (BtP) – companies that undertake specific processes, dictated by the OEM, to build A&D 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[7].Where they service components they designed and manufactured which are already in use. Similarly, a company may fall into different categories depending on the customer and the component/final product.

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

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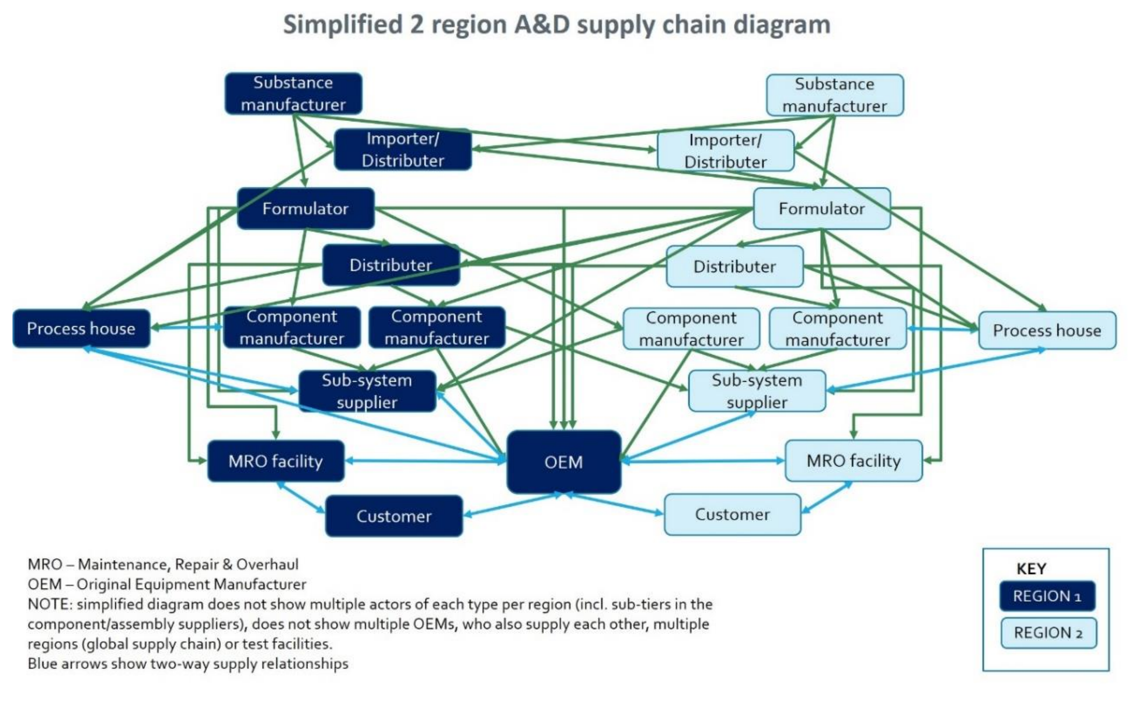
[6] Also referred to as “design and make” or “design responsible” suppliers.

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



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

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

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

Table 2-4: Numbers of companies providing SEA information of Wash primers

Role	Number of Companies
OEMs/MROs	1[8]
Design-to-Build	3
Build-to-Print	3
Total	**7**

2.3.3.3 OEMs, DtB and BtP Manufacturers

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. OEMs, as design owners, are responsible for the integration and validation of the final product and certification approval. While they may apply wash primers themselves, as part of their own manufacturing activities, the primers are also

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[8] OEM indicated that MRO activities was also provided.

used by a range of companies within the supply chain. The OEMs operate at the global level, and therefore may have facilities both in GB and located in other regions. They may also be global exporters of final A&D products. In the case of GB-based OEMs, the suppliers are often located in the same country (if not the same region) as their main OEM customer.

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, defence, and/or 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 GB.

2.3.3.4 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 systems and also 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 use of Cr(VI)-based wash primers as a portion of such activities.

A representative life cycle of a typical aerospace product – a commercial aircraft – is illustrated in **Figure 2-3**. This highlights that: the development of a new aerospace system can take up to 15 years; the production of one type of aerospace system may span more than 50 years; and the lifespan of any individual aircraft is typically 20-30 years. **Figure 2-4** provides an overview of the life cycle of weapon systems, which are usually used much longer than the originally projected lifetime. Such life cycles can be significantly longer than 50 years. For such systems, it is extremely costly to identify and replace legacy applications of chromates without impacting performance, where performance has been assured for many decades.

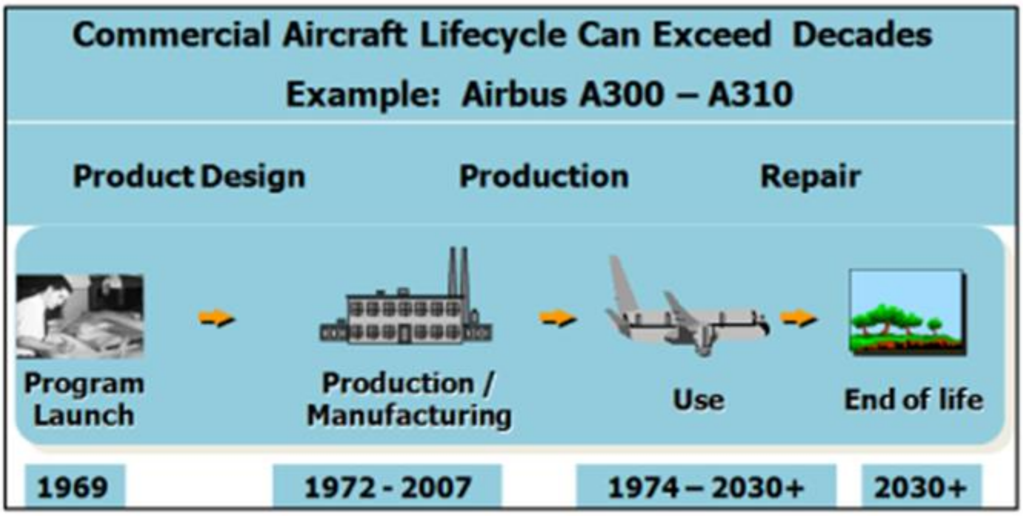

Figure 2-3: Commercial Aircraft Service Life, from ECHA & EASA (2014)[9]

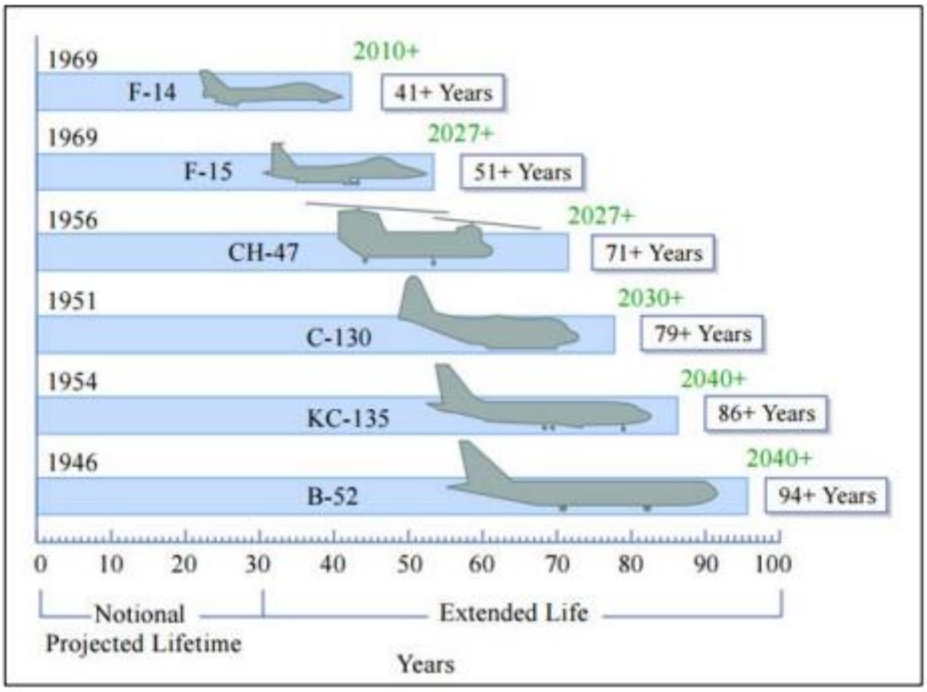

Figure 2-4: Life cycles of defence aircraft, from A Haggerty (2004)[10]

Even if new designs/components – coming onto the market, as well as those no longer being produced in the short to medium term – might succeed in dispensing with the need for use of wash

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

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

primers containing Cr(VI), products already placed on the market, as well as those no longer being produced still need to be maintained and repaired using Cr(VI)-based primers 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 apply wash primers containing potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide in strict adherence to the requirements of qualified repair and maintenance schemes to ensure continued safe operation of the final A&D products.

2.3.3.5 Estimated number of downstream user sites

Calculation of the estimated total number of sites is based on a combination of SEA questionnaire results, and consultation with ADCR members. It was estimated that there were around 150 total sites in GB, based on data from ADCR members and their supply chain.

The ratio of SEA respondents identifying use of each primer type were then used to inform the distribution of the 150 sites across each primer type. These values were then split by supplier type using ratios derived through consultation with the ADCR members. The assumed number of total sites in GB using wash primers has been taken to be 25.

2.3.3.6 Customers

The final actors within this supply chain are the customers of A&D final products to which wash primers have been applied.

With respect to civil aviation, the global air transport sector employs over 10 million people to deliver some 120,000 flights and 10 million passengers a day in a normal year. In 2017, airlines worldwide carried around 4.1 billion passengers. They transported 56 million tonnes of freight on 37 million commercial flights. Every day, aeroplanes transport over 10 million passengers and around US$ 18 billion (€16 billion, £14 billion) worth of goods. Across the wider supply chain, assessment of subsequent impacts and jobs in tourism made possible by air transport, show that at least 65.5 million jobs and 3.6% of global economic activity are supported by the industry[11]. UK-based aircraft are responsible for the vast majority of the UK's unique international connectivity, accounting for 73%. They also serve 85% of international routes, all domestic routes, and offer 67% of all international seats. This dominance of UK-based airlines and aircraft enhances UK connectivity, particularly on less frequented direct routes from regions outside London[12]. These benefits cannot be realised without the ability to undertake regular maintenance works and to repair and maintain aircraft as needed with replacement components manufactured in line with airworthiness approvals.

In 2022/23, total government expenditure on defence across the GB equated to 1.9% of GDP. In 2022/23 defence spending totalled £54.2 billion,[13] part of this expenditure is related to military

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

[12] https://airlinesuk.org/about-us/

[13] https://researchbriefings.files.parliament.uk/documents/CBP-8175/CBP-8175.pdf

aviation, with an uncertain but significant proportion also spent on non-aviation defence products that rely on the use of wash primers.

Focusing on military aircraft, the dynamics of aircraft development and the market are significantly different than for commercial aircraft. Military aircraft are extremely expensive and specialised products. As a result, to have an effective military force, Ministries of Defence require equipment that is well-maintained and mission ready. Although the in-service military fleet is expected to grow rapidly in the future, older aircraft and other equipment will continue to require more frequent scheduled maintenance to replace components that are reaching the end of their "service 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 notification data, information on volumes placed on the market and numbers of customers. This has included consultation with the formulators to gather information on their efforts to develop alternatives on their own, in collaboration with the downstream users, and as part of research projects funded by national governments, the EC, and more, internationally;

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

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

Further details of each are provided below.

2.4.2 Consultation with Applicants

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

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 2023 to collect a range of data relevant to both the AoA and the SEA for all ADCR dossiers. This consultation was carried out with all downstream user members of the ADCR (i.e., members located in GB), and regardless of their role within the supply chain. Consultation took place over different phases:

1) Phase 1 involved collection of information on use of primer products that each member undertook. This included:
    a. Supply chains,
    b. Substances used in each primer-type and associated volumes,
    c. Key functions provided by the substance,
    d. Locations for each activity, and
    e. Likelihood of substitution before 2026.

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

3) Phase 3 then took the form of detailed one-on-one consultations between ADCR members and the AoA technical service team. The focus of these discussions was to:
    a. Ensure additional critical details were collected concerning core aspects of the AoA/SP portions of the dossiers (e.g., confirm current technology readiness levels of shortlisted alternatives and address outstanding questions regarding alternatives and their comparative performance), and
    b. Confirm information on R&D and substitution timelines previously gathered was up-to-date, and that the information reflected progression up to MRL 10 in order to recognise the transition to full production.

4) Phase 4 collected information for the SEA sections of this document, 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 GB,
    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, and

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 offering to provide information and participate in the re-authorisation work to ensure their conditions of use were covered. The scope of these questionnaires was similar to that described above for the ADCR members.

As a final count, for this primer use data for 8 sites operated by the ADCR OEMs and their DtB and BtP suppliers was provided in response to these questionnaires. The information provided by the companies forms the basis for the SEA component of this document.

2.4.3.3 Maintenance, Repair and Overhaul suppliers

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

3 Analysis of Alternatives

3.1 SVHC use applied for

3.1.1 Substance ID and Overview of the key functions and usage

A wash primer is defined by the ADCR as follows[14]:

“A thin coating applied prior to a primer or topcoat scheme. Where higher corrosion protection is required, the wash primer is usually overcoated by a basic primer before the final coating is applied. Wash primers passivate the surface by neutralising metal (hydr)oxides and/or etching the surface. They contain typically phosphoric acid designed to be applied directly to bare metal or treated metallic surfaces to provide corrosion resistance and adhesion.”

3.1.1.1 Process steps and overview of key functions

Cr(VI)-based coatings are specified in the A&D sector primarily because they provide superior corrosion protection and active corrosion inhibition. They must also provide maximum adhesion both to the substrate and to subsequently applied primers/topcoat.

Wash primers, sometimes referred to as etch primers, are an example of a ‘pre-treatment’ coating. This is an organic coating that contains at least 0.5% acids (by weight) and is applied directly to metal surfaces to provide surface etching and/or surface activation, corrosion resistance and adhesion. Wash primers can be applied to untreated or abraded metal because they have the ability to react with the surface to replace native oxides with a reaction layer that adheres the primer to the substrate. Wash primers can be further characterised as a thin surface coating (4-12 µm) applied prior to the primer or primer topcoat scheme, although on some parts layer thickness can be up to 20 µm. As most wash primers are not resistant to hydraulic fluids typically used in commercial aircraft, they must be overcoated with a hydraulic fluid resistant primer. However, there are also some applications where wash primers are applied without subsequent primers or topcoats (e.g. dynamic parts on areas where some corrosion resistance in combination with low thickness is required) (CCST, 2015a).

In order to provide the desired functionality, the chromate has to be available in sufficient quantity and capacity to diffuse into an unprotected scratched area on the material in sufficient concentration to modify or prevent the corrosion process. The corrosion inhibitive particles of the chromates contained in wash primers are only effective in solution, however, are extremely effective at low loadings (i.e., concentrations).

Wash primers passivate the surface by neutralising metal (hydr)oxides and/or etching the surface. They help to establish corrosion resistance and promote adhesion between the substrate and subsequent coating for a component. Most wash primers are yellow to yellow-green because of the Cr(VI) content. The underlying surface or substrate may still be visible through the very thin wash primer layer (CCST, 2017).

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[14] ADCR Scoping phase DU Q 14Jan, Appendix 1 Use Definitions

Although a number of key functions are attributed to wash primers in the parent AfAs, the key functions of the SVHC (PCO/PHD) in wash primers (supported by the information on mode of action provided in the parent AfAs and through member consultation) are:

- Corrosion resistance (including 'active corrosion inhibition');
- Adhesion promotion;
- Chemical resistance;
- Temperature resistance;
- Layer thickness;
- Compatibility with substrate/other coatings; and
- Compatibility with processing temperatures.

Further detail on the modes of action of chromates in the delivery of the key functions listed above is given in the following sections:

Corrosion resistance (including 'active corrosion inhibition')

Cr(VI) has two-fold corrosion inhibition properties. Firstly, it combines with the naturally occurring metal oxide to form a mixed oxide layer that forms a passive corrosion resistant protective layer on the surface of the metal which prevents oxygen from contacting the metallic substrate. Secondly, 'active corrosion inhibition' is possible due to the presence of mobile Cr(VI), Which is retained within the organic binder. Should the coating be damaged locally to reveal bare metal then, after the initial formation of a thin metal oxide layer, this mobile Cr(VI) reacts with the metal oxide, renewing the passive chromium oxy-hydroxide protective barrier and thus re-establishing a corrosion inhibiting layer (CCST, 2015a). This process is illustrated in **Figure 3-1** below.

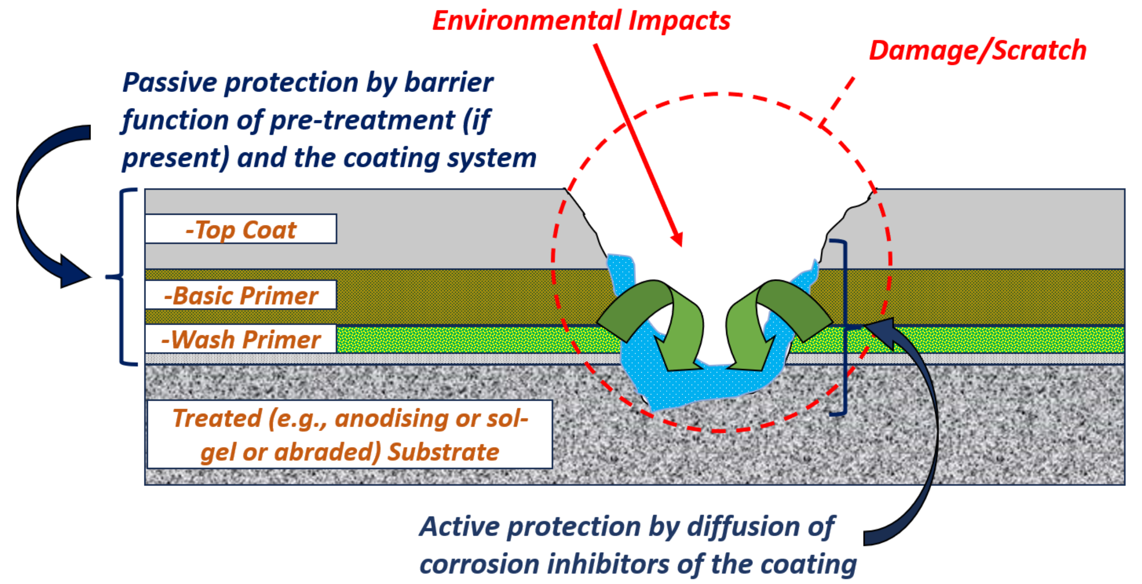

Figure 3-1: Basic functions of an example surface protection system (CCST, 2015a)

The 'active' layer is typically composed of both Cr(VI) and Cr(III). The interior of the layer is composed of the Cr(III) oxy-hydroxide, which forms a covalent bond, $Cr^{(III)} – O – Cr^{(VI)}$, with residual Cr(VI) species. This promotes a Cr(VI) enriched outermost region of the protective layer. Should the passive coating be damaged, exposing the underlying substrate to corrosive agents, Cr(VI) is released, or diffuses, from this region of high Cr(VI) concentration, thereby renewing the passive barrier (Jiang et al., 2016). It should be noted that this mode of action as reported by Jiang et al. is specific to chromate conversion coatings, though it is believed that this is also an adequate description of the mode of action of the chromates in providing active corrosion inhibition to substrates treated with wash primers.

Areas close or adjacent to the damaged site will become depleted in Cr(VI), reducing corrosion protection in that area. However, the process of continuous diffusion provides a mechanism for Cr(VI) ions from more distant adjacent areas to migrate into the depleted area. This dynamic process represents the active corrosion resistance process, or “self-healing” mechanism that appears to be unique to Cr(VI) (CCST, 2015a).

Unlike most corrosion inhibiting compounds, chromates are both anodic and cathodic inhibitors, meaning that they can restrict the rate of metal dissolution, and simultaneously lower the rate of reduction reactions (oxygen and water reduction) in many environments and over a broad range of pH. This makes the Cr(VI) compounds uniquely capable of providing/ensuring the corrosion protection required for the safety and reliability of A&D products over the wide range of use environments in which they operate. The specific physico-chemical properties and unique functionalities of Cr(VI) make it an ideal substance in protective primers as illustrated in **Figure 3-2** below:

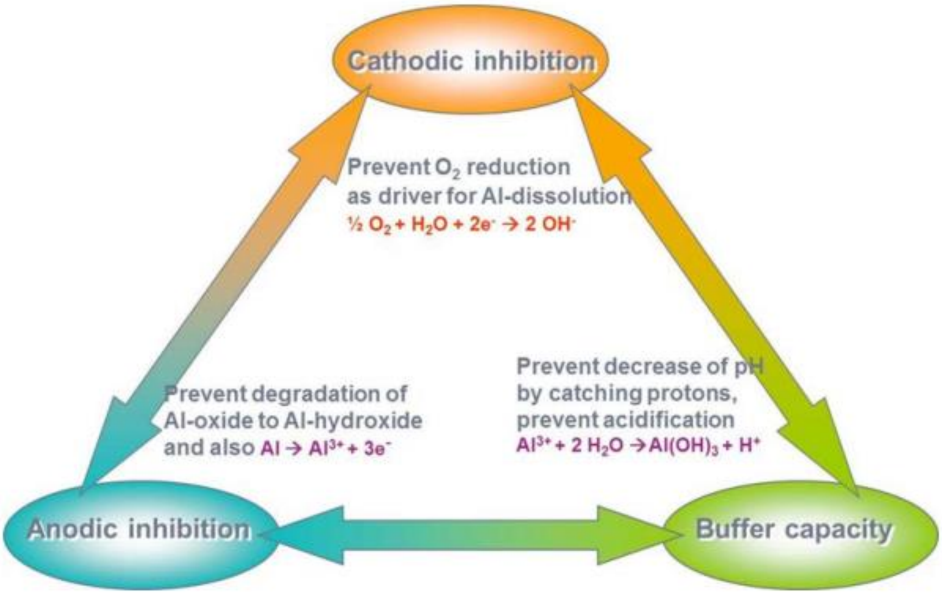

Figure 3-2: Key Cr(VI) functionalities illustrated with aluminium substrate (CCST, 2015a)

Adhesion promotion

Adhesion promotion refers to the ability of the wash primer to improve the adhesion of subsequent primer and coating layers. Adhesion promotion also includes the adhesion of the wash primer to the substrate. Cr(VI)-based wash primers promote adhesion of subsequent coating layers to the substrate through two main mechanisms.

Firstly, the wash primer typically contains phosphoric acid or another acidic component which etches the metal surface to a degree, resulting in the formation of a highly microporous surface with increased surface area than the substrate prior to application of a wash primer. This increased surface area lends itself to stronger intermolecular forces of attraction between the substrate and subsequent coating layers. The chromate component of the wash primer acts as a moderator to this etching process, controlling the rate of etching and maintaining a stable pH through buffering action, ensuring that over-etching does not occur and that an ideal etched surface is achieved.

chemical reaction taking place during the etching process is given for a generic metal substrate below where the value x is variable and greater than one depending on the valence of the oxidised substrate material.

$$H_3PO_4 + 3/x\ M \rightarrow 3/x\ M^{x+} + PO_4^{3-} + 3/2\ H_2$$

Secondly, the chromate compound reacts with the metal surface to form a mixed-valence layer of chromium oxides, hydroxides and chromates. This layer demonstrates favourable intermolecular interactions such as hydrogen bonding between Cr-OH moieties at the layer surface and hydrogen bond donors and acceptors within subsequent layers, resulting in a strong force of adhesion between the treated substrate and the subsequent layer.

Chemical resistance

Due to the intrinsic strong corrosion prevention and inhibition of chromates, formulations can be developed without strictly focussing their efforts on controlling the leaching and diffusion rates of corrosion inhibitors. This allows in more freedom in the choice of the polymer matrix that is used as a binder. Therefore, a binder can be selected which shows excellent resistance to chemicals such as fuels, hydraulic fluids and de-icing fluids, rather than needing to select a binder system which allows for optimal control over the corrosion inhibiting pigments. In addition, the strong oxidising power of chromates and the highly polar nature of chromates has been reported to be beneficial in resisting detrimental action by chemicals encountered during operation by aircraft, which are typically organic and apolar molecules.

Temperature resistance

Chromate compounds are known to provide excellent corrosion resistance over a wide range of temperatures, therefore preventing corrosion resistance of a coated component even when exposed to corrosive agents at elevated temperatures.

Layer thickness

Cr(VI)-based wash primers are able to provide exceptional corrosion resistance at low loadings, meaning that only a very thin layer of the wash primer needs to be applied to meet corrosion resistance requirements. If a worse performing corrosion inhibitor were to be used, the thickness of the coating layer may need to increase to meet corrosion resistance requirements, this can impact the performance of the coating in a number of ways including the loss of adhesion of the coating and subsequent layers, and the overall component failing to meet dimensional tolerances.

Compatibility with substrate/other coatings

For similar reasons to those discussed for adhesion promotion, the strong bonding interaction between the chromate and chromium oxide layer and the substrate and subsequent layers results in strong adhesion between and allows chromated wash primers to show excellent compatibility with a wide range of substrates and subsequent coatings.

Compatibility with processing temperatures

The chromate pigments used in wash primer formulations are sufficiently compatible with the room temperature processing requirements of coating activities. These chromates do not solidify or otherwise change in rheology when held at room temperature for extended periods of time, allowing for consistency in the wash primers properties throughout the duration of coating processes. This is particularly important when coating high-area components. Though this is a property of the overall wash primer formulation, it is necessary that the corrosion inhibitor substances themselves does not cause changes in the rheology of the wash primer when exposed to processing temperatures. In addition, the overall Cr(VI)-free wash primer formulation should be suitable for room-temperature curing.

3.1.1.2 Usage

Components that may be treated with the Annex XIV substance

As detailed above, wash primers, aim to modify the surface of the substrate to provide enhanced corrosion protection and/or support adhesion of subsequent coatings. There are many corrosion prone areas on A&D products. Examples of these are included in **Table 3-1** below:

Table 3-1: Examples of corrosion 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, 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	Blade erosion shells	Gearbox	Pyrotechnic Equipment
Fuselage and floors		Hydraulic intensifier	Radomes (radar domes)
Hydraulic damper		Ram air turbine	Rocket motors
Hydraulic intensifier		Starter	Safe and arm devices
Landing equipment		Vane pump	Sonar
Nacelles			
Pylons			
Rudder and elevator shroud areas			
Transall (lightning tape)			
Undercarriage (main, nose)			
Valve braking circuit			
Window frames			
Wing fold areas			

Source: (GCCA, 2017)

It is important to note that even with the highly developed Cr(VI)-containing primers available, corrosion 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 appropriate inspection, maintenance, and repair intervals.

Cr(VI)-free alternatives can only be introduced where they have been proven to have no detrimental impact on performance in key functions, since some or all the following consequences may occur:

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

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

Despite diligent adherence to qualification and validation requirements, 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.

Types of corrosion

There are a number of different kinds of corrosion which may occur at prone areas such as those listed in **Table 3-1**. Examples of some of these are given below (CCST, 2015):

- Grain boundary corrosion (intergranular corrosion) is a type of corrosion commonly seen in components made of aluminium alloys that contain alloying elements that are less noble than aluminium (e.g., aluminium-zinc-alloys like AA7050, see **Figure 3-3**) and can occur either in the presence of impurities in the grain boundaries or to the local enrichment of one of the elements;

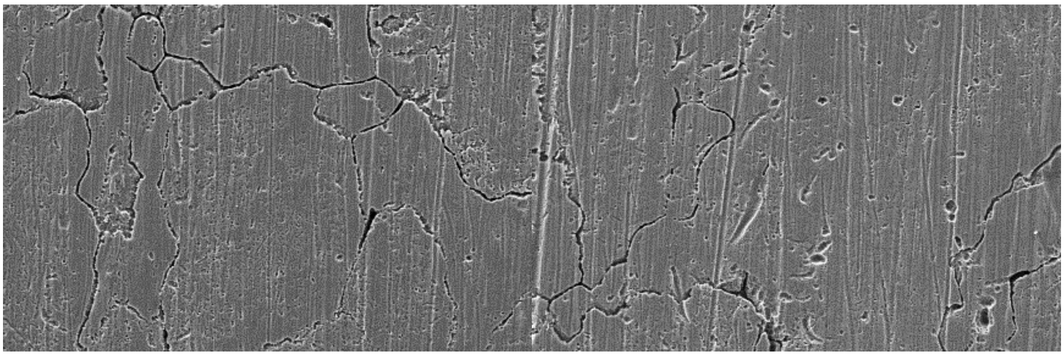

Figure 3-3: Early stage of dissolution of intergranular zinc precipitations in high-strength aluminium-zinc-alloy AA7050

Source: ADCR member

- Galvanic corrosion can occur at locations where there is contact between dissimilar conductive materials;
- Filiform corrosion occurs on painted surfaces and is localised corrosion under the coating;
- Crevice corrosion can be observed where there is a crevice between materials.;
- Corrosion fatigue and stress corrosion cracking may occur where stress is concentrated, such as in structural components, or fastener holes;
- Exfoliation corrosion may occur in unprotected metal areas where end-grain is exposed, such as countersinks or the crevices of rolled metal plates; and
- Fretting corrosion occurs when overlapping metallic joints are subject to repeated or cyclic relative movement.

Highly corrosive environments presented in certain systems can also lead to accelerated corrosion, particularly for components such as helicopter rotor heads, and aircraft engine air inlets. Any structural detail where there is an unsealed gap between adjacent components and where moisture can become entrapped (like a joint) is also highly susceptible to corrosion.

Service life and maintenance intervals of components

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

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

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

As an example, for a commercial aircraft, the A-checks occur every 400-600 flight hours, the B-checks are performed every 6-8 months, and the C-checks are completed every 20-24 months. C-checks typically take up to 6,000 man-hours to complete. The D-checks are completed every 6-10 years and typically take up to 50,000 man-hours to complete. At Lufthansa, the D-check begins with the stripping of the exterior paintwork. The aircraft is taken apart and each system is checked thoroughly using the most modern methods for non-destructive material testing, such as X-rays, eddy current probes and magnetic field checks. After several weeks and thousands of hours of intensive MRO work, the aircraft is overhauled completely. The D-check is the most extensive check foreseen for aircraft. Even at the D-check, certain areas of the aircraft, such as bonded structures and inaccessible regions, cannot typically be disassembled for inspection (GCCA, 2017). Corrosion protection of these regions must therefore be sufficiently robust to last throughout the life of the aircraft.

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

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

3.1.2.1 Introduction

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

In the civil aviation sector of the Aerospace industry, large numbers of aircraft **safely carry billions of people every year**[15]**,** 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 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 primer allows corrosion pits to form. These can turn into fatigue cracks, which potentially endanger the final product.

The civil aviation industry must comply with the airworthiness requirements derived from Regulation(EC) No 2018/1139[16] in the EAA. Similar airworthiness requirements exist in all countries

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[15] 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

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

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 Civil Aviation Authority (CAA), 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 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 3-4**).

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

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, including primers, hundreds of individual components in each final product will be affected.

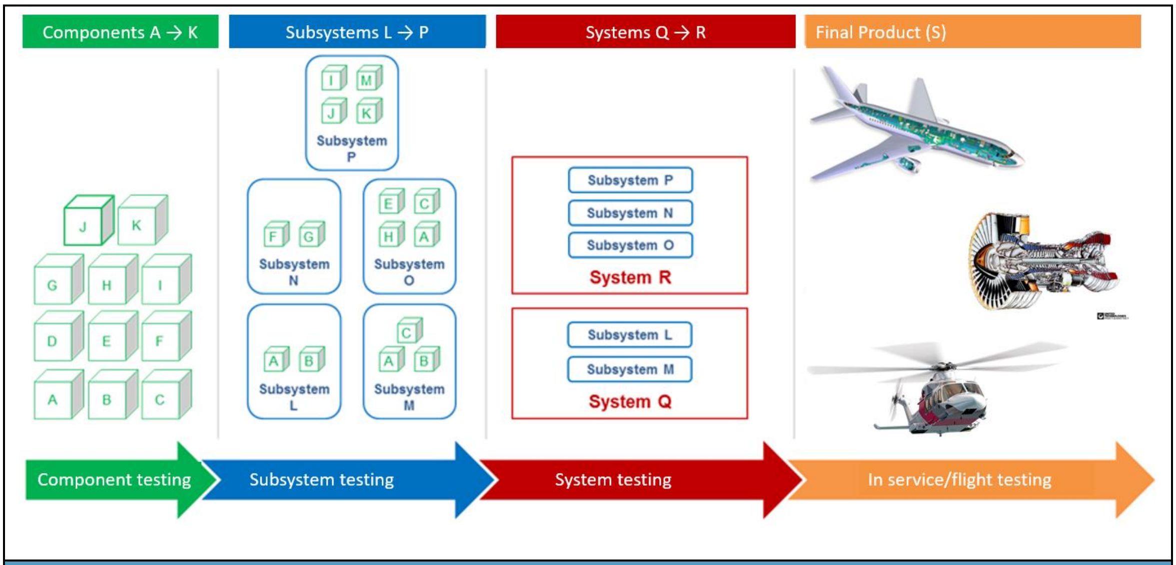

Figure 3-4: Assessment requirements in the implementation of alternatives
Source: Adapted from GCCA white paper

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

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

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

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

TRL	Definition	Description
		environment. Examples include "high-fidelity" laboratory integration of components.
6	System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7	System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space).
8	Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation (DT&E) of the system in its intended weapon system to determine if it meets design specifications.
9	Actual system through successful mission[b] operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.

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

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

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

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

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

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

MRL	Definition	Description
1	Basic Manufacturing Implications Identified	Basic research expands scientific principles that may have manufacturing implications. The focus is on a high-level assessment of manufacturing opportunities. The research is unfettered.
2	Manufacturing Concepts Identified	This level is characterized by describing the application of new manufacturing concepts. Applied research translates basic research into solutions for broadly defined military needs.
3	Manufacturing Proof of Concept Developed	This level begins the validation of the manufacturing concepts through analytical or laboratory experiments. Experimental

Table 3-3: Manufacturing Readiness Levels as defined by US Department of Defence		
MRL	**Definition**	**Description**
		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 production practices in place	Technologies should have matured to TRL 9. This level of manufacturing is normally associated with the Production or Sustainment phases of the acquisition life cycle. Engineering/design changes are few and generally limited to quality and cost improvements. System, components or items are in full-rate

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

MRL	Definition	Description
		production and meet all engineering, performance, quality and reliability requirements. Manufacturing process capability is at the appropriate quality level.

Source: *https://acqnotes.com/acqnote/careerfields/manufacturing-readiness-levelmanufact*

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, sealants, adhesives, 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 types of primer, as well as in other surface treatment processes. Whilst the proposed candidates will be different for each use, considering 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.

Cr(VI) endows primers with key functionality across a multitude of designs and substrates. If a test candidate with these universal performance and compatibility properties is not available, multiple workstreams using a variety of test candidates either individually or contained in multiple proprietary formulations may be required. Resource availability e.g., bespoke test facilities, may impact substitution of Cr(VI) with a staggered transition timeline across a breadth of designs.

3.1.2.2 Process, requirements, and timeframe

Identification & Assessment of need for substitution

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

The first step is to identify the extent to which the formulations containing the substance, are used. This must consider the entire life cycle of components onto which the formulations are applied 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 primers 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 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 containing 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, adhesion strength, scratch resistance, dynamic performance, 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 3-5**, 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.

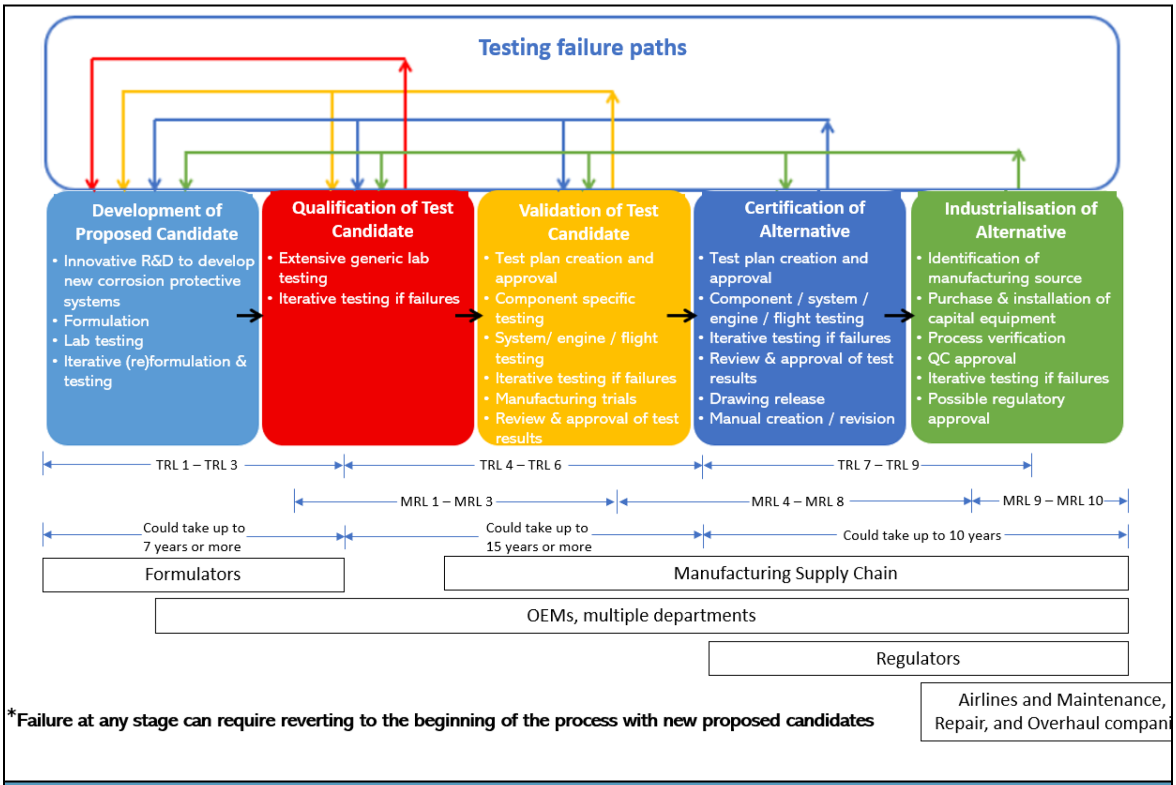

Figure 3-5: Schematic showing the key phases of the substitution process.
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note 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. As stated in 'Definition of requirements' alternatives must demonstrate non-regression across a broad range of requirements. It is not possible to accept lower performance of test candidates compared to the performance of Cr(VI) because systems have been certified with the performance derived from Cr(VI), and therefore test candidates must at least, match this level of performance.

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; refer to ADCR Formulation dossier. Initial activities in the development of proposed candidates stage include:

- Innovative R&D to develop new corrosion inhibitors/primer products;
- 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[17].

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 primer 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 (for examples, see Annex 1). 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 3-5** 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

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[17] CCST

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

Validation of test candidate

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

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

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

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

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

Some of the components impacted by the substitution of a primer 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 3-6** below.

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

Removing a formulation whose key function is 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[18], each of these components will need to be approved individually:

> *“Importantly, even if an alternative is in use in one component in aerospace[19] 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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[18] Application for Authorisation 0117-01 section 5.3 available at b61428e5-e0d2-93e7-6740-2600bb3429a3 (europa.eu) accessed 06 June 2022

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

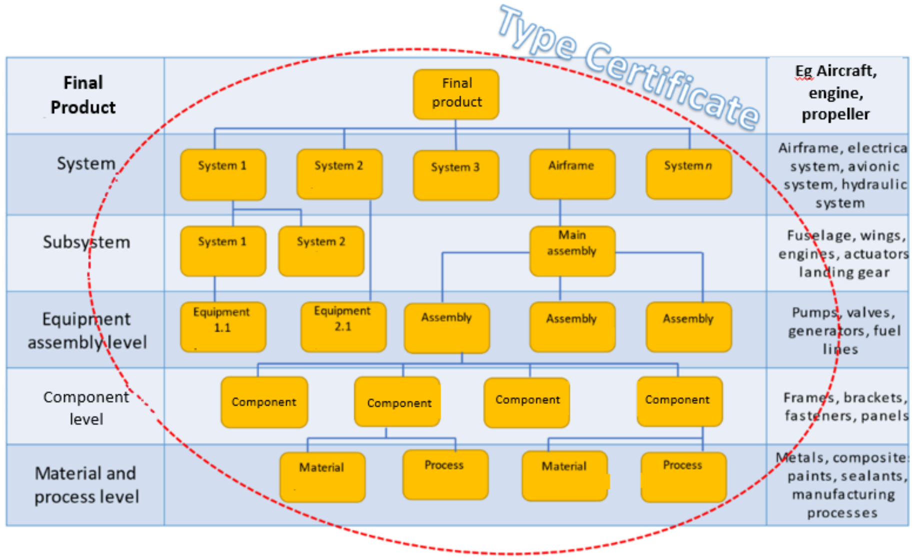

Figure 3-6: System hierarchy of a final product showing the interconnection of each level in the system hierarchy, and how changes at a lower level have impacts on higher levels.
Source: ADCR member

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

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

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

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

Industrialisation of alternative

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

Elements of the Industrialisation of alternative process include:

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

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

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

For components already in products, long-term contractual agreements are often already in place with suppliers. When a change is made to a drawing to incorporate a new alternative, the contract with the supplier needs to be renegotiated, and additional costs are incurred by the supplier when modifying and/or introducing a new production process. These may include purchase and installation of new equipment, training of staff, internal qualification of the new process, OEM qualification of the supplier, manufacturing certification of the supplier, etc. 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 3-7** below.

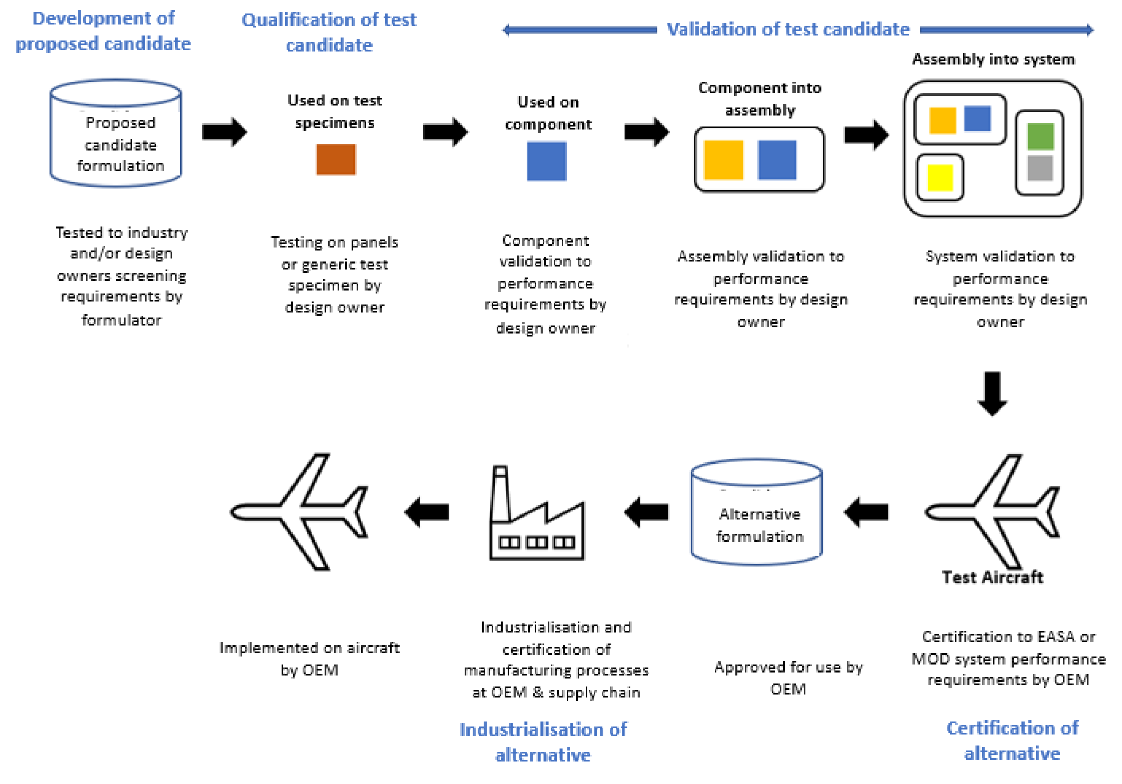

Figure 3-7: Process to Certify a Formulation for use on Aircraft.
Formulations used in production have completed this process. New or reformulations must follow same process for use in production.
Source: ADCR member

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

3.2.1 Technical feasibility criteria for proposed candidates to replace chromate-containing wash primers

3.2.1.1 Introduction

The development of technical feasibility criteria for proposed candidates to replace the use of Cr(VI) in wash primers 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 2022 and 2023) the ADCR consortium members were asked to thoroughly describe the key functions that Cr(VI) imparts in this use, the technical feasibility criteria and associated performance requirements that any test candidates (formulations and technologies) would need to fulfil in order to deliver the functionality currently provided by the chromate-containing wash primers.

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

- Corrosion resistance;
- Adhesion promotion;
- Layer thickness;
- Chemical resistance;
- Temperature resistance;
- Compatibility with substrate/other coatings;
- Compatibility with processing temperatures;
- Applicable over large areas and compatibility with different application methods (brush, roller, spray);
- Detectability/visibility; and
- Mechanical properties (impact resistance, scratch resistance, flexibility).

3.2.1.2 Technical feasibility criterion 1: Corrosion protection and active corrosion inhibition

Corrosion describes the process of oxidation of a metallic material due to chemical reactions with its surroundings, such as humidity but also corrosive electrolytes. In this context, the parameter corrosion resistance means the ability of a metal A&D component to withstand gradual destruction by chemical reaction with its environment.

For the A&D sector, this parameter is one of the most important since meeting its minimum requirements plays a key role in assuring the longest possible life cycle of final products and all the implicit components, the feasibility of repairing and maintenance activities and most importantly, the safety of those aboard the aircraft but also those on the ground. The aluminium alloy AA2024, for example, is commonly used in the aviation sector, and contains approximately 5% copper as an alloying element to provide the material strength. Copper, as a noble element acts as a built-in corrosion driver. Inhibition of the high copper alloys is mandatory for long-term corrosion stability.

The corrosion resistance requirements vary within the A&D sector and are dependent on the metal substrate (aluminium alloy, steel type) and the coating thickness. Corrosion inhibiting co-formulants can be categorised according to basic quality criteria which are inhibitive efficiency, versatility, and toxicity. Ideally, the co-formulant is applicable in all surface treatment processes, compatible with subsequent layers and performs effectively on all major metal substrates. Furthermore, it must guarantee product stability (chemically and thermally) and has to reinforce the useful coating properties.

The ability of a material to restore corrosion protection after mechanical damage is caused to the original coating is known as active corrosion inhibition or self-healing and is described in detail in **Figure 3-2** (see above). If this characteristic is given for a certain material, it is tremendously advantageous and will enhance service life duration of components, maintenance intervals and safety of air travellers.

The active corrosion inhibiting properties are generally tested in line with the corrosion resistance based on the same test methods and requirements, as the active corrosion inhibition of a coating is a characteristic feature.

3.2.1.3 Technical feasibility criterion 2: Adhesion promotion

Depending on the functions of the components, they may be coated with additional protective layers to enhance, on the one hand the aesthetic quality which includes decorative aspects but also camouflage of military vehicles, and on the other hand it's for protection against aggressive agents in the service environment. The parameter of "adhesion" describes the tendency of dissimilar particles or surfaces to cling to one another. In the A&D industry, many components are exposed to harsh environmental conditions, often in contact with other metallic components and are subjected to strong mechanical forces. It is extremely important that the coatings applied on these components can withstand these effects and keep functioning properly for the longest period possible. For example, rain erosion resistance is part of the adhesion tests, which emulate forces of high-speed exposure at the leading edges of surfaces. These tests are also used in relation to technical feasibility criterion 9: Mechanical properties (*vide infra).* It is of note, that, whilst the Cr(VI) plays a role in adhesion promotion, as described above, the adhesion properties of a wash primer and subsequent primer formulation, are influenced by different factors including the complex interplay between corrosion inhibitor, matrix and other additives.

Generally for wash primers, a polyurethane matrix is required as the phosphoric acid in the wash primer will inhibit the cure of epoxy amine coatings (the amine is basic and will be neutralised by the acid) (CCST, 2015a). However, other matrix types can also be used which are not polyurethane-based Any alternative corrosion inhibitor must therefore be compatible with the wash primer matrix in order to avoid any detrimental interactions between the corrosion inhibitor and the matrix.

3.2.1.4 Technical feasibility criterion 3: Layer thickness

The thickness of the different layers or coatings on the substrate, specified in nanometres or micrometres, is also crucial for optimum performance of all parts of the aircraft. The objective is to achieve maximum performance with minimum thickness, which equates to minimum weight, as weight is critical to the fuel efficiency of an aircraft. Layer thickness is also important as it affects component dimensions and tolerances, which affect the performance of the component when it is integrated into assemblies and sub-systems. For example, if layer thickness increases it can cause reduced fit of fasteners that require close compliance to the specified tolerances, and increased wear when the component is integrated with other components and where it moves in relation to those other components. The increase in layer thickness could also have an impact on the whole aircraft (e.g., weight and balance aspects).

Layer thickness is not directly influenced by Cr(VI), but any alternative must not adversely affect this attribute. Not meeting the specified requirements of this parameter could lead to deficiencies in other characteristics of the components, for example less corrosion and chemical resistance, inadequate adhesion of coatings to the substrate or decreased cracking resistance. The process capability of Cr(VI)-free paint systems therefore needs to be considered in order to guarantee even coverage of components with complex geometries.

3.2.1.5 Technical feasibility criterion 4: Chemical Resistance

This parameter is defined as the ability of solid materials to resist damage by exposure to chemicals. Especially for aeronautic applications, it is highly important that all parts withstand contact with different chemicals like de-icing fluids, greases, oils and lubricants and especially aggressive fire-resistant aviation hydraulic fluids used in the sector. Chemically induced damage to protective coatings or the metal components themselves could significantly increase maintenance costs.

3.2.1.6 Technical feasibility criterion 5: Temperature Resistance

This parameter describes the ability of a material to withstand repeated low and high temperature cycling. For the same reasons stated above, it is a necessity that components and coatings are able to meet every functional requirement at all temperatures to which the components are going to be exposed during their service life.

3.2.1.7 Technical feasibility criteria 6: Compatibility with substrates/other coatings

Compatibility with a wide range of substrates (refer to Section 1.3.2), and primers is a key performance characteristic within the aviation sector. In the case of wash primers, compatibility with other primers is essential. Wash primers shall not deteriorate the properties of any subsequent layer.

3.2.1.8 Technical feasibility criteria 7: Applicable over large areas and compatibility with different application methods (spray, roller, brush)

Wash primers are regarded as large-area surface treatments, promoting adhesion for subsequent coating and painting schemes, and as such, are required to be efficiently sprayed over large areas (>15 m^2). Any alternative must be compatible with processes which facilitate the efficient spraying of these areas (e.g., spraying) but must also be compatible with smaller scale detail processes (e.g., brush, roller). Furthermore, it is necessary that a wash primer is able to be cured at room temperature rather than elevated temperature due to the large surface areas typically coated with wash primers.

3.2.1.9 Technical feasibility criteria 8: Detectability/visibility

To ensure uniform coverage of the wash primer across the component, it is necessary that the coating is visible to the naked eye. While other optical methods of detecting the presence of coating on a component are known (e.g., X-Ray fluorescence), it may be impractical or infeasible to perform these methods on all components coated with wash primers, particularly components with large areas as described in Section 3.2.1.8. The main consequence of non-uniform coating across the component is loss in adhesion of the subsequent layer and a loss in corrosion resistance of the overall coating system.

3.2.1.10 Technical feasibility criteria 9: Mechanical properties (including flexibility, scratch resistance and impact resistance)

Wash primers which make up a part of the coating system applied to leading edges/control surfaces, or components which may expand in use may have increased requirements for flexibility. In addition, surfaces which can be exposed to abrasive or impact conditions such as dust or precipitation during use may have increased requirements for scratch and impact resistance. Without proper mechanical performance in these areas, the risk of coating detachment or damage is increased. It should be noted, however, that mechanical properties are typically tested on a full coating system, rather than on components treated with wash primers alone. Therefore, the mechanical properties of subsequent coatings may contribute to achieving this technical feasibility criteria overall.

3.2.1.11 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 identified above for potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide. These criteria are measured against performance thresholds using standardised methodologies. The performance thresholds are most often assigned by the design owner of the component to which the primer is applied.

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 bodies such as British Standards Institution (BSI) or International Organization for Standardization (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 incumbent Cr(VI)-containing primer mixture.

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 technologies such as test rigs or prototype systems, see example in **Figure 3-8**. Attempts to replicate environmental in-service conditions are built upon bespoke testing regimes developed over decades of experience using Cr(VI) from laboratory scale test panels to test rigs housed in purpose-built facilities. However, they cannot fully reproduce natural environmental variations therefore there can be differences between what is observed in the laboratory and experienced in the field.

Figure 3-8: 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 A1-1** in Annex 1 of this document. 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 such that any suitable test candidates can be identified and further progressed.

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

Although 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), when considering the replacement of chromates this should be set against the diversity of applications of metal alloys across the sector. Aerospace and Defence sector finished products include fixed wing aircraft, rotary wing, powered lift aircraft, land-based equipment, military ordnance, and spacecraft. Examples of finished products within the scope of the ADCR are shown in **Figure 3-9**. Consequently, the industry requires a diverse range of metal alloys to fulfil all performance requirements that these various applications demand. Whilst wash primers containing potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide show a wide substrate compatibility, most Cr(VI)-free primers are more specific regarding suitability for different alloys. 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 3-9: Examples of finished products in A&D sector
Rheinmetall – Systems & Products, n.d.; Royal Navy, 2021

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

Various R&D activities were reported within the two parent applications for authorisation relating to wash primers. Proposed candidates for the replacement of Cr(VI) in wash primers are shown in **Table 3-4**. This list comprises all the alternatives that were reported in the parent AfAs and their technical readiness levels (TRLs)[20]

Table 3-4: Cr(VI)-free proposed candidates for the replacement of PHD/PCO in wash primers reported in parent AfAs

Proposed candidate	Implementation status (TRL level) reported in parent AfA	AfA ID
Cr(VI)-free inhibitors (Confidential)	TRL 2. At least 15 years required for implementation after a viable candidate is developed.	0047-02
Magnesium-rich corrosion inhibitors	Not a viable alternative to current wash primer systems due to clear technical limitations.	0047-02 0118-02
Molybdate-based corrosion inhibitors	Molybdate-based formulations are not thought to be a suitable	0047-02 0118-02

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[20] Includes alternatives that failed to meet the substitution criteria, and any reasons given.

Table 3-4: Cr(VI)-free proposed candidates for the replacement of PHD/PCO in wash primers reported in parent AfAs

Proposed candidate	**Implementation status (TRL level) reported in parent AfA**	**AfA ID**
	alternative to wash primers containing Cr(VI)	
Organic corrosion inhibitors	TRL 2. At least 15 years required for implementation after a viable candidate is developed.	0118-02
Phosphate-based corrosion inhibitors	TRL 2. Not considered a wash primer replacement due to clear technical limitations.	0047-02 0118-02
Rare earth-based corrosion inhibitors	Failed to meet requirements at laboratory scale. No R&D for replacement of Cr(VI)-containing wash primers was reported.	0047-02
Zinc-based inhibitors	TRL 2. Questionable if these systems will qualify for further R&D.	0118-02
Silane-based coatings	TRL 2. At least 15 years required for implementation after a viable candidate is developed.	0047-02 0118-02
Zirconate-based corrosion inhibitors (Organometallics)	Cat 1$^{(a)}$	0047-02 0118-02
Electrocoat primer technology	This technology was dismissed early in the parent AoA due to clear technical limitations	0118-02

Source: (CCST, 2015a, 2017)

(a) Parent AfA designation Category 1 (relevant R&D on this substance ongoing)

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

Since the initial AfAs, further R&D has been undertaken by the A&D sector to evaluate and improve the performance of existing and new Cr(VI)-free test candidates. During this time, a number of shortlisted alternatives which were reported in the parent AfAs have been eliminated from further consideration due to a clear inability to provide the required key performance requirements listed in Section 3.2.1. Namely, some candidates that have been eliminated from further evaluation are electrocoat primer technology and wash primers which are based on molybdenum-based inhibitors, organic corrosion inhibitors or rare-earth based corrosion inhibitors. While these alternative categories have been dismissed on grounds of poor technical performance, some of the chemistries involved may be used as a part of formulations under other shortlisted alternative categories. Conversely, an additional test candidate, lithium-based primers, is under currently under evaluation by some ADCR members. However, due to the early stage of R&D for this test candidate, no further information can be provided on lithium-based primers at this time. Lithium-based corrosion inhibitors have been shown to increase the corrosion resistance of various aluminium alloys in scientific literature and have been incorporated into primer systems by formulators which have been provided to OEMs for evaluation as potential alternatives to Cr(VI)-based wash primers.

The remaining shortlisted alternatives which have not been eliminated from evaluation since the parent applications have been further researched and developed by the consortium members to varying degrees of success. The most commonly identified test candidates were those reported as Cr(VI)-free inhibitors (confidential). As many OEMs are not informed of the proprietary constituents of the formulation by formulators, it is not always possible to identify the specific corrosion inhibitors of a Cr(VI)-free test candidate. It may be the case that this category of test candidates may contain any of the other specific chemistries listed within the shortlist of alternatives, or other chemistries known only to the formulators. This category of test candidates comprises potential alternatives where a proprietary mixture of test candidates has been formulated to achieve greater functional performance than achieved with the individual test candidates used in isolation. The specific composition of inhibitors used in these blends is often confidential business information to the formulators and could therefore not be disclosed to the ADCR consortium or its members Further information on shortlisted alternatives is presented in Section 3.5.

To further highlight the significant efforts being made by the aerospace and defence sector to substitute chromates, examples of ongoing R&D collaborations are identified below. It is noted that multiple collaborations are mentioned within the parent AfAs associated with the ADCR consortium Review Reports, however not all include research into the development of alternatives for wash primers.

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

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.

One ESTCP project sought to validate the performance of an organic-inorganic hybrid pre-treatment combining advanced silicon compound oligomers and water-soluble inorganic compounds to form a nano-structured film on a metal surface by immersion or by spraying-on and drying-in-place. The pre-treatment film significantly enhanced the corrosion resistance of metals by offering excellent paint adhesion for a wide variety of paints. A SERDP project focussed on the same alternative demonstrated that it could perform as well as the incumbent chromated wash primer in ASTM B117 neutral salt spray and the GM 9540P cyclic tests on cold rolled steel, AA 2024-T3 and AA 7075-T6 aluminium alloys when applied under an epoxy primer (Noblis, 2016).

In addition, members of the ADCR participate in national and international working groups such as the IAEG (International Aerospace Environmental Group) and the GIFAS (Groupement des industries françaises aéronautiques et spatiales) in which knowledge and information surrounding the substitution process and strategy is shared amongst the industry.

R&D partnerships between design owners and formulators formed under the bounds of Cooperation Research Agreements (CRAs) and Non-Disclosure Agreements (NDAs) have resulted in identification and shortlisting of specific wash primer products which have shown varying degrees of success. For example, one company reports identification of seven specific wash primer products which were shortlisted but ultimately failed to progress either due to failure at initial corrosion resistance screening tests, or failure to pass the requirements of promotion to TRL 3 or 4.

3.4.2 Consultations with customers and suppliers of alternatives

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

3.4.3 Data Searches

3.4.3.1 High level patent review

A patent search was performed with the aim of identifying examples of potential technologies related to wash primers. The search was performed using Espacenet[21], 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 terms "Wash primer" and "Chromate free" was filtered via the main group classification filters C09 and C23 (description below):

C09: Dyes; paints; polishes; natural resins; adhesive; compositions not otherwise provided for; applications of materials not otherwise provided for.

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

This search returned 14 results. These 14 patents were screened by reading of the abstracts, and those identified as potentially relevant are presented in Table **3**-**5** below.

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[21] Espacenet Patent Office (2022): Available at https://worldwide.espacenet.com/ accessed 20 February 2023

Table 3-5: Patent search technology summary		
Title	**Patent publication reference**	**Summary**
Wash primer composition	US2021332258A1	A coating composition includes a (A) binder component and a (B) pigment component. The (A) binder component includes (A1) polyvinyl butyrate, (A2) a particular film forming resin, (A3) an acid, (A4) an optional functionalized tri-alkoxy silane, and (A5) an optional polymeric phosphate ester. The (B) pigment component includes (B1) a calcium ion-exchanged silica, (B2) a corrosion inhibiting pigment, and (B3), a polyalkylene oxide phosphate. The coating composition is formed by combining the aforementioned components. In a method, the coating composition is applied to a substrate. **Cr(VI)-Free Corrosion inhibitors**: Aluminium(III) zinc(II) phosphate, Basic zinc phosphate, Zinc phosphomolybdate, Zinc calcium phosphomolybdate, Zinc borophosphate.
Chromate-free pretreatment primer	CN114106657A	A chromate-free pre-treatment primer is disclosed. A coating comprising an epoxy-functional resin, corrosion resistant particles, and a multifunctional cross-linking agent is disclosed as well as a method of coating at least a portion of a substrate using such a coating and the substrate coated thereby. **Cr(VI)-Free corrosion inhibitors:** zinc oxide (ZnO), magnesium oxide (MgO), cerium oxide (CeO)2) Molybdenum oxide (MoO)3) Praseodymium oxide and/or silicon dioxide (SiO)2)
Chromate free waterborne corrosion resistant primer	EP1842881A1	A waterborne corrosion resistant primer composition is composed of a waterborne resin system; an optional curing agent; and a non-chromate containing corrosion inhibiting additive. The non-chromate corrosion inhibiting additive includes at least one of an anodic corrosion inhibitor, a cathodic corrosion inhibitor and a metal complexing agent. The metal complexing agent increases the solubility of at least one of the anodic and cathodic corrosion inhibitors. **Cr(VI)-Free corrosion inhibitors:** Metal salts of the elements of Group IIIB of the Periodic Table; elements from Groups VB and VIB of the Periodic Table

Table 3-5: Patent search technology summary		
Title	**Patent publication reference**	**Summary**
Corrosion protective layer with improved characteristics	US2010068555A1	The invention relates to a corrosion-protective layer for protecting steel substrates from corrosion, comprising a zinc-chromium layer applied on the steel substrate by electrolytic joint deposition of zinc and chromium ions, and a chromate-free organic thin layer applied thereon, substantially comprising synthetic resins, and to a method for improving the paint adhesion of a zinc-chromium corrosion-protective layer. **Cr(VI)-free corrosion inhibitor:** Zinc sulphate heptahydrate/Chromium(III) potassium sulphate dodecahydrate
Acetoacetylated polyvinyl polymers and curable coating compositions made therefrom	EP1606347A1	The present invention relates to curable coating compositions containing acetoacetylated polyvinyl polymers obtained from polyvinyl polymers, such as polyvinyl butyrals. These coating compositions are especially suitable for use as wash primers in automotive OEM and refinish coating applications. **Cr(VI)-Free corrosion inhibitor:** Organic polymer, no additional corrosion inhibitors mentioned
Hydroxy functional binder for a primer coating	WO2009106646A1	The invention relates to a hydroxy functional binder for a primer coating composition comprising one or more epoxy functional compounds wherein epoxy groups have been esterified with a phosphorus acid compound. **Cr(VI)-Free corrosion inhibitor:** None specified

As with all patents, those listed in Table **3**-**5** introduce concepts and developments that may be advantageous within a given field in the fullness of time. However, it should be remembered that patents are granted for their novelty. Novelty does not necessarily translate to feasibility or applicability. The presence of these published patents within the public domain is by no means an indicator of their applicability within the demanding requirements of the A&D sector. Patented technologies are still bound to the requirements of the substitution process which will determine if a novel concept can be transformed into a feasible test candidate. Patents can also introduce limitations on the availability of a particular technology for example through the requirements for licencing. Where this is the case, a third party may obtain access to the technology if a licensing or some other commercial arrangement is available and meets the requirements of both parties.

Of those technologies listed above, some (US2021332258A1 and CN114106657A) appear to represent solutions similar to other proposed candidates which were discussed in the parent AfAs, whilst others

(EP1606347A1, and WO2009106646A1) do not make clear the identity of the corrosion inhibitor used. The patent with publication reference EP1842881A1, whilst including some rare-earth elements also appears to include elements which would represent novel technology not described previously, and the patent with publication reference US2010068555A1 includes zinc sulphate heptahydrate in combination with chromium potassium sulphate dodecahydrate. This is also considered to be a novel technology compared to the zinc-based corrosion inhibitors discussed in the parent AfAs.

ADCR members who reviewed the output of this high-level patent search responded that this kind of patent review is normally conducted at early stages of development (< TRL 2). Since OEMs receive a formulated product from formulators and are not typically informed of the specific proprietary chemistry taking place, it is not possible to determine whether the chemistries identified during the high-level patent search have been incorporated into test candidates evaluated by the ADCR. However, many ADCR members agree that some of the patents identified during this high-level search would be relevant to their requirements, though the specific use of these inventions may be limited to specific substrates or scenarios and would not be generally applicable for all test candidate development plans. In addition, due to the vague nature of the description of the chemistry in the patents, it is not always possible to assess the applicability of the invention to the specific requirements of substitution of Cr(VI)-based wash primers within the A&D sector. In one instance, the chemistry of one of the patents listed above has been evaluated by ADCR members. However it was noted that these technologies failed to meet the requirements of TRL 4 due to insufficient coating flexibility and unacceptable performance on alternate immersion testing.

3.4.3.2 High-level literature review

A non-exhaustive technical literature review was carried out using Science Direct (Journals and Books)[22] on-line service using the keyword search term 'Chromate-free corrosion resistant wash primer'[23]. The purpose of this search was to identify examples of alternatives to Cr(VI) for wash primers that have been investigated in the academic field or within other industry sectors. Although it is acknowledged that technical requirements for wash primers in another sector may not be relevant within A&D, this non-exhaustive review demonstrates any potential sources of cross-fertilisation from other industries or academic research. This exercise is an example of initial screening for candidates from industry and academia. The high-level literature review compliments the parallel non-exhaustive patent search. The results returned from the search are summarised in **Table 3-6.**

Table 3-6: Literature search for Chromate free wash primer in Science Direct

Search term	Time period	Research articles	Review articles	Open access
Chromate-free corrosion resistant wash primer	2010 – 2023	33	9	2

The title and abstracts of the 41 articles found were reviewed to identify those which were of genuine relevance to the analysis of alternatives to the use of chromates as corrosion inhibitors in wash primers. An expanded review is presented below for the 8 that were deemed to be of most relevance, these articles are summarised in Annex 4.

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[22] https://www.sciencedirect.com/

[23] Literature search conducted February 2023

Although some of the Cr(VI)-free corrosion inhibitors identified in the literature review are based on the same substances as those identified in the parent AfAs, the inclusion of additional additives means all can be considered sufficiently novel to be considered as distinct candidates.

It is important to note that the literature review was conducted to identify research activities relating to development of corrosion inhibitors applicable to wash primers. While this is arguably the most crucial technical feasibility criterion, and is typically screened first, the success of the formulations in this area within the literature holds no bearing on how coatings incorporating these pigments will perform against other technical feasibility criteria, most importantly, adhesion promotion but also chemical resistance, temperature resistance and others. Additionally, the responsibility of performing literature searches for new chemistries to implement into new coating systems lies primarily with the formulators, rather than the design owners.

3.4.4 Identification of alternatives

Proposed candidates for the replacement of Cr(VI) in wash primers are listed below. This list comprises all the alternatives that were reported in the parent AfAs, as well as any further proposed candidates identified during consultation.

- Magnesium-rich primers
- Organic corrosion inhibitors
- Phosphate-based corrosion inhibitors
- Rare earth -based corrosion inhibitors
- Zinc-based corrosion inhibitors
- Silane-based coatings
- Zirconate-based corrosion inhibitors (Organometallics)
- Molybdenum-based corrosion inhibitors
- Lithium-based primers
- Electrocoat technology
- Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors

Note, those solutions identified following the high-level literature patent review presented above are not included in this list as at present they have not been presented as proposed candidates by the formulating companies and performance has not been assessed. This may be because initial investigations by formulators have concluded that they would not meet performance requirements of customers' designs. If qualification, certification, or industrialisation of the test candidates currently being progressed were to fail for particular components, formulators and downstream users may look to develop proposed candidates based on these novel methods if the necessary licencing agreements can be reached.

As stated in Section 3.2.1, the technical feasibility criteria of test candidates for the substitution of Cr(VI) in wash primers which must show equal or better performance compared to the incumbent wash primers are:

- Corrosion resistance;
- Adhesion promotion;
- Layer thickness;
- Chemical resistance;
- Temperature resistance;
- Compatibility with substrate/other coatings;

- Applicable over large areas and compatibility with different application methods (brush, roller, spray);
- Detectability/visibility; and
- Mechanical properties (impact resistance, scratch resistance, flexibility).

In support of initial screening, testing, also referred to as "critical-to-quality-tests", is conducted to assess performance of proposed candidates in the laboratory environment for each of the criteria.

The most relevant method for the assessment of layer thickness is ISO 2808 and general methods are available in the A&D sector for the testing of temperature resistance (for example, BS 2X 33, PR EN 4160, and HMDC 0097A).

To determine the compatibility with substrates or structural primers, adhesion testing according to ISO 2409 or ASTM 3359 may be carried out.

For wash primer applications, corrosion resistance may be tested according to ASTM B117 or ISO 9227 (both salt spray tests), or EN 3665 (filiform corrosion test). In general, adhesion is tested according to ISO 2409 or ASTM 3359) whilst the most relevant method for the assessment of layer thickness is ISO 2808.

Further details on the above standards, as well as other examples of standards used for screening proposed candidates within the development phase of the substitution process are given in **Table A1-1** Both standards and specifications are tools used to evaluate proposed candidates to identify suitable test candidates. The specifications/standards listed here are test methods and do not define success criteria for alternatives validation.

Interrelationship of technical feasibility criteria and impact on the suitability of alternatives

Potential test candidates to replace the use of Cr(VI)-based wash primers must meet the technical feasibility criteria as described in Section 3.2.1.1. The interrelationship between these technical feasibility criteria plays a crucial role in determining the suitability of potential candidates, and improving the performance of the test candidate under one technical feasibility criterion should not come at a detriment to any of the others.

For example, a test candidate which shows regression in corrosion resistance when compared to the incumbent wash primer may pass corrosion resistance requirements if a greater volume of the alternative is applied, however this may also come at the cost of increasing the wash primer layer thickness beyond the allowed tolerance set within the specifications. Therefore, due to a regression in corrosion resistance, the layer thickness requirement could not be achieved.

It is also necessary that a wash primer provides adhesion promotion to the subsequent layer. While this may be possible for some subsequent coatings, chemical incompatibilities between the test candidate and the required subsequent coating may result in loss of the adhesion promotion qualities. Loss in adhesion promotion also has the effect of reducing corrosion resistance by reducing the effectively coated area of the component.

While these are illustrative and particularly impactful examples some of the ways the technical feasibility criteria are interconnected, it is by no means an exhaustive description of how each of the technical feasibility criteria are connected to the others. In reality, almost all of the technical feasibility criteria have some impact on the others, and it is often the case that when developing a wash primer, one specific technical feasibility criterion cannot be selectively targeted for improvement without some impact on the others. This interrelationship between technical feasibility criteria highlights another facet of complexity when substituting Cr(VI) in wash primers with alternatives.

The GCCA application for authorisation (GCCA, 2017) considers design and operating parameters that could impact similar components which can influence behaviour and compatibility with a primer, and therefore delivery of technical feasibility criteria. These are listed below[24]:

- Hardware[25] base alloy(s);
- Contact or mating surfaces with other components;
- Exposure to fluids (e.g., de-icer, lubricants, aqueous salt solutions, sea water/moisture);
- Structural stress and strain;
- External environment (including temperature, humidity, wind/rain erosion, etc.);
- Functional characteristics; and
- Service life.

Interaction effects such as galvanic influences from dissimilar metals, galling, erosion, and mechanical vibration can fundamentally affect the corrosion behaviour of a component and the performance requirements which any Cr(VI)-free primer alternative must meet. Due to the complexity of these assemblies and the variety of environments encountered in service, a single alternative may not provide a universal solution to delivery of all technical criteria under all scenarios of use.

3.4.5 Shortlist of alternatives

The shortlisted potential test candidates for alternatives to Cr(VI) in wash primers are shown below. This list comprises all of the alternatives that have been reported in the parent AfAs and have been reported as the focus of R&D activities relating to the substitution of Cr(VI) in wash primers within the ADCR. Not included in this list are candidates which have been evaluated through preliminary testing and eliminated at early stages of research.

The test candidates which have been the subject of a greater amount of focus and progression by the ADCR members are:

- Magnesium-rich corrosion inhibitors;
- Phosphate-based corrosion inhibitors;
- Zinc-based inhibitors;
- Silane-based coatings;
- Zirconate-based corrosion inhibitors; and
- Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors.

3.5 Assessment of shortlisted alternatives

3.5.1 Introduction

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

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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

Approval of the test candidate must include a complete understanding of the influence of the treatments applied prior to the primer, and the layers applied after the primer, within the surface treatment and coating system as a whole. This is to understand the influence of all processes involved in the treatment 'system' including surface treatments and coating layers. Evaluation of the technical feasibility of a test candidate for wash primers should consider its behaviour in combination with other supporting treatments within the 'system'. Any change in these system variables may lead to irregular or unacceptable performance of the test candidate for replacement of the primer and consequently impact or delay approval of the alternative for different component designs. This scenario is a leading reason for the graduated implementation of viable test candidates in combination with different component/design families. Different designs exhibiting varying degrees of complexity, have the potential to interact with elements of the treatment system differently and thus effect the performance of a test candidate.

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

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

When assessing the suitability of an alternative, reference is made to the European Commission note dated 27 May 2020 which clearly defines the criteria by which an alternative may be judged as suitable[26]. In order to be considered as suitable in the European Union (EU) the alternative should demonstrate the following:

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

To be available, a test candidate should meet the regulatory requirements of placing it on the market. Until the technical feasibility criteria and associated performance requirements of the use and wider treatment system are fulfilled, including all certification obligations as stipulated in the Airworthiness Directives[27], the test candidate cannot be deemed 'available'.

All civil aircraft operating in GB are subject to international safety standards including Airworthiness Directives issued by EASA on behalf of the EU and its Member States, and European third countries participating in the activities of EASA[28]. Changes to design of a product are subject to certification and

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[26] 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

[27] EASA (2022), available at https://www.easa.europa.eu/en/domains/aircraft-products/airworthiness-directives-ad accessed 18 October 2022

[28] UK CAA (2024), available at Our role | Civil Aviation Authority (caa.co.uk) accessed 20 June 2024

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

3.5.2 Test candidate 1: Magnesium-rich primers

3.5.2.1 Introduction

This category of test candidates refers to the use of powdered magnesium metal within an organic binder system to provide corrosion resistance to the substrate through a sacrificial mechanism, wherein the magnesium metal in electrical contact with the substrate forms a galvanic cell, allowing the magnesium within the coating to corrode preferentially to the base alloy upon contact with corrosive environments such as oxygen, moisture and electrolytes. Below is a description of the status of Mg-rich primers as reported in the parent AfAs.

Magnesium is the most electrochemically active metal and widely used as a sacrificial anode to provide cathodic protection to underground and undersea metallic structures. It was reported in the parent AfAs that Mg-rich primer systems, employing magnesium powder within an organic coating, could potentially provide a more robust galvanic protection mechanism than Cr(VI), whilst also exhibiting very good filiform corrosion resistance (CCST, 2015a).

Mg-rich primers were identified as unsuitable for use as wash primers as their high viscosity will not allow them to be applied at the required dry film thickness, and that the much higher pigment volume concentration of the formulation makes them unsuitable from a technical performance standpoint (CCST, 2017).

3.5.2.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of magnesium-rich primers

A number of technical results from the ongoing development of magnesium-rich alternatives for wash primers have been reported by ADCR members. These are discussed in the following sections. Of the relevant performance requirements discussed in Section 3.2.1, corrosion resistance and adhesion promotion were reported by members as key reasons for failure of the magnesium-rich primers. In addition, one member reported that while one of the test formulations performed well against all performance requirements, the formulation contains certain per- or polyfluorinated solvents which are banned in the country in which their customers are based. Additionally, it is within scope of the proposed PFAS restriction under REACH which is set to take effect before the end of the requested review period. It is clear that the PFASs used within the solvent system are crucial to delivering this exceptional functionality and therefore cannot be readily substituted without the loss of technical performance.

Corrosion Resistance

The corrosion resistance of magnesium-rich primer formulations which are PFAS regulation compliant was reported by one member to show regression when compared with the incumbent Cr(VI)-based wash primers. **Figure 3-10** below shows a comparison between the magnesium-rich test candidate and the incumbent treatment on both aluminium and steel following exposure to Neutral salt spray (NSS) for 1,400 hours and 860 hours respectively according to ISO 9227.

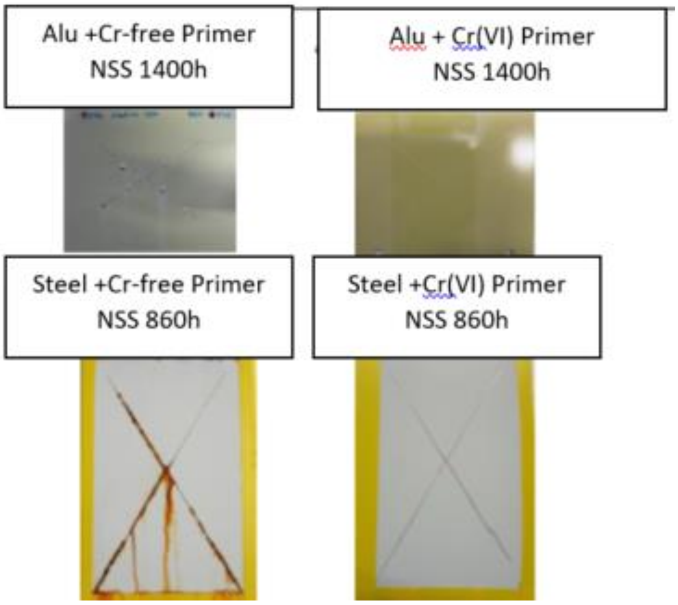

Figure 3-10: Photographic evidence of failed NSS corrosion tests of aluminium and steel substrates coated with magnesium-rich primers and comparison with the incumbent Cr(VI)-based wash primer treatments

Source: ADCR member

Whilst on aluminium substrates, visible corrosion appears to be minor, blistering and delamination of the coating as a result of corrosion can be observed at the site of inscription. This blistering and delamination constitutes a failure in this corrosion test.

On steel substrates, visible and significant corrosion can be observed at the site of inscription as red iron oxides. A comparison between the NSS exposure results for the test candidate and the incumbent Cr(VI)-based wash primer further demonstrates the severity of the loss in corrosion resistance from the use of magnesium-rich primers.

Adhesion and compatibility with substrates

Adhesion of Cr(VI)-free test candidates to metal substrates is a critical property which must be achieved before substitution is possible. In the case of regulatorily compliant magnesium-rich primers, adhesion to aluminium substrates was reported by one member to show significant regression when compared to the incumbent surface treatment. A photograph in **Figure 3-11** below demonstrates how the coating flakes off the aluminium testing panel following adhesion testing according to this member's internal standards. It is important to note that the majority of coating loss occurs at the edges of the panel, rather than the site of inscription, meaning that adhesion is poor even when the coating surface is undamaged. Moreover, it should be noted that particulate magnesium metal is highly reactive with acids such as phosphoric acid, and therefore would not be a suitable alternative to applications of wash primers where surface etching of the substrate by an acidic component is necessary to achieve adequate adhesion to the substrate.

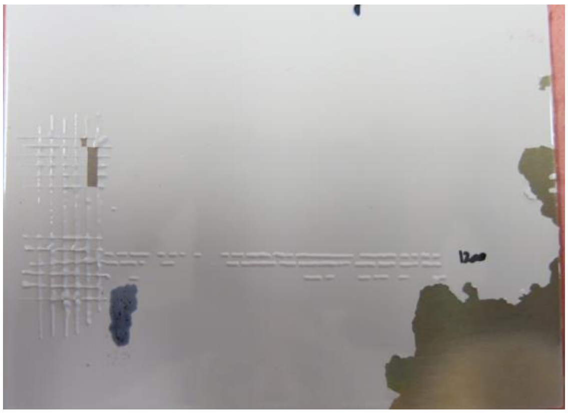

Figure 3-11: Photographic evidence of the loss of adhesion of a magnesium-rich primer following testing according to ISO 2049
Source: ADCR member

Layer thickness

As reported in the parent AfAs, magnesium-rich primers typically have higher viscosities than that required for wash primers. In addition to the rheological properties of magnesium-rich primers increasing the minimum applicable layer thickness, it was reported that magnesium particles and aggregates of the particles can exceed 50 µm, further limiting the minimum thickness at which a uniform layer can be applied to the substrate. While this increase in minimum layer thickness will limit the use of magnesium-rich primers as drop-in replacements to wash primers in the typical coating scheme, it is possible that given sufficient corrosion resistance and adhesion, application of a magnesium-rich primer may have the ability to form a part of an alternative coating 'system' which does meet layer thickness requirements of the component.

Due to these critical limitations in the performance of fluorinated solvent-free magnesium-rich primers, these are not regarded as technically suitable alternatives to Cr(VI)-based wash primers within the A&D industry, and as such, TRLs have not been reported by ADCR members.

Economic feasibility of magnesium-rich primers

Due to the primary action of magnesium-rich primers providing corrosion protection through the sacrificial mechanism rather than anodic, cathodic and buffer related corrosion protection as described in Section 3.1.1, it is possible that significant changes must be made to the overall coating 'system' to facilitate the wash primer substitution. These changes may incur significant costs in any new equipment required, as well as reducing the overall efficiency of the coating process. However, due to limitations in technical feasibility, magnesium rich primers have not been advanced to a stage where ADCR members are able to accurately predict quantitative economic impacts of substitution with magnesium-rich primers, should a well-performing and PFAS-restriction compliant formulation be identified.

Health and safety considerations related to the use of magnesium-rich primers

As stated previously, technical limitations of magnesium-rich primers have limited their adoption as an alternative to Cr(VI)-based wash primers within the A&D industry. In the case that a technically feasible formulation was identified by a member, this was rejected due to the presence of fluorinated solvents within the primer. These fluorinated solvents are subject to current EU Member State-specific restrictions, and future blanket restrictions on all PFAS on the grounds of their persistence, bioaccumulation and toxicity. Thus, making them a potential regrettable substitution.

An intrinsic hazard to all magnesium rich primer formulations is the extreme flammability of high-surface area magnesium power. In its dry state, magnesium powder is self-heating in contact with moisture and oxygen and in some cases can spontaneously ignite. When present within a mixture with organic solvents and binders as supplied to the applicator, the risk of spontaneous combustion is largely mitigated.

Availability of magnesium-rich primers

While magnesium-rich formulations are available on the EU market, limitations in technical feasibility and regulatory constraints prevent their application as an alternative to Cr(VI)-based wash primers. If a technically feasible and regulatorily compliant magnesium-rich primer formulation were to be identified, it is likely that there would be no fundamental limitations to meeting the demand required by the A&D sector such as raw materials availability. However, since magnesium-rich primers are fundamentally incapable of providing a layer thickness low enough to adhere to dimensional tolerances of components, it is unlikely that a magnesium-rich primer will be developed which is a direct substitute to Cr(VI)-based wash primers.

Suitability of magnesium-rich primers

Magnesium-rich primers may be used to replace Cr(VI)-based coatings in some capacity in the future. However, due to fundamental technical limitations in the rheology of these formulations it is highly unlikely that magnesium-rich primers will provide the same key functionality as Cr(VI)-wash primers and cannot therefore be considered a suitable alternative. Where tested formulations have shown promise in replacing Cr(VI) in the overall coating scheme, implementation and acceptability of these formulations has been prevented by PFAS-regulations and the non-use of fluorinated solvents which are critical to this alternative's performance.

3.5.3 Test Candidate 2: Phosphate based corrosion inhibitors

3.5.3.1 Introduction

Phosphate produces a surface layer on the applied substrate which provides a measure of corrosion protection. Polyphosphates are amongst the technically most promising Cr(VI)-free anticorrosive inhibitors where high performance protection is required, and several phosphate-based inhibitors are undergoing R&D by formulators. The exact substance identity and composition in primers is not known as this is confidential business information (CCST, 2015a).

In the parent AfAs, it was reported that in general, phosphate-based anticorrosive agents were not currently seen as alternatives for wash primer on aluminium alloys as they do not provide the required level of corrosion protection. More specifically, they failed to meet the A&D industry's requirements in salt spray testing, whilst none of the phosphate-based corrosion inhibitors show sufficient active corrosion inhibition (CCST, 2017).

Required adhesion properties and chemical resistance had been demonstrated on aluminium alloy AA2024-T3 pre-treated with tartaric-sulphuric acid anodising (TSA) or conversion coatings, and compatibility with the substrate proved to be sufficient for wash primer applications. The assessed candidate was also able to provide sufficient performance regarding layer thickness. However, it was stated that phosphate-based primers are ultimately technically unacceptable for wash primer applications since they are a high temperature cure (bake) primer for use with epoxy stoving coatings (CCST, 2017).

Phosphate-based primer systems were reported to not be technically equivalent to Cr(VI)-based products and were not considered as a wash primer replacement due to clear technical limitations (CCST, 2015a).

3.5.3.2 Progression reported by ADCR members

Technical feasibility of phosphate-based corrosion inhibitors

While phosphate-based corrosion inhibitors were determined to be unsuitable alternatives to Cr(VI)-based wash primers in most situations, one ADCR member has reported that formulations based on phosphate corrosion inhibitors remain a part of their testing regime. However, this member reported that tests are ongoing and are not at a stage where a full commentary on the technical performance of phosphate-based test candidates could be reported. For this reason, at this time, phosphate-based corrosion inhibitors cannot be considered as a technically feasible alternative to Cr(VI)-based wash primers.

Economic feasibility of phosphate-based corrosion inhibitors

Due to the limited technical feasibility of phosphate-based corrosion inhibitors, no detailed economic feasibility assessments have taken place by ADCR members. However, considering that the alternative formulations would be applied using mostly the same equipment as the incumbent wash primer, it is predicted that additional capital investment in new application equipment will be low. Other considerations for economic feasibility include the operational efficiency relating to the applicability of the coating over large surface areas. Since testing of phosphate-based corrosion inhibitors is at an early stage within the ADCR membership, tests have not been conducted to determine the efficiency of coating with this test candidate at this time.

Health and Safety considerations relating to the use of phosphate-based corrosion inhibitors

Though no thorough assessment has been conducted on phosphate-based test candidates, these absence of non-threshold carcinogens such as Cr(VI) within the formulations would constitute an overall reduction in risk to human health during use compared to the use of the incumbent wash primer products. In the parent AfAs, it was reported that the worst-case scenario for phosphate-based formulations were classified as Skin Irrit. 2, Eye Dam. 1, STOT SE 3, Aquatic Acute 1, Aquatic Chronic 1, Acute Tox. 4. During consultation, no mention of new alternatives with a greater hazard profile than this was made.

Availability of phosphate-based corrosion inhibitors

Should future testing indicate that phosphate-based corrosion inhibitors can be used as technically feasible alternatives to Cr(VI)-based wash primers, there is no reason as to why these formulations would not be commercially available within the EU market. However, since no phosphate-based formulations have been determined to be technically feasible, ADCR members have not commented on the availability of any potential future formulations.

Suitability of phosphate-based corrosion inhibitors

Though phosphate-based corrosion inhibitors have seen additional and ongoing R&D activities since the submission of Parent AfAs, clear limitations in their technical performance indicates that these test candidates will not likely be considered a viable alternative for the wider A&D sector. Technical maturity as reported in the Parent AfAs saw phosphate-based corrosion inhibitors stagnate at TRL 2, and very limited progression of these test candidates has been reported since.

3.5.4 Test candidate 3: Zinc-based inhibitors

3.5.4.1 Introduction

Zinc-based inhibitors refer to corrosion inhibitors which are either powdered zinc metal, or various zinc salts such as zinc silicate. It was reported in the parent AfAs that zinc-based inhibitors have been used to provide limited corrosion resistance to a number of substrates in a number of industries. However, as an alternative to Cr(VI)-based wash primers, zinc-based inhibitors were generally considered not to be suitable due to fundamental limitations in corrosion protection, substrate compatibility and mechanical properties such as impact resistance and flexibility. Below is a summary of the status of zinc-based inhibitors as reported in the parent AfAs.

Various zinc-based primers are commercially available, and these are used only to provide temporary corrosion protection (CCST consortium, 2017). When tested on clad and unclad Al alloys, zinc-based formulations demonstrated acceptable performance in the salt spray test, however corrosion from scratching exceeded the acceptable maximum in the filiform corrosion test. In addition, long-term corrosion protection on scratched surfaces is deemed to be insufficient. The zinc-based formulation tested also failed to meet active corrosion inhibition requirements due to the observation of pitting after 1000hrs (CCST consortium, 2017).

Adhesion performance of zinc-based inhibitors in coatings on Al alloys and in epoxy primer on Al alloy pre-treated with tartaric-sulphuric acid anodising (TSA) was sufficient, whilst zinc-based inhibitors in both coatings applied to Al alloys demonstrated sufficient performance in water, hydraulic fluid, fuel and humidity. They also fulfilled the requirements regarding layer thickness (CCST, 2017).

In conclusion, products containing zinc compounds are of low maturity and cannot be considered as a replacement for wash primer applications due to clear technical limitations (CCST, 2017).

3.5.4.2 Progression reported by ADCR members

Technical feasibility of zinc-based inhibitors

Though testing of several zinc-based inhibitors has been conducted since submission of the parent AfAs, test candidates of this category have all been eliminated at very early stages of R&D due to clear limitations in corrosion resistance, adhesion and compatibility with substrates. Below in **Figure 3-12** is a photographic example of a real component in which the zinc-based coating has been stripped completely from the substrate following the removal of a section of masking tape, demonstrating a clear regression in performance when compared to the incumbent Cr(VI)-based wash primers.

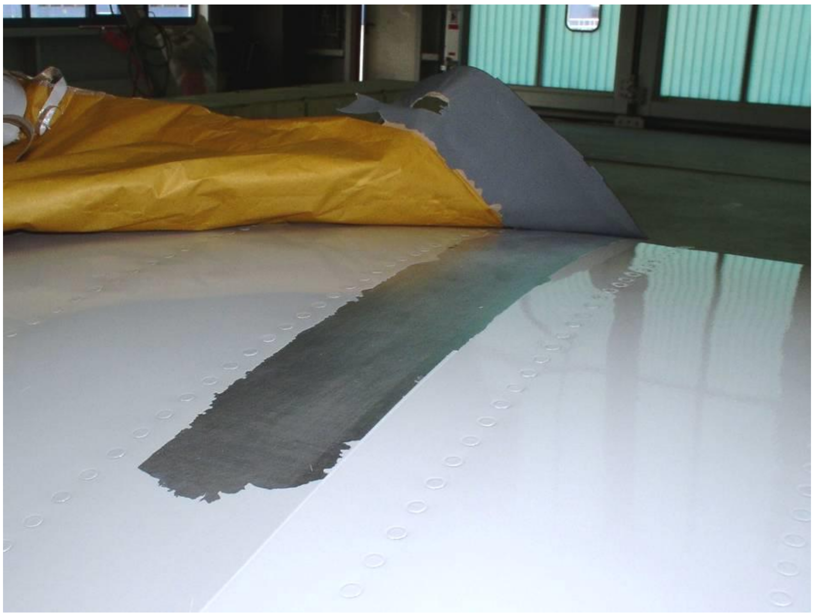

Figure 3-12: Photographic evidence of failed adhesion and substrate compatibility of a zinc-based coating following the removal of masking tape, resulting in the elimination of this candidate at early stages of research.

Source: ADCR member

Economic feasibility of zinc-based inhibitors

Due to clear limitations in the technical feasibility of current zinc-based inhibitors, no detailed assessment of the economic feasibility of these test candidates has been conducted. However, during consultation, there was no indication that these alternatives would be economically infeasible should a technically feasible candidate be identified.

Health and safety considerations relating to the use of zinc-based inhibitors

Although no thorough assessment has been conducted on zinc-based inhibitor test candidates, the absence of non-threshold carcinogens such as Cr(VI) within the formulations would constitute an overall reduction in risk to human health during use compared to the use of the incumbent wash primer products. In the parent AfAs, it was reported that the worst-case scenario for zinc-based inhibitor formulations were classified as Skin Irrit. 2, Eye Irrit. 2, Acute Tox. 4, STOT SE 3, Aquatic Chronic 3. During consultation, no mention of new alternatives with a greater hazard profile than this was made. In the case of zinc-rich primers containing zinc powder rather than zinc salts, these would be classified primarily as Aquatic Chronic 1 and Aquatic Acute 1, as well as any additional hazards arising from the organic binder formulation.

Availability of zinc-based inhibitors

Formulations containing zinc-based inhibitors are widely available on the EU market primarily for use on steel substrates. The status zinc-based inhibitors was reported to be at TRL 2 at the time of submission of the parent AfAs. While additional research has been conducted into the use of zinc-based inhibitors as alternatives to Cr(VI)-based wash primers, no further progression in the TRL of this candidate has been reported due to clear limitations in technical feasibility.

Suitability of zinc-based inhibitors

Zinc-based inhibitors have been tested to a degree since the submission of the Parent AfAs, however these have been eliminated at very early stages of assessment. This is due to clear limitations in key performance criteria such as adhesion to substrate. Therefore, zinc-based corrosion inhibitors are not currently considered to be suitable alternatives to Cr(VI)-based wash primers, and it is questionable whether these test candidates warrant further testing within the A&D sector.

3.5.5 Test candidate 4: Silane-based coatings

3.5.5.1 Introduction

Silane-based coatings typically refer to sol-gel systems which are comprised of a network of silica formed upon the substrate surface following hydrolysis of an alkyl silicate such as tetra-ethyl orthosilicate. Silane-based coatings are typically used to promote adhesion between the substrate and subsequent coating layers, where covalent bonds form between the thin metal oxide layer of the substrate surface and the silicon atoms of the silane. Hydrogen bonding between the terminal Si-OH bonds of the silane coating network promote the adhesion of the coating and the silane treated substrate. Below is a summary of the status of silane-based coatings as reported in the parent AfAs.

When comparing the general functionalities provided by Cr(VI) in wash primers (cathodic and anodic inhibition and buffer stabilisation), sol-gel systems alone do not exhibit the same properties. Sol-gel chemistries do not provide sufficient standalone corrosion resistance and there are no known additives to the silane matrix that have shown corrosion resistance that meets aviation requirements. Sol-gel systems do not adhere directly to the metal, they adhere to a very thin oxide phase on the metal surface. This leads to susceptibility to bond line corrosion unless acidic pickling of the surface is undertaken before sol-gel application (CCST, 2015a).

Achieving the required level of corrosion protection requires a thick sol-gel layer, but with increasing layer thickness the coating becomes brittle, which compromises corrosion protection and is therefore not acceptable. The process for the application of sol-gel coatings is also complex and has limited reproducibility. The technologies show limitations in applying the coating to complex parts and more sophisticated strategies have not yet been developed (CCST, 2017).

Currently Cr(VI)-free sol-gel systems are not considered to be a one-to-one replacement for Cr(VI)-based wash primers, however they are subject to ongoing R&D. Importantly, the implementation of sol-gel solutions is strongly limited by the industrial conditions under which they have to be applied, and significant improvements have to be made in applying these systems on complex parts and controlling their layer thickness (CCST, 2015a).

3.5.5.2 Progression reported by ADCR members

Technical feasibility of silane-based coatings

While various silane-based coating systems have been researched and tested, achieving sufficient corrosion resistance has been the major shortfall of these systems. As such, ADCR members who are actively researching silane-based coating systems have reported that all candidates have failed to progress beyond TRL 2 for their substitutions. In addition to failed corrosion resistance, the mechanical properties of silane-based coatings, particularly when applied in a thick layer to abate corrosion resistance shortfalls, have been deemed unacceptable by the industry due to brittleness and low flexibility. As a result, silane-based corrosion inhibitors are not currently considered technically feasible alternatives to Cr(VI)-based wash primers.

As an illustrative example, one ADCR member provided a photograph of the results of an alternate immersion corrosion test performed on a test coupon treated with a silane-based coating as shown below in **Figure 3-13**. The photograph shows significant corrosion pitting on the scribed area. This level of corrosion is unacceptable and therefore this coating formulation is not considered an alternative to Cr(VI)-based wash primers.

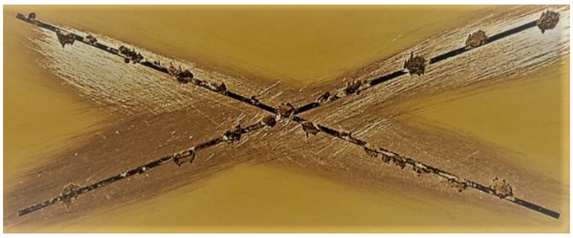

Figure 3-13: Photographic evidence of unacceptable corrosion resistance performance of a silane-based coating following an alternate immersion test

Source: ADCR member

Due to this regression in technical performance when compared to the incumbent coating systems in this key criterion, further tests to examine other key performance criteria were not conducted.

Economic feasibility of silane-based coatings

Due to clear limitations in the technical feasibility of current silane-based coatings, no detailed assessment of the economic feasibility of these test candidates has been conducted. To prevent bond-site corrosion, the substrate must first undergo a pickling step, which may constitute a significant change in the current process where the substrate is only prepared by mechanical means such as sanding or grit-blasting. This process change may require significant investment which will impact the economic feasibility of substitution by silane-based coatings.

Health and safety considerations relating to the use of silane-based coatings

As these test candidates have not shown sufficient technical performance to replace Cr(VI)-based wash primers in the A&D sector, no detailed health and safety assessments have been reported by ADCR members. However, as reported in the Parent AfAs, in the worst case, substance identified which are used in silane-based coatings are classified as Flam. Liq. 3, Acute Tox. 4, Eye Dam. 1, Skin Irrit. 2, Eye Irrit. 2, STOT SE 3, Asp. Tox 1, Muta. 1B, Carc. 1B. The substance which is most responsible for this classification is vinyl trimethoxysilane . However, subsequent to the publication of the parent applications, a Substance Evaluation Conclusion report[29] published by Kemi, concluded that this substance should be classified as a skin sensitiser, Skin Sens.Cat.1B, which was agreed by RAC.

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[29] https://echa.europa.eu/documents/10162/6709659e-4c4c-06a7-ea70-5aa094c25203

Availability of silane-based coatings

Silane-based coatings are widely available on the EU market due to their use as adhesion promotors in multiple industries, and therefore these test candidates are expected to be available in sufficient quantities in the event that future testing proves that silane-based coatings are qualified to be a part of alternative to Cr(VI)-based wash primers in alternative coating schemes.

Suitability of silane-based coatings

Due to the clear shortfalls in corrosion resistance when compared to the incumbent Cr(VI)-based wash primer treatments, silane-based coatings cannot be considered a suitable alternative. In addition, the potentially higher hazard profile of silane-based coatings compared to other test candidates may further limit their overall suitability as an alternative.

3.5.6 Test candidate 5: Zirconate-based corrosion inhibitors

3.5.6.1 Introduction

Zirconate-based corrosion inhibitors have been examined further as a test candidate for the substitution of Cr(VI)-based wash primers. In the parent AfAs, zirconate-based corrosion inhibitors were identified in the literature as a potential candidate, though little testing had been conducted at the OEM level. For this reason, a TRL was not attributed to this test candidate in the parent AfAs. Information regarding this test candidate as described in the parent AfAs is summarised below.

Organometallics are mainly investigated as a replacement to chromate chemical conversion coatings and as part of sol-gel formulations, but not as a direct wash primer alternative. Organo-zirconates build up very thin layers on surfaces to enhance adhesion of subsequent coatings, but do not provide sufficient corrosion protection. These Cr(VI)-free conversion coatings therefore do not meet the necessary requirements for wash primers (CCST, 2015a).

The current first generation of zirconate-based sol-gel coatings also do not provide sufficient corrosion protection on various aluminium alloys, and adhesive failure is seen between primer and substrate. Organo-zirconates build up in very thin layers of 1 µm on surfaces – for wash primer applications within the A&D sector, a layer thickness of 8-12 µm is required. For Cr(VI)-free systems based on organometallics, no multilayer compatibility can be achieved (CCST, 2017).

In conclusion, the tested zirconate-based systems do not meet the technical requirements of wash primers and are far from technically equivalent to Cr(VI)-based primer systems in this use (CCST, 2015a).

3.5.6.2 Progression reported by ADCR members

Technical feasibility of zirconate-based corrosion inhibitors

While one ADCR member has reported that further R&D has taken place on the use of zirconate-based corrosion inhibitors since the submission of the parent AfAs, progression to TRL 3 has been limited by continuously poor performance in corrosion inhibition. Namely, filiform corrosion testing demonstrated regression compared to Cr(VI)-based wash primer treatments where corrosion filaments of length beyond 7 mm formed following the test. A photograph of the results of this filiform corrosion test is shown below in **Figure 3-14**.

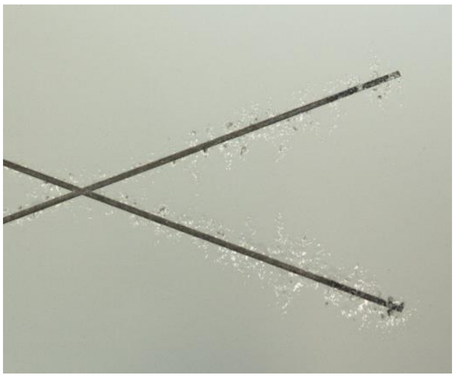


Figure 3-14: Photographic evidence of a failed filiform corrosion test on a metallic substrate coated with a zirconate-based conversion coating demonstrating corrosion filaments of length greater than 7 mm.
Source: ADCR member

Despite this failure in corrosion resistance, zirconate-based corrosion inhibitors have been shown to perform well in other key performance criteria such as adhesion to substrate, layer thickness, chemical resistance and mechanical properties such as impact resistance and flexibility. Nonetheless, as corrosion resistance of this test candidate is not sufficient to replace Cr(VI) in wash primers, zirconate-based corrosion inhibitors cannot be considered a technically feasible alternative at this time.

Economic feasibility of zirconate-based corrosion inhibitors

Due to clear limitations in the technical feasibility of current zirconate-based corrosion inhibitors, no detailed assessment of the economic feasibility of these test candidates has been conducted. However, no information was obtained during consultation that would suggest that this test candidate would not be economically feasible.

Health and safety considerations relating to the use of zirconate-based corrosion inhibitors

As this test candidate is not considered technically feasible, no rigorous assessment of the health and safety of zirconate-based corrosion inhibitors has been conducted by the A&D sector. In the parent AfAs, the worst-case classification of substances used within test candidates of this category are Met. Corr. 1, Acute Tox. 2, Skin Corr. 1B, Eye Dam. 1, STOT SE 3. There was no indication by ADCR members who had evaluated this test candidate further that any substances with a greater hazard profile than this had been used. Therefore, if technically feasible wash primer formulations based on zirconate chemistry were identified, these would likely constitute an overall reduction in risk in comparison to wash primer formulations containing non-threshold carcinogens like the incumbent Cr(VI)-based wash primers.

Availability of zirconate-based corrosion inhibitors

Commercial products based on zirconate chemistry are currently available on the market as adhesion promotors. Their use as alternatives to Cr(VI)-based wash primers in the A&D sector is not technically feasible, and therefore there are no technically feasible zirconate-based formulations commercially available to the A&D sector. However, in the event that a technically feasible zirconate-based alternative is identified, there was no indication that this could not reasonably be supplied in the quantities required by the sector.

Suitability of zirconate-based corrosion inhibitors

Due to clear shortfalls in corrosion resistance performance, zirconate-based corrosion inhibitors cannot be considered a technically feasible alternative to the incumbent Cr(VI)-based wash primers for the A&D sector.

3.5.7 Test candidate 6: Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors

3.5.7.1 Introduction

This category of test candidates comprises potential alternatives where a proprietary blend of previously described test candidates has been formulated to achieve greater functional performance than the individual test candidates. The specific composition of inhibitors used in these blends is confidential business information to the formulators and could therefore not be disclosed to the ADCR consortium or its members. However, during consultation with formulators, it is understood that these proprietary blends are comprised primarily of test candidates 1-5 in combination with polymer binders, solvents, and usually an etchant such as phosphoric acid. In some cases, organic corrosion inhibitors may be included in the formulation to further supplement the corrosion resistance of the alternative, though organic corrosion inhibitors have not been shortlisted as a standalone test candidate due to issues with corrosion performance.

In the parent AfAs, the test candidate “Cr(VI)-free (confidential)” was used to describe most of the alternative formulations comprised of mixtures of other test candidates. As such, the progression of test candidates previously described as Cr(VI)-free (confidential) since the submission of the Parent AfAs is reported below.

Following is the status of Cr(VI)-free (confidential) candidates as reported in the parent AfAs.

Composition of the alternative was reported as confidential business information and the specific corrosion inhibiting substance was not disclosed in the parent AfA, however the below information on technical feasibility was reported (CCST, 2015a).

Preliminary results when applied to aluminium alloys showed that corrosion performance capabilities in developmental formulations were not in line with requirements of extended corrosion tests for aerospace uses assessed.

Layer thickness was also identified as a limiting factor for wash primers. The viscosity of the epoxy-based system used for in the formulation needed to be reduced to apply the product in the required thickness range. It was reported to be possible to generate the required layer thickness by thinning the formulation, however it was predicted that this could detrimentally affect other aspects of the performance of the material.

Development of these formulations was reported to be at a very early stage (TRL 2) and therefore the compatibility with different substrates and subsequent coatings had not yet been demonstrated. Satisfactory adhesion properties were achieved when the wash primer alternative was overcoated with epoxy and polyurethane primers, however no testing with topcoat schemes had yet been conducted. From experience however it was felt that, as an epoxy-based formulation, a high level of compatibility with a wide range of topcoats could be expected.

3.5.7.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors

A number of technical results from the ongoing development of Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors as alternatives for wash primers have been reported by ADCR members. These are discussed in the following sections. Of the relevant performance requirements discussed in Section 3.2.1, corrosion resistance and adhesion promotion were reported by members as key reasons for failure of the wash primers based on Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors. Due to these reasons, candidates under this category are typically at TRL 3, however it has been reported that some test candidates have surpassed TRL 5 for less challenging substitutions.

Corrosion resistance

Multiple ADCR members reported that Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors demonstrated regression compared to the incumbent coating when tested according to ISO 9227 in neutral salt spray chambers on some substrates. It was reported that some aluminium alloys perform better in corrosion tests than others when treated with the test candidates. For example, the aluminium alloy unclad AA6061 yields better results with Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors than aluminium-zinc alloys such as AA7050 during corrosion tests. As a result, corrosion resistance requirements have been achieved in some cases with some alloys. However Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors have not been identified for all components, particularly corrosion-prone alloys. In addition, the corrosion resistance performance of a Cr(VI)-free wash primer is highly dependent on the subsequent Cr(VI)-free layer that is applied on top of the wash primer. It has been reported that no tested candidates have yet met the corrosion resistance performance of Cr(VI)-based coatings, however some have shown promising results and are currently being investigated further. In certain instances, Cr(VI)-free inhibitors are close to achieving TRL 6 for non-aluminium substrates.

Adhesion, chemical compatibility and thermal resistance

Multiple ADCR members reported that the adhesion of Cr(VI)-free test candidates to the substrate did not meet requirements when tested according to ISO 2409 particularly after submersion in water. A photograph of a failed adhesion test of a Cr(VI)-free candidate according to ISO 2409 after water submersion is provided in **Figure 3-15** below.

Figure 3-15: Photographic evidence of the loss in adhesion of a Cr(VI)-free wash primer from the test coupon substrate according to ISO 2409 following submersion in water

Source: ADCR member

One member reported that scratch tests and flexibility tests have shown particular regression on sealed anodised substrates when compared to Cr(VI)-based wash primers, but good adhesion was observed on other substrates. Another member reported that coating adhesion of Cr(VI)-free wash primers on cadmium plated substrates are the most challenging and most test candidates fail to meet requirements on this substrate.

It was also reported by one member that when exposed to elevated temperatures, their most promising candidate can become brittle and crack when subjected to slow deformation testing as shown in **Figure 3-16** below. This cracking then leads to delamination of the coating, exposing bare substrate to corrosive environments.

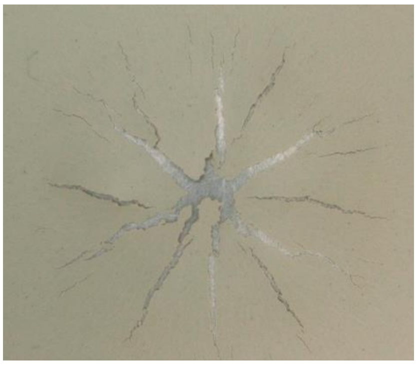


Figure 3-16: Photographic evidence of failed performance of a proprietary Cr(VI)-free test candidate in temperature resistance and mechanical properties showing unacceptable brittleness and loss in adhesion

Source: ADCR member

In addition, chemical compatibility between Cr(VI)-free wash primers and subsequent coating layers has been reported to be a significant issue, where incompatibility has resulted in poor adhesion between the wash primer layer and the subsequent layer. An example of this loss in adhesion between layers on a testing panel is shown below in **Figure 3-17**.

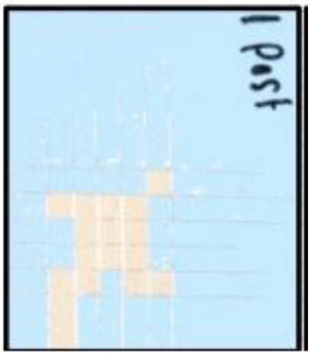


Figure 3-17: Photographic evidence of incompatibility between the Cr(VI)-free wash primer layer and subsequent layer according to ISO 2409
Source: ADCR member

Economic feasibility of Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors

It was reported by several ADCR members that Cr(VI)-based wash primers can be replaced with Cr(VI)-free wash primers without the need for significant changes to the coating process. No new equipment would be required to facilitate the application of Cr(VI)-free formulations. However, due to limitations in the adhesion performance of Cr(VI)-free test candidates on some substrates, the number of non-conforming coatings which would require rework may increase as a result of the substitution, therefore lowering the overall efficiency and output of wash primer application. However, it should also be noted that since the alternative must show equal or greater performance to the incumbent treatment, and therefore this scenario is unlikely to occur as the test candidates which demonstrate regression in adhesion promotion would fail to progress into higher TRLs.

Health and safety considerations related to the use of Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors

Due to the confidential nature of the main point of difference between Cr(VI)-based and Cr(VI)-free wash primer formulations, it is not possible to assess the specific health and safety considerations for these test candidates. However, since Cr(VI)-free formulations are developed with the intention of removing the CMR hazard arising from the presence of Cr(VI), it is likely that all confidential Cr(VI)-free inhibitors used do not present carcinogenic, mutagenic or reprotoxic properties. Therefore, these should constitute a reduction in overall risk compared to the incumbent Cr(VI)-based wash primers. One ADCR member reported that a specific Cr(VI)-free formulation did demonstrate an unnecessary risk to human health based on the properties of a non-corrosion inhibiting component of the formulation and has therefore been eliminated from further consideration as to avoid a regrettable substitution.

Availability of Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors

Cr(VI)-free inhibitors are typically the most advanced test candidate to date with TRLs ranging from TRL 2 in substitutions at an early stage of development or for more challenging substitutions, to TRL 5 in specific situations where substitution of Cr(VI)-based wash primers is less challenging.

While Cr(VI)-free alternative formulations are for the most part in early stages of development, ADCR members generally reported that these alternatives are expected to be supplied in quantities required to meet the demands for their activities once fully certified.

Suitability of Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors

Confidential corrosion inhibitors have shown the most progression within the A&D sector thus far, TRLs range from TRL 2 to TRL 5 depending on the specific requirements of each substitution. While these alternatives have shown the most progression since the submission of the Parent AfAs, they are still by no means considered technically equivalent to Cr(VI)-based wash primers and therefore cannot be considered a generally suitable alternative for the A&D sector.

3.6 Conclusions on shortlisted alternatives

Table 3-7 summarises the current development status of the test candidates to replace potassium hydroxyoctaoxodizincate dichromate and pentazinc chromate octahydroxide in wash primers. A qualitative assessment (Low, Moderate, or High) has been provided for each of the criteria: technical feasibility, economic feasibility, risk reduction, availability, and suitability. The qualitative assessment is provided as a high-level summary and is based on the detailed discussions in the preceding sections. To confirm, 'high', 'moderate' and 'low' represent an acceptable, partial, and poor level of compliance with the individual criterion, respectively.

Table 3-7: Summary of the suitability of shortlisted alternatives to Cr(VI)-based wash primers

Test candidate	Technical feasibility	Economic Feasibility	Risk reduction	Availability	Suitability
Proprietary blends of Cr(V)-free test candidate corrosion inhibitors	Moderate	Moderate	Moderate	Moderate	Moderate
Magnesium-rich corrosion inhibitors	Low	Low	Moderate	Low	Low
Phosphate-based corrosion inhibitors	Low	Moderate	High	Moderate	Low
Zinc-based inhibitors	Low	Moderate	High	Moderate	Low
Silane-based coatings	Low	Moderate	Low	Moderate	Low
Zirconate-based corrosion inhibitors (Organometallics)	Low	Moderate	Moderate	Moderate	Low

As seen in the summary table above, the only test candidate whose overall suitability as a potential alternative to Cr(VI)-based wash primers is Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors. This is based on the grounds of this being the only category of candidates to show sufficient technical feasibility to progress beyond early TRL levels, where candidates under this category are typically at TRL 3, though in rare cases, candidates have progressed to TRL 5. Though further R&D has been undertaken and new formulations have been developed and evaluated by design owners for potential candidates under the remaining alternative categories, most have been eliminated at pre-TRL stages of testing due to significant regression in technical performance when compared to the incumbent Cr(VI)-based wash primer treatment. Aside from technical feasibility, alternative categories generally show good promise in other assessment areas, where no particular issues in economic feasibility, risk to human health or availability were identified during consultation. On the other hand, detailed assessments in these areas are not generally carried out before the candidate has achieved higher technical maturity as to not waste valuable resources on a candidate which is likely to be technically infeasible.

3.7 The test candidate development plan

3.7.1 Introduction

3.7.1.1 Factors affecting the test candidate development plan

The test candidate development 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 wash primers. They require continuous review and monitoring to ensure that the test candidate development plan progresses through its phases and all changes are clearly documented. Monitoring of progress markers associated with the test candidate development plan includes a timetable of steps and targeted completion dates, assessment of the highest risks to progression, and how these risks can be reduced (if possible), which may not always be the case.

3.7.1.2 Test candidate development plans within individual members

Each ADCR member has a test candidate development plan to replace wash primers containing Cr(VI) that is uniquely reflective of their individual situation. Additionally, an individual member often has multiple test candidate development plans for wash primers, running in parallel work streams. The reason for different test candidate development plans within one member is that they are segmented by factors such as type of substrate, type of component, type of alternative, and type of coating system. These different test candidate development 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, the number of components onto which the existing primer is applied, the availability of expert resource and specialist test facilities, and prioritisation of certain types of component.

3.7.1.3 Interplay with pre-treatments and post-treatments and other test candidate development plans

Since the application of wash primers is typically a single step in the overall surface treatment ‘system’, typically with at least one more subsequent Cr(VI)-based protective primer applied on top, the test candidate development plans and timelines for replacing Cr(VI) within the entire system are also heavily dependent on the progress of other substitutions. In many cases, a member will target substitution of both the wash primer and protective primer at the same time. In one case, a member is looking to eliminate wash primers altogether through qualification of a protective primer which provides sufficient performance when applied without a wash primer. Any unexpected obstacles affecting the progression of test candidate development plans for protective primers will impact the planned timing of the test candidate development plan for wash primer replacement.

In addition, it may be discovered that a Cr(VI)-free alternative to wash primers may only show chemical compatibility with a certain type of subsequent primer/coating. If that subsequent primer/coating is then disqualified for any reason such as technical performance, economic feasibility, health and safety or availability, then the test candidate development plan for the qualified wash primer will also be set back until a new compatible subsequent primer/coating can be found. Due to the evolutionary and iterative nature of R&D in the A&D sector, minor changes in the formulation or process of one alternative to a Cr(VI)-based treatment can cascade and set-back or otherwise impact test candidate development plans of preceding or subsequent treatment steps. While all efforts are made to avoid this kind of setback, it is not always possible to predict accurately given the complexity of the A&D sector's supply chains and research environment.

3.7.2 Test candidate development plans for ADCR members using wash primers

3.7.2.1 Test candidate development plans

The expected progression of ADCR members' test candidate development plans to replace wash primers containing potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide is shown in **Figure 3-18** below. The progressive stages of the test candidate development plan (development, qualification, validation etc.) are shown in the diagram and described in detail in Section 3.1.2. Implementation and progression of test candidate development plans ultimately leads to reduced Cr(VI) usage. MRL 10 is the stage at which manufacturing is in full rate production. Therefore, Cr(VI) use is expected to be eliminated due to replacement with an alternative whose use is covered by the relevant test candidate development plan.

Recognising the SEAC's need for information which reflects the position of individual companies and their value chains, the test candidate development plans have been developed based on a granular analysis of the progression made by each OEM and DtB company supporting the use of wash primers in achieving substitution. As design owners, the test candidate development plans of these companies impact on their suppliers (other DtBs, BtPs) and MROs, who are unable to also substitute until the design owners have fully implemented the alternatives (i.e. progress to TRL9 and MRL10).

The data in the figure below (**Figure 3-18**) shows the expected progress of 20 distinct test candidate development plans for wash primers containing potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide. This covers different plans across different members, and multiple plans for individual members. The data has been aggregated to present the expected progress of the substitution of wash primers containing potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide for the ADCR consortium as a whole.

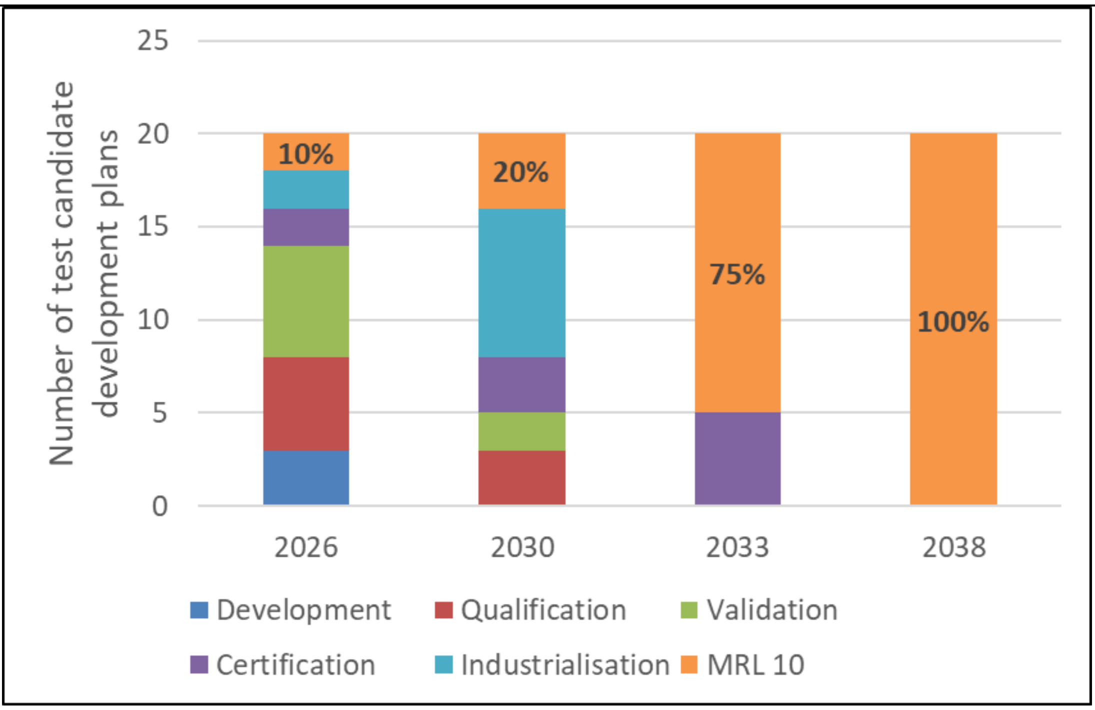


Figure 3-18: Expected progression of test candidate development plans for the use of wash primers containing potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide, by year.
The vertical axis refers to number of development plans (some members have multiple development plans for wash primers). The percentage value shown on each of the orange bars indicates the proportion of development plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which manufacturing is in full rate production/deployment and it is therefore where it is expected that Cr(VI) will be fully substituted under the relevant plan.
Source: RPA analysis, ADCR members

The above summary shows:

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

The dates at which each test candidate development plan is expected to achieve each stage are estimates provided by the members. 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 development plans, especially in the outer years 2033 and 2038 where there is more uncertainty, may be slower (or faster) than estimated today, as presented in **Figure 3-18**. The actual status of the development plans 12 years from now could be different to our expectations today.

Because some members have multiple development plans for wash primers, it is the case that for those development plans that are not expected to have achieved MRL 10 by a given date, other development plans from the same member will have progressed to this level. This highlights the complexity of multiple development plans within members. The timeline associated with any individual substitution activity will dependent on a multitude of factors including: the number and nature of technical criteria associated with the formulation to be substituted; the level of research into proposed candidates which has already been undertaken by formulators; the number of components onto which the existing formulation is applied; the availability of expert resource and specialist test facilities; the interrelationships with other processes which are also being substituted; the availability of a supply chain to industrialise the new process; and the level of process change, for example, commissioning equipment, staff training, and health and safety considerations associated with implementation of the alternative.

The timeframes associated with the activities presented in **Figure 3-18** 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.

It is of note that for 10% of development plans shown, MRL 10 is anticipated to be reached before the end of the existing review period. As discussed in Section 3.1.2.2, industrialisation of alternatives is usually scheduled to follow a stepwise approach to minimise technical risks. However significant investment, worker training and support documentation may be required to adapt the manufacturing processes before alternatives can be implemented. Unforeseen delays in any of these areas may impact on substitution being completed prior to 2026. Additionally, for those development plans within this 10% for which certification is currently ongoing, additional actions may arise as an outcome of the certification process, which could delay implementation beyond 2026.

3.7.2.2 Requested Review Period

It can be seen in **Figure 3-18** that despite ongoing and concerted efforts of the members to develop and implement alternatives to wash primers containing potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide, it has not proved possible to replace Cr(VI) by the end of the review periods granted in the parent authorisations (which end in 2026).

It is clear from the chart that in 2033 (equivalent to seven years beyond the expiry date for the existing applications), while many test candidate development plans are expected to have successfully progressed to MRL 10 and the consortium is expected to have reduced its Cr(VI) use, a proportion are not expected to have achieved MRL 10 and are expected to be at the validation, certification, or industrialisation stage. The bespoke nature of test hardware; to validate treatment changes can extend development plans, refer to Section 3.1.2.2 – Validation. Time may be required to build bespoke test rigs or identify and procure appropriate test facilities. As introduced in Section 3.1.2.1, where multiple design owners are progressing individual development plans, demand may exceed supply for out-sourced test facilities, including specialised expertise, potentially delaying some development plans. Where this isn’t a restriction and internal test facilities and expertise are available, test programme prioritisation may still be necessary. For example, availability of human resources may be finite over a given time period preventing parallel rate of progression for multiple development plans. It may be preferable to prioritise testing of in-production designs over out of production legacy aircraft and equipment, depending on individual design owners’ commercial requirements. The consortium is expected to have reduced its Cr(VI) use, although a proportion are not expected to have achieved MRL 10 and are expected to be at the certification stage. For these a test candidate development plans there is still expected to be a need for the use of Cr(VI).

As a result of the individual members’ test candidate development plans summarised above, the ADCR consortium requests a review period of **12 years** for the use of wash primers containing potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide.

4 Continued Use Scenario

4.1 Introduction

Section 3 provided an analysis with respect to the technical feasibility, economic feasibility, risk reduction, availability, and suitability of alternatives. The assessment highlights the importance of Cr(VI) for corrosion protection (resistance and inhibition) in wash primers. Although some of the companies supporting this use have industrialised Cr(VI)-free alternatives for some components, this has not yet been achieved across all components or products.

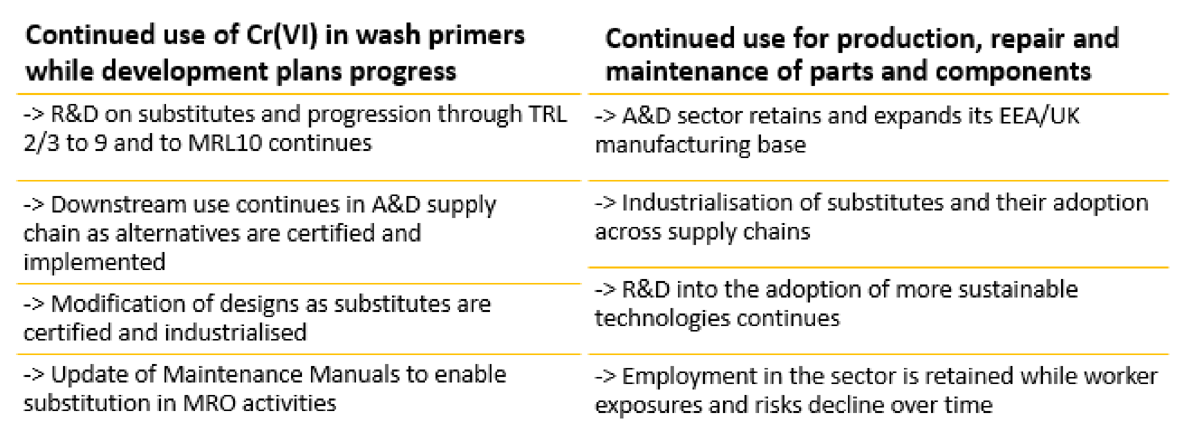
Until suitable alternatives which are compatible with all the treatment system, and including pre-treatments and subsequent coatings are approved via the substitution process described below, use of potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide in wash primers will continue to be required. Their use is essential to meeting airworthiness and other safety requirements. Therefore, there are no alternatives which can be considered “generally available” in the context of A&D.

In some cases, for example where sufficient corrosion resistance is provided by subsequent layers and the wash primer is applied mainly for its adhesion promotion properties, 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 wash primers, implementation itself may take several years (e.g., 6-8 years 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 test candidate development plan, the OEMs and DtBs as a whole (and as design owners) require at least 12 years to complete substitution across all components and final products.

The Continued Use Scenario can be summarised in **Figure 4-1** below.



Continued use of Cr(VI) in wash primers while development plans progress	Continued use for production, repair and maintenance of parts and components
-> R&D on substitutes and progression through TRL 2/3 to 9 and to MRL10 continues	-> A&D sector retains and expands its EEA/UK manufacturing base
-> Downstream use continues in A&D supply chain as alternatives are certified and implemented	-> Industrialisation of substitutes and their adoption across supply chains
-> Modification of designs as substitutes are certified and industrialised	-> R&D into the adoption of more sustainable technologies continues
-> Update of Maintenance Manuals to enable substitution in MRO activities	-> Employment in the sector is retained while worker exposures and risks decline over time
-> Continued production, repair and maintenance of aircraft and other final products ensured	-> Impacts on civil aviation, emergency services and military mission readiness is minimised

Figure 4-1: Continued use scenario

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 potassium hydroxyoctaoxodizincate dichromate and pentazinc chromate octahydroxide used in wash primers, including projected tonnages over the requested review period; and
- The risks associated with the continued use of potassium hydroxyoctaoxodizincate dichromate and pentazinc chromate octahydroxide.

4.2 Market analysis of downstream uses

4.2.1 Introduction

Separate companies within the A&D industry have jointly assessed and continue 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 GB; and
- Continuity of supply of critical products containing hexavalent chromium.

The requirements of the ADCR members, as downstream users and design owners supporting this application, have been carefully identified and analysed, taking the starting point the parent authorisations and the substance-use combinations covered by these.

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

4.2.2 Overview of the European aerospace and defence sector

In 2020, the European A&D industry comprised over 3,000 companies of all sizes and employed over 880,000 highly skilled employees (with these figures including the UK[30]). As noted by the European Commission, the industry is "characterised by an extended supply chain and a fabric of dynamic small- and medium- sized enterprises throughout the EU, some of them world leaders in their domain"[31]. **Figure 4-2** provides details of turnover and employment for the industry in 2021, based on the Aerospace, Security and Defence Industries Association of Europe (ASD) publication "2022 Facts & Figures".[32]

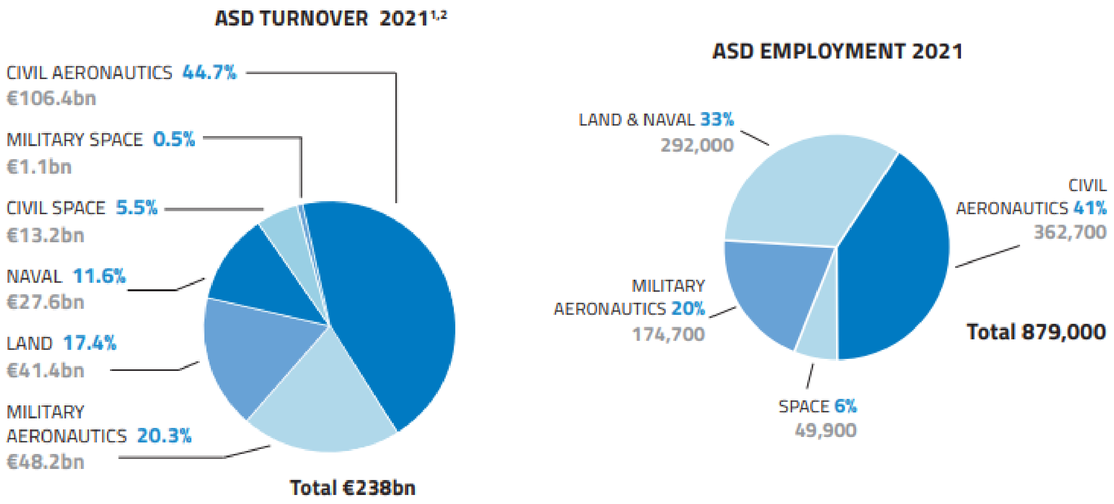


Figure 4-2: Turnover and Employment for the European A&D Industry in 2021 (snip taken from ASD, 2022), available at https://asd-europe.paddlecms.net/sites/default/files/2022-11/ASD_Facts%20%26%20Figures%202022.pdf

As can be seen from **Figure 4-2**, civil and military aeronautics alone accounted for 65% of turnover and 61% of employment in 2021.

Civil aeronautics alone accounted for 362,700 jobs, revenues of €106.4 billion and exports of €92.5 billion. Across Europe, the civil aeronautics industry turnover increased by over 30% from the year 2020, rising to €106.4 billion for the year 2021, which compares to €81.6 billion seen in 2020. The defence industry accounted for around 467,000 jobs, revenues of over €118 billion and exports of €45.1 billion.

The A&D sector is therefore recognised as important to the ongoing growth and competitiveness of the GB economy. 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 service over long time periods. For example, the Boeing 747 first entered service in 1970, and continues to be flown and produced in 2022 (although

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

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

[32] ASD, 2022: Facts & Figures, available at: https://www.asd-europe.org/facts-figures

it will now go out of production but remain in service). Given the need to ensure on-going airworthiness and due to certification requirements, there will continue to be a “legacy” demand for the use of primers containing potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide for maintenance of existing aircraft and equipment, as well as in the production of components for models that are still in production for long periods after the first aircraft or military products were placed on the market.

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

- 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 potassium hydroxyoctaoxodizincate dichromate and pentazinc chromate octahydroxide. As indicated below with respect to R&D activities, research on substitution of hexavalent chromates has been underway for several decades, with the substitution of potassium hydroxyoctaoxodizincate dichromate and pentazinc chromate octahydroxide in wash primers proving a difficult task for some products (and in particular some military final products).

- There are over 20,000 commercial aircraft and 15,000 business jets currently in operation globally. Given the global nature of civil aviation, it is important that global solutions are found to the use of wash primers containing potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide 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 products containing hexavalent chromates where these are mandated by the original equipment manufacturers.

4.2.3 Economic characteristics of Companies using wash primers

4.2.3.1 Profile of downstream users

As noted in Section 2, use of wash primers containing potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide is common within the aerospace sector. The primers are applied in-house by some of the OEMs, as well as being used by BtP suppliers, DtB suppliers and MROs.

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

- Overhaul of complete aircraft
- Skin panels
- Frames
- Ribs
- Spars
- Stiffeners

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

- Tubes
- Brackets
- Flight actuators

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 large sized companies within their sectors of activity. The number of responses covering MROs is also low compared to what might be expected.

Table 4-1: Numbers of SEA respondents using potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide in wash primers

Role	Number of companies/sites	Company Size[34]
Build-to-Print	3/3	1-Medium 2-Small
Design-to-Build	2/3	2-Large
MRO/OEM	1/2	1-Large
Total	**68**	-

4.2.3.2 Economic characteristics

Table 4-2 provides a summary of the number of companies identifying their activities against different Standard Industrial Classification (SIC) codes, which are used here to develop the economic characteristics of the "typical" OEM, DtB, BtP or MRO company. Companies may have indicated more than one SIC code as being relevant to their activities, with the result that the number of relevant SIC code counts is higher than the number of SEA responses relevant to use of potassium hydroxyoctaoxodizincate dichromate and pentazinc chromate octahydroxide in wash primers.

The table also provides relevant ONS data for each NACE/SIC 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.

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

Table 4-2: Economic characteristics of "typical" companies by SIC in sectors involved in use of potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide in wash primers (2022 ONS data))

	Number of responses by SIC 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	5	13.75	51,122	30,408	22%
C2599 - Manufacture of other fabricated metal products not elsewhere classified	1	155.09	56,993	30,784	19%
C2815 - Manufacture of bearings, gears, gearing and driving elements	1	209.76	69,726	39,863	18%
C3030 - Manufacture of air and spacecraft and related machinery	1	648.17	11,6492	67,263	16%
C3040 - Manufacture of military fighting vehicles	2	648.17	116,492	67,263	16%
C3316 - Repair and maintenance of aircraft and spacecraft	1	114.23	80,556	41,500	18%
Note: The count total is by number of SIC code identifications by company and not by sites, with 7 companies providing data					

Turnover is calculated as the weighted average by company size, as this is the most appropriate means of reflecting the level of turnover across GB linked to use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide and taking into account the size distribution of the companies that are involved in such activities[35]. 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/SIC 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[36] (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 18% which is an average across the various SIC codes weighted by the number of companies declaring each SIC code. GOS was calculated as GVA at basic prices minus personnel costs, according to the income approach. Then the GOS divided the turnover is the GOS rate. **Table 4-3** demonstrates the estimated turnover and gross operating surplus based on ONS data.

Table 4-3: Key turnover and profit data for market undertaking use of potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide in wash primers (based on 2022 ONS data)

Sites covered by SEA responses/Extrapolated number of sites	Estimated turnover based on weighted average	Gross operating surplus (estimate based on 18%)
8 GB sites	£ 600 million	£ 109 million
Extrapolation to all sites involved in use of potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide in wash primers in GB		
25 GB sites	£ 1,810 million	£ 329 million
Source: Based on SEA questionnaire responses, combined with ONS data		

4.2.3.3 Economic importance of use of wash primers to revenues

Use of wash primers will only account for a percentage of the calculated revenues, GVA and jobs associated with the results given in **Table 4-3**. To understand its importance to the activities of individual companies, a series of questions were asked regarding other processes carried out, production costs, and the share of revenues generated from the use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide.

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. It is of key critical importance that the design owners use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide are able to continue to be able to use the substances. The loss of these primers would result in the loss of a significant level of turnover due to the inability to meet

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[35] The Weighted Average Turnover was calculated using data from ONS and Eurostat for the UK. The total turnover and the number of enterprises by turnover size for year 2022 was used from ONS (for the selected 4 digit SIC codes). The weights were calculated using turnover by turnover size band from Eurostat for UK in year 2018. With that information the proportion of turnover corresponding to small, medium and large companies was calculated. These proportions (%) were estimated only for the selected 3 digit SIC codes, as data for 4 digit SIC codes wasn't available. In the case of C3040 the same figures as C3030 were applied due to confidential information restrictions.

[36] ONS defines the GOS rate (i.e., % of turnover) as profits of all companies and public corporations, and excluding profit on rental of buildings and stock appreciation; it is officially defined as the balance between GVA and labour costs paid by producers.

airworthiness requirements, even though as a process it accounts for only a very small percentage of production costs.

Table 4-4 shows the revenue linked to using chromate-containing primers for companies in GB. Responses vary, with some companies stating that10%-25%of revenue was linked to the use of primers, and others stating that more than 75% of turnover is linked to use of the primers.

Companies stating that less than 75% of turnover was attributed to primer use, often perform other machining work within the aerospace and defence industry. This includes manufacture of fasteners, fabrication of composite parts and assembly of large structures.

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

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

	<10%	10% - 25%	25% - 50%	50% - 75%	>75%	No response
Build-to-Print	0	2	0	1	0	0
Design-to-Build	0	0	1	0	2	0
MROs/OEM	0	0	0	0	0	2

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

OEMs have carried out R&D into the substitution of the chromates for over 30 years, but as detailed in the AoA technical difficulties remain in substituting the use of the two chromates in wash primers. Although some have developed, validated, qualified and are currently certifying alternatives for use in the manufacture of their final products, others are still in the testing and development phase. These differences are driven by differences in operating performance requirements, previous surface treatments and subsequent primer layers, and substrates across final components.

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

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

Across respondents, regardless of role in the supply chain, the majority of companies identified better relations with authorities as a benefit. Significant numbers also identified better public, shareholder and community relations.

4.2.4 End markets in civil aviation and defence

4.2.4.1 Importance to end-user markets

The use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide provides corrosion resistance to A&D products that must operate safely and reliably, across different geographies, often in extreme temperatures, and in aggressive environments with a high risk of corrosion (due to extreme temperatures, precipitation, salt spray and altitudes).

Because wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide cannot be fully substituted at present, they play a critical role in ensuring the reliability and safety of final products because they are the only qualified solutions currently proven to meet the performance requirements of the airworthiness/defence customer certification, which ensures overall product safety, reliability and performance. Thus, although the economic importance of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide is indirect in nature, their significance is clear with respect to:

- The ability of MROs (civilian and military) to undertake their activities within GB, 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-kilometres and cargo km translating into significant economic losses not just within GB 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 passengers), 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 the ADCR consortium demonstrates the critical nature of potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxidechromates are to the on-going preparedness of their military forces in particular.

4.2.4.2 Expected growth in the A&D sector

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 2023-2033 are given in **Figure 4-3**[37], with this suggesting CAGR from 2023 to 2033 of around 2.9%.

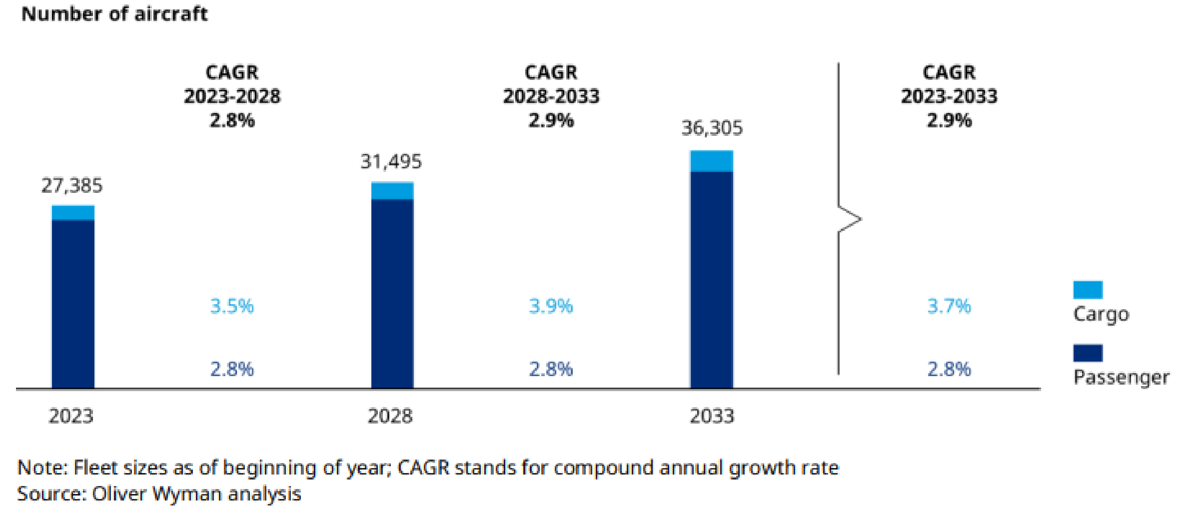

Figure 4-3: Passenger and cargo fleet forecasts, 2023-2033
Source: Oliver Wyman analysis **(2021)**

Market reports issued by Airbus and Boeing indicate that future growth is expected to extend beyond 2033. Airbus' Global Market Forecast for 2021-2041 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.[38]

Boeing's 2023 Commercial Market Outlook[39] indicates a similar level of increase, noting that the global fleet will increase by around 3.5% through to 2042.

Based on figures publicly available on Airbus' website, the demand for new aircraft will progressively shift from fleet growth to accelerated replacement of older, less fuel-efficient aircraft. This will mean a need for over 39,000 new passenger and freighter aircraft, delivered over the next 20 years – around 15,250 of these will be for replacement of older less fuel-efficient models. By 2040, the majority of commercial aircraft in operation will be of the latest generation. Projections based on generic neutral seating categories (100 plus seater passenger aircraft and 10 tonnes plus freighters) are given in **Table 4-5** below.

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

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

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

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**

**Pax = the number of people carried by a passenger aircraft.*

***CIS = Commonwealth of Independent States*

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 British aerospace sector is a significant and leading global exporter of aircraft, and A&D products make a significant contribution to the overall balance of trade. For example, the UK export market (which includes NI) was around US$13.2 billion (€11.7 billion, £10.3 billion) in 2020[40].

However, unless operations in GB can remain financially viable in the short to medium term, the ability of GB 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 GB with a consequent loss in Gross Value Added (GVA) to the GB economy, with enormous impacts on employment.

The MRO market

The aircraft spare components/final products market encompasses the market for both new and overhauled components available as spares for aircraft and other products. This market was projected to grow with a CAGR of 2.9% over the period from 2023-2033, although this rate may now be lower due to COVID-19. Growth is due to the increase in the commercial aircraft fleet as well as the need for timely MRO services to keep aircraft in service.

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

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

10 years. Globally, the market is expected to have a CAGR of 2.9% over the period from 2023-2033, as illustrated in **Figure 4-4**.[41, 42]

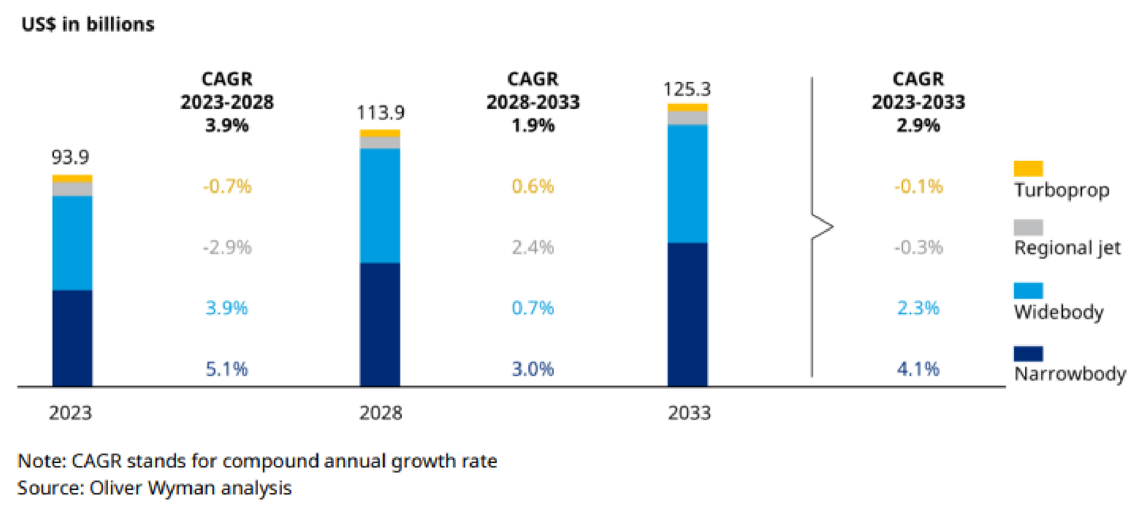

Figure 4-4: MRO market forecast by aircraft class, 2023-2032
Source: Oliver Wyman analysis (2021)

This growth is due to three factors:

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

The defence market

The war in Ukraine has led several EEA countries and the UK to revisit their defence expenditure. Several countries that are NATO members and which previously did not meet the target of spending 2% of GDP on defence are now committed to meeting that target. This compares to Eurostat figures for total general government expenditure on defence in 2020 of around 1.3% of GDP for the EU.[43] 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 aim for a target

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[41] Mordor Intelligence, Commercial Aircraft Maintenance, Repair, and Overhaul (MRO) Market – Growth, Trends, Covid-19 Impact and Forecasts (2023 – 2033)

[42] Oliver Wyman analysis: at: https://www.oliverwyman.com/our-expertise/insights/2023/feb/global-fleet-and-mro-market-forecast-2023-2033.html

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

of 3% of GDP by 2030. 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 wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide 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%.[44]

4.3 Annual tonnages of potassium hydroxyoctaoxodizincate dichromate and pentazinc chromate octahydroxide 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 potassium hydroxyoctaoxodizincate dichromate and pentazinc chromate octahydroxide used per site and is discussed in more detail in the CSR.

The CSR reported tonnage of:

- 0 to 25 kg PHD used per year per site: therefore up to 6 kg Cr(VI) per year per site.
- 0 to 20 kg PCO used per year per site, therefore up to 1.8 kg Cr(VI) per year per site.

4.3.2 Consultation for the SEA

The SEA questionnaire also asked for information on the chromates used in wash primers by site, with these data providing an additional basis for estimating the maximum volumes used in wash primers per site.

Based on consultation for the SEA, it is estimated that 2.35 tonnes of PCO and 0.02 tonnes of PHD are used in wash primers per year across all sites.

4.3.3 Projected future use of hexavalent chromates

The A&D industry is actively working to phase out the use of Cr(VI), however it will take further time to qualify alternatives across all components and products for the A&D industry. Individual companies are at different points along this path, although there are also variations based on specific aircraft/defence application and across different types of components/final products. At the end of the current review period, a majority of members alternative development plans are anticipated to

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[44] 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

be at the qualification (25%) or validation (30%) phase, with most of the remaining plans expected to be spread across development (15%), certification (10%) and industrialisation (10%) (See **Figure 3-18** in Section 3.7.2). If alternative development plans progress as anticipated the remaining 10% will be at MRL10 by 2026, with use of Cr(VI) covered under this plan fully eliminated.

Where possible, requirements for use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide in new designs are being phased out. However, aircraft that require their use remain in production and operation. Use of potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide in wash primers therefore remains important to the protection of A&D components.

4.4 Risks associated with continued use

4.4.1 Classifications and exposure scenarios

4.4.1.1 Human health classifications

Potassium hydroxyoctaoxodizincate dichromate (Entry No. 30) and pentazinc chromate octahydroxide (Entry No. 31) have been included into Annex XIV of Regulation (EC) No 1907/2006 due to their intrinsic carcinogenic properties. PHD and PCO are both classified as carcinogenic Cat. 1A. The most important route of exposure is inhalation. The hazard evaluation follows recommendations given by RAC[45]:

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

4.4.1.2 Overview of exposure scenarios

All A&D sites that use wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide within the ADCR supply chains are specialised industrial sites active in GB. They have rigorous internal, health, safety, and environment (HS&E) organisational plans. A mix of technical, organisational and personal-protection-based measures are in place to reduce workplace exposures. The sites adhere to best practices to reduce workplace exposures and environmental emissions to as low as technically and practicably feasible and use automated processes to the maximum extent possible. The feasibility and the degree of automation can vary between different sites and depend, among other factors, on the size of the site and the frequency of use of wash primers. See the CSR for further details of measures in place.

As reported in Section 4.2.3.4, due to the conditions placed on the continued use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide, additional risk management measures were implemented by A&D companies, requiring significant investment. A full summary of these conditions is provided in the CSR that accompanies this combined AoA/SEA.

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[45] 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 4-6: Overview of exposure scenarios and their contributing scenarios

ES number	ES Title	Environmental release category (ERC)/ Process category (PROC)
ES1-IW1	Use of wash primers containing pentazinc chromate octahydroxide or potassium hydroxyoctaoxodizincate dichromate in aerospace and defence industry and its supply chains – use at industrial site	
Environmental contributing scenario(s)		
ECS 1	Use of wash primers containing pentazinc chromate octahydroxide or potassium hydroxyoctaoxodizincate dichromate – use at industrial site leading to inclusion (of Cr(VI) or the reaction products) into/onto article	ERC 5
Worker contributing scenario(s)		
WCS 1	Spray operators for manual spraying in spray room/booth	PROC 5, PROC 7, PROC 8b, PROC 9, PROC 28
WCS 2	Spray operators for manual spraying in dedicated spray hangar	PROC 5, PROC 7, PROC 8b
WCS 3	Operators performing brushing/rolling	PROC 10
WCS 4	Machinists	PROC 21, PROC 24
WCS 5	Sanders in a dedicated hangar	PROC 21, PROC 24
WCS 6	Workers performing media blasting in closed system	PROC 21, PROC 24
WCS 7	Workers performing media blasting in a room/hall	PROC 21, PROC 24
WCS 8	Maintenance and/or cleaning workers for spray area(s)	PROC 8b, PROC 28
WCS 9	Maintenance and/or cleaning workers (excluding spray areas)	PROC 28
WCS 10	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 wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide. 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 4-7**, which presents the excess lung cancer risks to workers involved in use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide. The risks are calculated using a combination of measured inhalation data and modelling for different SEGs (Similar Exposure Groups). The SEGs include:

Table 4-7: Excess lifetime cancer risk by SEG

#	SEG	Average number of workers exposed per site	Excess lifetime lung cancer risk
WCS1 - part 1	Sprayers room/booth not spraying outside	10 workers per day per site	1.00E-05
WCS1 - part 2	Spraying outside	1 worker per day at 20% of sites	3.42E-05
WCS2 - part 1	Sprayers hangar - short-term spraying	8 workers per day at 20% of sites	5.34E-04
WCS2 - part 2	Long-term spraying	18 workers per day at 20% of sites	3.42E-04
WCS3	Operators brushing/rolling	18 workers per day per site	1.23E-05
WCS4	Machinists	18 workers per day at 30% of sites	3.66E-06
WCS5	Sanders hangar	16 workers per day at 30% of sites	5.88E-06
WCS6	Media blasting closed system	6 workers per day at 30% of sites	7.36E-06
WCS7	Media blasting room	6 workers per day at 10% of sites	3.71E-05
WCS8	Maintenance spray	3 workers per day per site	9.10E-07
WCS9	Maintenance non-spray	9 workers per day per site	2.53E-06
WCS10	Incidentally exposed workers	14 workers per day per site	3.00E-06

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 to humans via the environment presented in the CSR has been carried out for the general population at the local level only. No regional assessment has been conducted as it can be assumed that Cr(VI) from any source will be reduced to Cr(III) in most environmental situations. 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 potassium hydroxyoctaoxodizincatedichromate in paints, in primer, sealants and coatings (including as wash primers) (ID 0047-02). This reference states that regional exposure of the general population is not considered relevant by RAC.

The assessment presented in the CSR is based on measured data for emission to air and wastewater. For this assessment, combined exposure of humans via the inhalation (air) and the oral (uptake of water and fish) route is considered. The resulting 90th percentile risk estimates are presented in **Table 4-8**.

Table 4-8: Excess lifetime cancer risk estimates for humans via the environment (general population, local assessment)

Inhalation		Oral		Combined
Local Cr(VI) PEC in air [µg/m3]	Inhalation risk	Oral exposure [µg Cr(VI)/kg x d]	Oral risk	Combined risk
1.58E-04	4.58E-06	7.77E-07	6.21E-10	4.58E-06

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

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

4.4.3 Populations at risk

4.4.3.1 Worker assessment

The CSR figures are taken here, as they are based on site visits and detailed discussions with companies. The average figures assumed in the CSR extrapolated out to the total numbers of sites gives the figures set out in **Table 4-9** as the number of workers exposed under each WCS.

Table 4-9: Number of employees using protective primers containing the chromates

Worker Contributing Scenarios		Average No. Exposed from CSR	Number of exposed in 25 GB sites
WCS1 - part 1	Workers not also spraying outside of spray booth/room/hangar	10 workers per day per site	250
WCS1 - part 2	Workers also spraying outside of spray booth/room/hangar	1 worker per day at 20% of sites	5
WCS2 - part 1	Workers performing short-term spraying	8 workers per day at 20% of sites	40
WCS2 - part 2	Workers performing long-term spraying	18 workers per day at 20% of sites	90
WCS3	Operators performing brushing/rolling	18 workers per day per site	450
WCS4	Machinists	18 workers per day at 30% of sites	135
WCS5	Sanders in a dedicated hangar	16 workers per day at 30% of sites	120
WCS6	Workers performing media blasting in closed system	6 workers per day at 30% of sites	45
WCS7	Workers performing media blasting in a room/hall	6 workers per day at 10% of sites	15
WCS8	Maintenance and/or cleaning workers for spray area(s)	3 workers per day per site	75
WCS9	Maintenance and/or cleaning workers (excluding spray areas)	9 workers per day per site	225
WCS10	Incidentally exposed workers	14 workers per day per site	350
Sum total			**1,800**

Source: CSR

4.4.3.2 Humans via the Environment

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

- Number of downstream user sites in total;
- The population density per km^2, based on an average of the population density around sites responding to the SEA questionnaire;
- The relevant distance from sites for the local assessment, taken as the default assumption of a 1,000m radius (or 3.14 km^2).

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

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 4-10: Total exposed population used for HvE

Populations	No Sites	Population Density per km2	Exposed population
GB	25	2580	202633

4.4.4 Residual health risks

4.4.4.1 Introduction

Under the Applied-for-Use Scenario, use potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide in wash primers would continue after the end of the current review period for a total of 12 years if the requested review period is granted.

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.[46] 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[47] cancer cases were derived from the Cancer Today database, see **Table 4-11** below.

Table 4-11: 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:

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

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[46] 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).

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

Since the dose-response relationship gives the incidence (instead of cancer mortality), the figures from Cancer Today reported in **Table 4-11** above are applied to the estimates to calculate the number of fatal and non-fatal intestinal cancer cases.

- 0.45 x total number of cases (fatal + non-fatal) = δ
- 0.55 x total number of cases (fatal + non-fatal) = η

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 estimated number of intestinal cases are found to be orders of magnitude lower than the number of lung cancer cases (for humans via the environment). Therefore, combined risk figures carried forward for valuation in the following sections.

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 4-7**). These risk estimates reflect the additional safety measures that have been implemented due to the conditions placed on continued use by the initial authorisation decisions. The number of excess cancer cases is calculated by multiplying the number of workers assumed to be exposed in each task by the value of the excess cancer risk given above adjusted for the requested review periods, i.e., over 12 years. This value is then multiplied by the number of workers exposed in each WCS to calculate the total excess cancer cases arising from the continued use of potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide in wash primers **Table 4-12** provides a summary of the results across all WCS for GB workers.

Table 4-12: Number of excess cancer cases to GB workers

WCS	Number of workers exposed	LUNG CANCER - Excess lifetime cancer risk	LUNG CANCER - Number of excess fatal cancer cases	LUNG CANCER - Number of excess non-fatal cancer cases
WCS1 - part 1	250	1.00E-05	0.00	0.00
WCS1 - part 2	5	3.42E-05	0.00	0.00
WCS2 - part 1	40	5.34E-04	0.02	0.01
WCS2 - part 2	90	3.42E-04	0.03	0.01
WCS3	450	1.23E-05	0.01	0.00
WCS4	135	3.66E-06	0.00	0.00
WCS5	120	5.88E-06	0.00	0.00
WCS6	45	7.36E-06	0.00	0.00
WCS7	15	3.71E-05	0.00	0.00
WCS8	75	9.10E-07	0.00	0.00
WCS9	225	2.53E-06	0.00	0.00
WCS10	350	3.00E-06	0.00	0.00
	Years - Lifetime	**40.00**	0.06	0.02
	Years - Review period	**12.00**	0.02	0.01
	Years - Annual	**1.00**	0.00	0.00

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

The total number of people exposed via the environment as given in **Table 4-13** 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 4-13**. The basis for estimating the number of people exposed is given in section 4.4.3.2.

Table 4-13: Number of people in the general public exposed via the environment (local assessment)

Locations of DUs	No. of Sites	Exposed population	Combined excess lifetime cancer risk	Number of excess fatal cancer cases	Number of excess non-fatal cancer cases
GB	25	202633	**4.58E-06**	**9.28E-01**	**0.57**
Years – Lifetime cases			**70.00**	9.28E-01	5.69E-01
Years - Review period			**12.00**	1.59E-01	9.75E-02
Years - Annual			**1.00**	1.33E-02	8.13E-03

4.4.5 Economic valuation of residual health risks

4.4.5.1 Economic cost estimates

In order to monetise human health impacts, a timeframe that goes from 2026 (inclusive of the end of 2026) to the end of 2038 (i.e., a 12-year review period) has been adopted and a 3.5% discount rate has been employed for calculating present values.[48] It has been assumed that the levels of exposure to Cr(VI) for workers and members of the general population remain constant throughout the length of the review period, even though this is a very conservative assumption. In fact, downstream users will gradually reduce the amount of Cr(VI) consumed as the transition to the alternative proceeds. Combined with the investment in risk management measures put in place by the sites to protect workers as a result of the conditions placed on continued use by the initial authorisations, this should ensure that excess lifetime cancer risks reduce over the review period.

The economic valuation of the health impacts takes into account two important welfare components, the costs associated with mortality and morbidity. The basis of our calculations is the study led by the Charles University in Prague[49] 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.[50] The values used are:

- Value of statistical life for the avoidance of a death by cancer: €3.5 million to €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[51]. This suggests that the aforementioned figures should be multiplied by a factor of 1.14. Thus, the following values are employed in the analysis below:

- Value of statistical life lower bound (mortality): €3.5 million × 1.14 = €3.97 million (rounded);
- Value of statistical life upper bound (mortality): €5 million × 1.14 = €5.68 million (rounded); and
- Value of cancer morbidity: €0.41 million × 1.14 = €0.47 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 4-14**.

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

[49] 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.

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

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

Table 4-14: Alternative estimates of medical treatment costs

Study	Year for prices	Average direct costs in original units (per annum)	Direct costs in € 2021
Lung cancer[52]			
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)[53]			
Luo et al (2010)	2000 (assumed)	US$29,196	€36,230
Lang et al (2009)	2006	US$28,626	€31,740
York Health Economics Consortium (2007)	2004	£8,808	€12,180
York Health Economics Consortium (2007)	2004	£12,037	€16,410

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

These average medical costs are annual figures and apply to survivors over the period of time that they continue to be treated. With respect to lung cancer morbidity cases, we have taken a percentage survival of 32% after one year since diagnosis, 10% after 5 years, 5% after 10 years.[54] With respect to intestinal cancer morbidity cases, we have taken a percentage survival of 76% after one year since diagnosis, 59% after five years, and 57% after 10 years. Based on these time periods, the PV of average future medical costs per lung cancer case is estimated at €30,110 in 2021 prices, using a 4% future discount rate. The Present Value (PV) 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.

An average of lung cancer and intestinal cancer treatment costs is used in the subsequent calculations.

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[52] 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.

[53] 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.

[54] 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 values 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:

- Fatal cases × € 3,970,000 + (fatal and non-fatal cases) × (€ 470,000 + (€ 30,840+€84,790)/2) = **Lower bound value of cancer cases**

- Fatal cases × € 5,680,000 + (fatal and non-fatal cases) × (€ 470,000 + (€ 30,840+€84,790)/2) = **Upper bound value of cancer cases**

These values are converted to GBP applying an exchange rate of €1:£0.897[55]. Taking into account the latency period of cancer after exposure, a 10-year lag is applied[56]. Not that this is a conservative assumption because 10 years is based on occupational lung cancer exposure. A longer lag (i.e., discounted more heavily) is more relevant to other types of cancers (e.g., intestinal cancer) and exposure of general population via the environment. In short, the cancer cases occur after the 10-year latency period for 12 years corresponding to the applied for review period.

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

Table 4-15 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 around **£68,000 to £96,000** for the GB, based on the assumption that use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide 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 4-15: Present value and annualised economic value of mortality and morbidity effects to workers (discounted over 12 years @3.5% per year, 10 year lag, figures rounded)

	Lower bound costs		Upper bound costs	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cases	1.92E-02	5.11E-03	1.92E-02	5.11E-03
Annual number of cases	1.60E-03	4.26E-04	1.60E-03	4.26E-04
Present Value (PV, in 2021 prices)	£66,125	£2,192	£94,464	£2,192
Total PV costs	£68,316		£96,656	
Total annualised cost	£7,070		£10,002	

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[55] https://www.exchangerates.org.uk/EUR-GBP-spot-exchange-rates-history-2023.html#:~:text=Average%20exchange%20rate%20in%202023,GBP%20on%2011%20Jul%202023.

[56] https://echa.europa.eu/documents/10162/17228/echa_review_wtp_en.pdf/dfc3f035-7aa8-4c7b-90ad-4f7d01b6e0bc

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

Due to the small number of cases estimated for intestinal cancer (orders of magnitude lower than the number of lung cancer cases for humans via the environment), all cases are assumed to have a 10-year latency period, and include medical costs considered for the average of lung and intestinal cancer (on top of value of statistical life and value of cancer morbidity). This has been done to err on the side of overestimation.

Table 4-16 applies the economic value of the associated health impacts to the additional statistical cases of cancer for 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 £591,00 to £825,000 for the GB, based on the assumption that use of wash primers continues over the entire review period at consistent tonnages and number of downstream user sites; 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 4-16: Present value and annualised economic value of mortality and morbidity effects to the general population, local assessment (discounted over 12 years @3.5% per year, 10-year lag, figures rounded)

	Lower bound costs		Upper bound costs	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cases	1.59E-01	9.75E-02	1.59E-01	9.75E-02
Annual number of cases	1.33E-02	8.13E-03	1.33E-02	8.13E-03
Present Value (PV, in 2021 prices)	£546,892	£44,378	£781,274	£44,378
Total PV costs	£591,270		£825,652	
Total annualised cost	£49,558		£69,203	

4.4.6 Human health impacts for workers at customers sites

Customers sites are not addressed in the CSR.

4.4.7 Summary of human health impacts

Table 4-17 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 wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide across the sector at an estimated 25 GB sites covered by this combined AoA/SEA. It should also be recognised that workers using wash primers may also be using hexavalent chromates for other processes. As a result, their monitoring data may reflect aggregate exposures rather than just wash primer-related exposures.

Table 4-17: Combined assessment of health impacts to workers and general population (discounted over 12 years @3.5% per year, 10-year lag, figures rounded)

	Lower bound costs		Upper bound costs	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cases	0.18	0.10	0.18	0.10
Annual number of cases	0.01	0.01	0.01	0.01
Present Value (PV, in 2021 prices)	£604,420	£46,285	£875,738	£46,570
Total PV costs	£650,705		£922,308	
Total annualised cost	£47,449		£67,254	

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 use wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide across the GB would be severe. This use is critical to the key functions provided by the chromates: corrosion resistance (including active corrosion inhibition); adhesion promotion; chemical resistance; temperature resistance; layer thickness; compatibility with substrates/subsequent layers and compatibility with processing temperatures. These functions are essential to a broad range of components and assemblies, including structural parts such as engines, wings and landing gear assemblies. This includes application to newly produced components, touch-ups during manufacturing activities and for ensuring on-going performance following maintenance and repair activities.

If use of chromate-based wash primers was no longer authorised and where qualified and certified alternatives are not available according to the definition of “generally available”[57], design owners (i.e. OEMs and DtB companies) would be forced to re-locate some or all of their components production, manufacturing and maintenance activities outside the GB, where qualified and certified alternatives are not available.

A refused Authorisation would have impacts on GB formulators and the critical set of key functions provided by wash primers would be lost to A&D downstream users in GB

Due to certification and airworthiness requirements, downstream users in the A&D value chain would be forced to undertake chromate-based wash priming outside GB or shift to suppliers outside of GB

OEMs would shift manufacturing outside GB due to the need for wash priming to be carried out in sequence with other treatments. It would be inefficient and costly to transport components and products outside GB for wash priming only (especially for touch-up repairs)

DtB suppliers may have more flexibility and be able to shift only part their production activities outside GB, resulting in the loss of profits and jobs inside GB

BtP suppliers in the GB would be forced to cease chromate-based wash priming, leading to loss of contracts and jobs due to relocation of this and related activities outside GB

MROs, which make up a significant percentage of users, would have to shift at least some (if not most) of their activities outside GB, as wash priming is an essential part of maintenance, repair and overhaul activities

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[57] 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)

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

↓

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

↓

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

As indicated in the above diagram, because wash primers 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 entire value chain (production, repair and maintenance) outside of the GB, as summarised below.

5.1.2 Identification of plausible non-use scenarios

Discussions were held with the applicants, OEMs, DtBs, BtP suppliers and MROs to establish the most likely non-use scenarios in the event of the non-Authorisation of use of potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide in wash primers. The subject of these discussions included:

- The effects from the loss of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide;
- 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.

These discussions acted as the basis for a series of questions in the SEA questionnaire aimed at:

- Gathering information on the role of different types of companies;
- How the role impact reasons for using wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide;
- Past investments and R&D; and
- The most likely impacts of a refused re-authorisation.

Information on the first three of these points 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 the feasibility of producing components overseas and shipping them back to GB, with this then ruled out based on the answers received regarding the logistical difficulties and economic infeasibility. These were considered to be non-plausible scenarios and are discussed in Section 5.1.3 below.

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

Respondents were asked to provide further comments to support their responses, and to explain any other possible responses not included in the 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. Note, that the responses are provided by company, not by site. Multiple sites may be represented by each company response.

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

	OEM/MRO	Build-to-Print only	Design-to-Build only	MROs
It is unclear at this time/The decision is up to our customer	0	1	1	0
We may have to cease all operations as the company will no longer be viable	0	0	0	0
We will focus on other aerospace uses or on non-aerospace and defence uses	0	10	0	0
We will shift our work outside GB	0	0	0	0
We will stop undertaking use of the chromate(s) until we (or our customer) have/has a certified alternative	0	1	1	0
No responses	1	1	0	0
Total number of responses (companies)	1	2	2	0

5.1.2.1 OEMs

In discussions, the OEMs all stressed that the aim is the replacement of the use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide with an alternative that enables the components to be qualified and certified.

- **We will shift our work involving Chromates to another Country outside the GB. This is the most plausible scenario for the majority of OEMs directly involved in the use of wash primers** containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide. It would not be possible for the OEMs (or some divisions of the larger OEMs) to maintain manufacturing activities which take place after primers have been applied inside the GB while transferring use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide outside the GB. This would result in huge numbers of components being transferred outside the GB for repairs or touch-up, which would not be economically feasible. Furthermore, given the reliance on the use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide in supply chains, it is also the most likely response for the OEMs or divisions of them who rely on their suppliers using wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide on components prior to their delivery to the OEM. Wherever operations were transferred to in the event of a non-use scenario, there would need to be a qualified supply chain in place with sufficient capacity to absorb the additional demand.
- **We will stop using the chromates until we have certified alternatives.** It is clear that in most cases substitution activities and especially the industrialisation phase of moving to

alternatives will not be completed before the end of the current review periods, especially given the number of BtP suppliers and MROs involved, as well as the number of components of relevance. In some cases, a significant number of additional years is required which would mean a potential stop to both production and associated MRO activities over this period. The current "road map" for substitution and industrialisation cannot be sped-up, and some margin is needed to allow for any delays or possible failures. The potential duration of such a production stoppage would not be economically feasible.

- **We may have to cease all operations as the Company will no longer be viable.** If shifting work to countries outside the GB is unacceptable due to the costs or timeframe involved in setting up the required manufacturing sites and supporting infrastructure, a cessation of all operations may be the ultimate outcome for some of the OEMs, or divisions of them. It is important to note that this scenario translates to a cessation of aircraft production within the GB, with consequent reductions in revenues from aircraft assembly operations; the loss of this turnover would result in other operations (R&D, Engineering, Sales, etc.) also becoming non-viable with the final outcoming being a shut-down of all activities.

- **We will focus on other aerospace uses or on non-aerospace and defence applications**. The OEMs supporting the ADCR consortium are mainly involved in the manufacture and repair of civilian and military aircraft. As a result, this scenario is not technically or economically feasible for most of them to switch all or most of their focus to other sectors, as their sole areas of expertise reside in the aerospace field and/or defence fields.

The extent to which the OEMs would move all or only some of their manufacturing outside the GB depends on the integrated "system" of activities undertaken at individual sites. Wash primers are only used at a subset of sites, but their use may be critical to certain divisions and to the operations of suppliers to those sites.

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 cease only the use of wash primers; all activities related to the manufacture of the relevant components, aircraft and other products may need to be moved outside the GB. Note that this shifting of activity outside the GB 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 GB. This includes relocation of ancillary activities, such as machining, due to the increased likelihood of corrosion of machined components prior to coating.

Particular difficulties would be faced by companies in the defence sector. Possibilities for relocating some activities outside the GB 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 GB.

5.1.2.2 Design-to-Build

Two responses were received from DtB companies. One company stated that the decision is up to the customer and the other stated that we will stop undertaking use of the chromate(s) until we have certified alternative.

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

5.1.2.3 Build-to-Print

Build-to-Print companies rely on their customers to define the production methods that they must use. As a result, the potential responses of BtP companies to the non-use scenario are constrained. The companies confirmed that the choice of whether to use wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide is not theirs but their customers'. Some noted that they could not shift to alternative wash primers until these were qualified and certified for use in the production of components by their customers and the authorities, and the alternatives were deemed suitable and sustainable for their customers' uses.

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

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 aerospace and defence 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 primers may be required, may not be directly foreseeable. Very often, the level of work required only becomes clear after disassembling the component. The coating 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 require primer application. 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 use of wash primers containing potassium hydroxyoctaoxodizincate dichromate or pentazinc chromate octahydroxide 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 use wash primers containing potassium hydroxyoctaoxodizincate dichromate or pentazinc chromate octahydroxide, where the use of these is set out in Maintenance Manuals, may make repair and overhaul services unviable for MROs. Without the ability to provide the full range of processes that require the use of these substances, it would be difficult to maintain or win business. There is no scope for them to operate outside the requirements detailed in the OEMs' service manuals, which are based on the qualified and approved uses of wash primers. Where these requirements mandate the use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide then the MRO must use the primer as instructed unless the manuals also list a qualified alternative.

For example, within the Mobile Engine Services (MES) product, maintenance work is performed at the customer's site on an assembled aircraft engine. This can involve non-destructive testing or component changes that do not require the complete disassembly of an engine. In the course of this maintenance work - depending on the findings - corrosion protection with prescribed chromate-containing materials must be carried out in individual cases. In order to complete the maintenance work to the prescribed extent and to be able to release it under airworthiness requirements. If this step is not possible, the entire maintenance process of the engine and thus the product is compromised.

Similarly, in the course of overhauling an airframe (Base Maintenance), the use of chromates on structural components for the purpose of corrosion protection is occasionally necessary - depending on the specific findings - and is a binding requirement under aviation law (airworthiness requirements). As a rule, the necessity of using chromate-containing materials can only be determined after partial or complete dismantling or exposure of the structural components. In this state of construction, however, a relocation of the production site is de facto impossible/ruled out since the aircraft is then in an extremely high dismantling state. If the safety-relevant corrosion protection treatments, which are an integral part of the certification-relevant maintenance specifications, can no longer be carried out, the entire maintenance process of the aircraft is also compromised here.

5.1.2.5 Additional considerations

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

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

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

5.1.3 Non-plausible scenarios ruled out of consideration

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[58], 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 is not possible. In this scenario, the reason OEMs cannot accept an alternative that is less efficacious in delivering corrosion protection is because it would downgrade the performance of the final product, giving 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, fewer flying hours, etc.; and
- Increased risks to passengers, cargo operators and operators of military equipment.

With an inadequately performing primer, corrosion pits (pitting) can form in the substrate. These can turn into fatigue cracks which potentially endanger the whole final product. This is a particularly critical risk for the aerospace industry as corrosion pits can be extremely difficult to detect. Such issues likely would not appear suddenly but after several years, when hundreds of aerospace components are in-service. The potential for decreased performance from Cr(VI)-free wash primers 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.

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

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

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[58] 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.

- 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 be overhauled on similar schedules. 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 wash primer. By default, the entire system would now be de-rated to 5,000 cycles. Take a compressor blade that is located in the middle of an engine. If that blade can only survive for a portion of the life of an engine due to the limitations of a change to the surface treatment system, the engine would require disassembly to access the blades. This means taking the engine off the wing, sending it to a repair centre, disassembling the engine and replacing the components at much shorter intervals than needed for the remainder of the engine. Thus adding inherent inspection, maintenance, and repair costs to the manufacturers, operators, and end use customers who will also be impacted by increased out of service times.

As noted in Section 3.1.1.2, MSG-3 provides a system for OEMs and the regulators to identify the frequency of inspection for any component or system. Without adequate experience and proven success, and therefore possible unknown or hidden properties, the performance of a Cr(VI)-free wash primer cannot be highly rated. The consequence of this would be a significant reduction in the maintenance interval, which 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 wash primers containing Cr(VI) are crucial to the manufacture of the relevant aircraft components in the GB; if there are no qualified alternatives certified for the use on components then such manufacturing work would cease.

Overseas production followed by maintaining GB inventories

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

- The costs of building adequate warehouse facilities in GB would be prohibitive and would not be economically feasible. In the UK, an industrial warehouse without climate control (which would be required for the storage of some A&D inventory) costs around €1,000 per m^2 to construct (a conservative estimate). It is assumed here that warehouses that would act as a hub for storing inventory would be around 10,000 m^2 as a minimum, given the range of components that would need to be stored. This implies a total build cost of around £10 million as a minimum, not taking into account the costs of land purchase, site preparation, design, construction, etc. which could easily add a further 25%, even after taking into account any potential economies of scale in pricing due to the large size of the warehouse[59]. If such facilities are required at around 100 sites across GB (to cover civilian and military requirements for storage of sealed 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 GB and the consequent profit losses and increased costs of shipping, etc.

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

- Existing facilities are not sized to store the amount of multi-year inventories required. Companies will need to build/invest in additional secure, high-quality warehouses to store the inventory. However, it is important to recognise that this scenario is not feasible at all for many components, such as airframes, because these components are not removed from the aircraft; these components only allow MRO activities in-situ. Therefore, the entire aircraft would need to be transported to another 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.

- Dependency upon local inventories and non-European suppliers (and in turn vulnerability to local economic and political issues affecting other countries)), means being unable to reliably fulfil MRO activities, and 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 GB anymore (if use of wash primers is still required). Consequently, it is clearly not possible to rely on a long-term stock of spare components that would fit all situations.

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

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

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

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

The result would be that the cost of operating in the GB 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-GB locations. As production moves outside the GB, related activities such as R&D will also re-focus to these other 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 sensitive components to be protected by application of primer quickly after machining. It was confirmed though that such an approach may be feasible for a small range of components for civilian aircraft and for a limited number of components for military aircraft and equipment. However, as an overall strategy, it would not be feasible.

5.1.4 Conclusion on the most likely non-use scenario

The most likely non-use scenario is driven by the responses of the OEMs to the questions on the non-use scenario. They are the actors that carry out the R&D and testing (sometimes in collaboration with their chemical suppliers) to determine whether an alternative is technically feasible, qualify and gain approvals for components using that alternative and then certify their suppliers against its use. In some cases, they also help their suppliers meet the financial costs of adapting existing paint shops 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. GB suppliers (importers and distributers) of the chromates/formulations used in wash primers would be impacted by the loss of sales, with the market for wash primers for A&D relocating outside the GB.

2. OEMs directly involved in use of wash primers would move a significant proportion of their manufacturing (if not all) outside the GB, with the consequent loss of significant levels of turnover and employment. In particular, they will move those manufacturing activities reliant on the use of wash primers where there is no qualified alternative or where implementation across suppliers is expected to take several years after the end of the current review period. **The losses to the GB are estimated at 45% of manufacturing turnover.** There would be a significant loss of jobs directly related to use of wash primers, as well as across other manufacturing activities.

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

4. As OEMs shift their own manufacturing activities outside the GB, they will have to carry out technical and industrial qualification of new suppliers or GB suppliers moving to the new location, to ensure suppliers have the capability to deliver the stringent airworthiness and certification requirements. This would then be followed by a ramping up of production in order to meet the manufacturing rate objectives.

5. In some cases, these will be developed using BtP and DtB suppliers who have moved operations from the GB to third countries in order to continue supplying the OEMs. However, a significant proportion of the existing BtP companies involved in use of wash primers will cease undertaking wash priming in the GB. Those that do not know what will happen as the decision is up to their customer, will either relocate outside of the GB, cease use of the primers, or cease trading although, depending on their reliance on use of the primers and whether it is financially viable to relocate. **For BtP companies, 20% turnover losses are estimated, whereas 44% is estimated for DtBs.**

6. MROs will also be severely affected, and the majority of operators indicated that they would cease trading, due to the need to maintain vertical integration across the surface treatment processes that they are able to carry out. **MROs estimate a loss of approximately 45% of turnover.**

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

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

9. Taken together there would be significant economic impacts from the loss of manufacturing and maintenance to the GB economy, together with the loss of highly skilled jobs (and potentially a highly skilled labour force) and the benefits derived from the R&D carried out by a high-tech sector.

The justification for this NUS takes into account that OEMs and DtBs will not have certified alternatives, which have been fully implemented across their supply chains for all components, by January 2026. Many will require a further 12 years to have fully implemented alternatives across all components/final products and GB 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".[60]

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

The impacted operations and socio-economic impacts to industry under the non-use scenario will therefore go far beyond production of just the specific components that require use of wash primers. **Figure 5-1** illustrates the interdependency of every single component used, and the effect of only one component missing for the overall assembly process of the aircraft. In the first box, a component reliant on use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide would be impacted. If this can no longer be produced according to type certification, then manufacture of a sub-assembly is impacted. This then impacts on manufacture of an assembly and places the manufacture of the entire aircraft in jeopardy. As a result, it is not possible to relocate single Cr(VI)-based activities on their own in most cases, as they are an integral part in the production chain and cannot be separated from previous or following process steps.

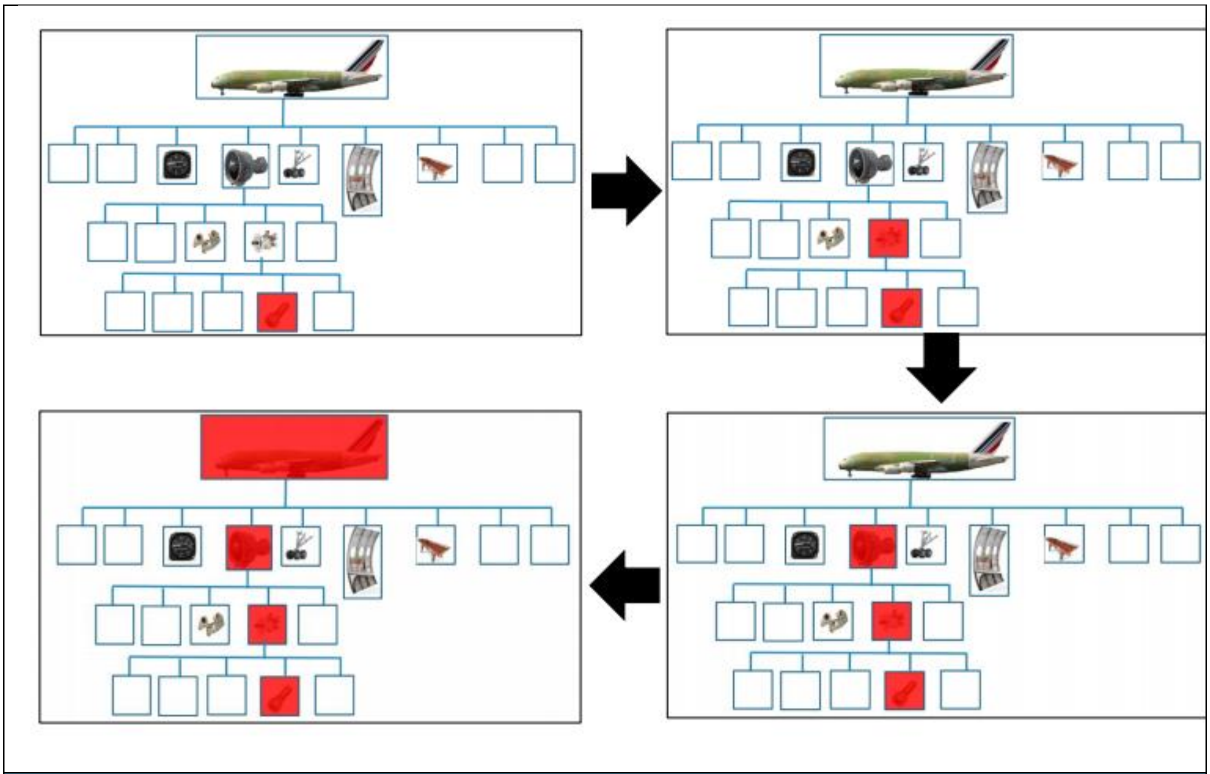

Figure 5-1: Interdependency of component availability in the manufacture of a final product
Source: GCCA (AfA 0116-01)

MROs will be similarly affected. It is technically not possible (or economically feasible) to carry out repairs to large components outside the GB, and then ship them back for reassembly in a final product

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[60] 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)](#)

in the GB. 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 GB, leading to OEMs having to create entirely new supply chains outside the GB, or increase capacity for existing supply chains. This scenario also implies a huge economic investment would be carried out by the OEMs as well as their GB suppliers. This level of investment is unlikely to be feasible and, in the meantime, the OEMs would have to cease manufacturing activities in the GB until the new industrial facilities were in place and ready to operate outside the GB.

5.2 Economic impacts associated with non-use

5.2.1 Economic impacts on applicants

Under the non-use scenario, all applicants would be impacted by the loss of sales of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide. At the specific supplier level, these impacts may vary in their significance, as the importance of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide to their revenues varies across the suppliers.

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. Over time, as consumption of the wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide reduces in line with companies' test candidate development plans, sales and hence revenues will continue to decrease.

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

5.2.2 Economic impacts on A&D companies

5.2.2.1 Introduction

It would theoretically be possible to move the use of wash primers outside the GB due to already existing supply chain sites in other countries, for example, the USA, GB, Canada, China, Mexico, Morocco, etc. and to outsource manufacturing as the supply chain is spread around the world. Wherever operations were transferred to in the event of a non-use scenario, there would need to be a qualified supply chain in place with sufficient capacity to absorb the additional demand. Granted authorisation in GB would provide access to qualified supply chains, however it is unknown if the GB supply chain would have the required capacity or how long it would take to ramp-up capacity to meet demand. There are several obstacles to such a scenario, which would make this economically unattractive even if it is the most plausible scenario. 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 GB, 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 GB 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, who 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 potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide 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 ONS data on GOS as a percentage of turnover.

Both approaches provide proxy estimates of profit losses based on current levels of employment and turnover. The approaches do not account for foregone future turnover that would be achieved under the continued use scenario due to growth in the global demand for air traffic. They also do not account for profit losses due to increased military and defence spending as a result of either a cessation in manufacturing activities or their relocating outside GB. In both approaches, the values have also been multiplied up to provide an estimation for the total number of sites across GB.

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 potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide and those whose jobs would be affected due to a cessation of production activities or due to companies moving outside the GB The resulting figures are presented in **Table 5-2** below.

The job losses reported by respondents, which range from a few per site where only use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide would cease to all employees in the event of closure are significant:

- Over 9000 jobs involving workers directly involved in use of potassium hydroxyoctaoxodizincate dichromate, and pentazinc chromate octahydroxide, where this includes jobs undertaking other linked processes/treatments (chromate and non-chromate based) as well as follow-on manufacturing, assembly, repair and maintenance activities;

- Over 900 additional jobs due to the cessation of manufacturing activities across product lines or to the cessation of MRO services, including due to 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	Additional direct job losses – due to a cessation of manufacturing/MRO activities
Build-to-Print	3	19	17
Design-to-Build	3	15	0
MROs/OEMs	2	344	341
Total	**8**	**378**	**358**
Job losses - Extrapolation of job losses under the Non-Use Scenario			
Build-to-Print	10	63	57
Design-to-Build	10	50	0
MROs/OEMs	5	860	853
Total	**25**	**973**	**909**
Total GB direct and indirect		**1,883**	
*Job losses have been estimated based on responses from similar GB sites.			

These predicted job losses have been combined with ONS data on Gross Value Added (GVA) per employee to GB 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 SIC code specific GVAs have been used for OEMs and MROs. The resulting estimated losses are given in **Table 5-3**.

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 - £	Additional GVA lost due to due to a cessation of manufacturing/MRO activities - £
Build-to-Print	54,619	1.04 million	0.93 million
Design-to-Build	54,619	0.82 million	N/A**
MROs/OEMs	80,556	27.71 million	27.47 million
Total		29.57 million	28.40 million
		Total GB	**£57.97 million**
Extrapolation of job losses under the Non-Use Scenario			
Build-to-Print	54,619	3.46 million	3.10 million
Design-to-Build	54,619	2.73 million	N/A**
MROs	80,556	69.28 million	68.67 million
Total		**£75.47 million**	**£71.77 million**
		Total GB	**£147.24 million**
*Weighted average GVA calculated for Build-to-Print and Design-to-Build companies as the GVA by SIC code multiplied by the SIC code counts across responding companies, divided by the total number of relevant NACE/SIC responses. MRO and OEM GVA figures from ONS (2021). ** DtB companies did not indicate that there would be any indirect jobs lost.			

The magnitude of these GVA losses reflects the fact that use of chromate-based wash primers as takes place across a large number of sites in the GB.

For comparison, turnover for the EU A&D industry is around €259 billion[61] per annum, while that for the UK A&D sector (including NI) is around €57 billion (£50 billion) in 2020.[62] 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 GB should use of chromate-based wash primers 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 ONS data for the relevant SIC codes, with an average weighted personnel cost adopted for BtP and DtB; the average personnel costs by SIC code from ONS 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 £88 million extrapolated out to the 25 GB sites using wash primers.

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

	Total GVA losses- £ per annum	Total personnel costs associated with lost jobs - £ per annum*	Implied operating surplus losses - £ per annum
Build-to-Print	1.97 million	1.15 million	0.82 million
Design-to-Build	0.82 million	0.48 million	.034 million
MROs	55.18 million	21.79 million	33.39 million
Total	57.97 million	23.41 million	34.55 million
Operating surplus losses - Extrapolation to the estimated 25 GB sites			
Build-to-Print	6.55 million	3.82 million	2.74 million
Design-to-Build	2.73 million	1.59 million	1.14 million
MROs	137.95 million	54.48 million	83.47 million
Total	147.24 million	59.89 million	87.35 million
*Weighted personnel costs calculated for Build-to-Print and Design-to-Build companies as the GVA multiplied by the NACE/SIC code counts across responding companies, divided by the total number of relevant companies. MRO and OEM GVA figures direct from ONS (2022) for GB 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 use of wash primers for the A&D sector, as well as coating 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 ONS data by SIC code with weighted averages used for BtP and DtB companies, and SIC 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.

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

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

Gross operating surplus losses are then calculated by applying GOS rate data for the different SIC codes from ONS for 2022. GOS was calculated as GVA at basic prices minus personnel costs, according to the income approach. Then the GOS divided the turnover is the GOS rate. The resulting losses are given in **Table 5-5**.

Table 5-5: Turnover and GOS losses under the Non-Use Scenario – (avg. 18% losses across all roles)

	Turnover loss %	Turnover lost per annum - £	GOS losses per annum - E
Build-to-Print	20%	37 million	8 million
Design-to-Build	43%	81 million	17 million
MROs/OEMs	45%	103 million	18 million
Total		220 million	43 million
Extrapolation to the estimated 25 GB sites			
Build-to-Print	20%	124 million	26 million
Design-to-Build	43%	268 million	57 million
MROs/OEMs	45%	257 million	46 million
Total		649 million	129 million

Note: Weighted average turnover and GOS calculated for Build-to-Print and Design-to-Build companies as the GOS multiplied by the SIC code counts across responding companies, divided by the total number of relevant companies. MRO and OEM figures direct from ONS (2022)) as available.

5.2.2.5 Comparison of the profit loss estimates

The totals presented in **Table 5-5** are higher than those given in **Table 5-4**:

- GVA based approach estimates of lost operating surplus across all sites:
  - Losses of £87.35 million per annum for the GB

- Turnover based approach estimates of lost operating surplus across all sites:
  - Losses of £129 million per annum for the GB

The two sets of figures are used in this SEA to provide lower and upper bound estimates of losses in producer surplus. It is important to note that these losses apply to commercial enterprises only.

5.2.2.6 Offsetting profit losses and impacts on rival firms

The losses in operating surplus given above would result not only from a cessation of manufacturing activities, but also from the premature retirement of existing capital equipment. Some of this capital equipment would be replaced in any event as part of substitution, over the next four to 12 years. Any such investment in new equipment would be focused on facilitating substitution (while the capital equipment associated with the continued use of the chromates over the next seven to 12 years would not be expected to be replaced).

As there are no suitable alternatives which are generally available, following SEAC's latest guidance, consideration has been given to the need to offset the profit losses for downstream users against the potential resale or scrappage value of the sector's tangible GB 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, especially as contamination from its current use for Cr(VI)-based primers 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 use of Cr(VI)-free wash primers is not relevant. The OEMs determine whether there are alternatives that can be used, not individual downstream users. Furthermore, as previously indicated, the ADCR is a sectoral consortium and downstream user members include competitors, which may also act as suppliers to each other, while the larger companies share many of the same BtP and DtB suppliers (an estimated 15-25% overlap in suppliers exists across some OEMs). Relationships between the OEMs and BtP and DtB are developed over time and often reflect long-term commitments given the need for OEMs and DtB companies to certify their suppliers in the manufacturing of components. As a result, rival suppliers cannot readily step in and replace their production activity.

The economic losses are therefore based on consideration of losses in operating surplus/profits only. These have been estimated over five time periods. Discounted losses over one, two, four, seven and 12 years are given in **Table 5-6**. In the following sections, a profit loss of two years will be used as a proxy to societal producer surplus loss over the review period. The default value suggested by SEAC is 4 years for cases with no suitable alternatives generally available (no-SAGA) and 2 years for cases with SAGA. The choice of 2 years is likely an underestimate in this case given SEAC's recommendation and the absence of SAGA, (lack of) offset by competitors and the high degree of specialisation in the A&D sector.

As discussed earlier, these losses are based on ONS turnover figures for 2021 (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 GB 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 5-6: Discounted profit/operating surplus losses under the Non-Use Scenario – Discounted at 3.5%, year 1 = 2025

	Lost Profit - £	GVA-based Operating Surplus Losses - £
1 year profit losses (2025)	128.80 million	87.35 million
2 year profit losses (2026)	244.69 million	165.94 million
4 year profit losses (2028)	473.11 million	320.84 million
7 year profit losses (2031)	787.58 million	534.10 million
12 year profit losses (2036)	1,244.68 million	844.09 million

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 GB, leading to a second wave of negative impacts on the GB market. These impacts have not been quantified here but would include as a minimum:

- Cancelled future orders and loss of contracts for new products if supplies are significantly interrupted;
- Customer penalties for late/missed delivery of products;

- Extended durations of maintenance, repair and overhaul operations for products in service leading to e.g. "aircraft on the ground" (AoG) and other out-of-service final products, with consequent penalties and additional impacts on turnover;
- Increased logistical costs; and
- Reputational damages due to late delivery or cancelled orders.

5.2.3 Economic impacts on competitors

5.2.3.1 Competitors in the GB

This combined AoA/SEA has been prepared so as to enable the continued use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide across the entirety of the GB A&D sectors. It is non-exclusive in this respect. It has been funded by the major (global) OEMs and DtB manufacturers in GB, 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 GB

Under the non-use scenario, it is likely that some of the major OEMs and DtB suppliers would move outside the GB, creating new supply chains involving BtP manufacturers and MROs. This would be to the detriment of existing GB suppliers but to the advantage of competitors outside the GB. These competitors would gain a competitive advantage due to their ability to continue to use wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide as well as 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 in the GB 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 use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide, they would have to be performed outside the GB. This would be 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 GB for repairs, with dramatic financial and environmental impacts.

Should MRO facilities be relocated outside the GB, airlines will also experience additional delays to routine aircraft maintenance due to transport requirements and capacity constraints at MRO facilities outside the EU and Northern Ireland. Indeed, it may take some time to build up capacity to accommodate additional demand from EU and NI-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 performed outside the GB would also lead to higher operational costs due to increased fuel use, in addition to greater environmental impacts (as discussed in section 5.3). 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-GB MRO facilities and back to the GB. The impacts for larger aircraft would also be significant. For example, flying from Western Europe to Turkey or Morocco adds approximately 3,000 km each way and for a Boeing 737 this would take slightly less than four hours. For an airline which has 50 aircraft requiring a “D check” (heavy maintenance inspection of the majority of components, carried out every 6-10 years), this would involve 400 hours of flight time (return trip) or 20 days of foregone revenue, equivalent to €1.4 million per annum. Scaling this up to the GB 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)[63], 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[64] a 49 to 50% decline in world total passengers in 2021 compared to 2019. In 2020, figures for Europe show a 58% decline in passenger capacity, -769 million passengers and a revenue loss of 100 billion USD. In addition, COVID-19 caused a 74% decrease in passenger demand for international travel in 2020 compared to 2019. The trend though is for the aircraft industry to continue expanding globally, with pre-COVID estimates suggesting that demand for air transport would increase by an average of 4.3% per annum over the next 20 years, as illustrated in **Figure 5-2**. Similar growth is

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

[64] https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf

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.

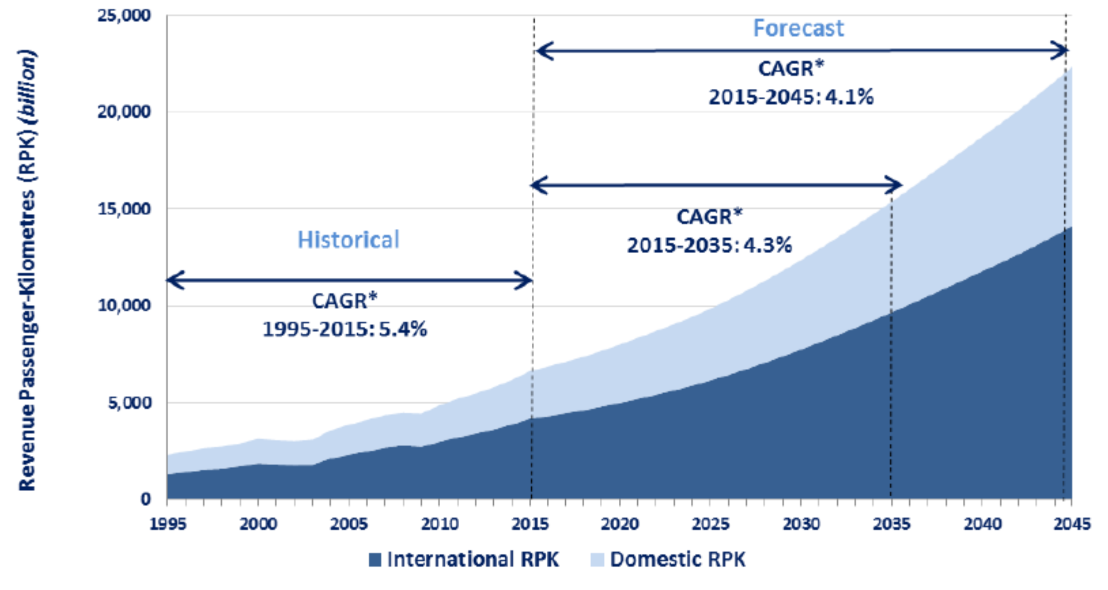

Figure 5-2: Forecast compound annual growth rates – Revenue Passenger-kilometres

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.[65] The impact of COVID-19 has resulted in an expected 2-year lag in growth, but the forecast remains unchanged with passenger numbers expecting to increase in line with the forecasts. This growth rate is relevant to global air traffic, with Europe expected to realise a lower compound annual growth rate of about 3.3% for total traffic[66] (covering inter-regional and intra-regional/domestic) for the period between 2018 and 2038.

This level of growth in GB 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 requiring the use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide 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 GB-based MRO operations in particular could impact the availability of aircraft until substitution has taken place as expected over the review period. This would have a detrimental impact on the ability of airlines to transport both passengers and freight (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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[65] Airbus (undated): Airbus Global Market Forecast 2021 – 2040. Available at: https://www.airbus.com/en/products-services/commercial-aircraft/market/global-market-forecast

[66] 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 wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide, 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.

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 UK, 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 be far more impactful than the economic impacts linked to the defence sector.

As a result, it is likely that under the NUS, companies manufacturing components for, and servicing, military products would have to apply for defence exemptions under Article 2(3) of REACH. Although for some companies, the turnover generated by military contracts alone may not be sufficient to maintain current production levels and it may not be economically feasible to operate dual manufacturing lines for military and civilian customers in different territories.

Companies in the European defence sector represent a turnover of nearly €100 billion and make a major contribution to the wider economy. The sector directly employs more than 500,000 people, of which more than 50% are highly skilled. The industry also generates an estimated further 1.2 million jobs indirectly. In addition, investments in the defence sector have a significant economic multiplier effect in terms of the creation of spin-offs and technology transfers to other sectors, as well as the creation of jobs. For example, according to an external evaluation of the European Union's Seventh Framework Programme, through short-term leverage effect and long-term multiplier effects each euro spent by the Seventh Framework Programme (FP7) generated approximately an additional €11 of estimated direct and indirect economic effects through innovations, new technologies, and products.[67]

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).[68] The aim will be to support high-end defence capability projects such as the next generation of fighter aircraft, 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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[67] https://www.evropskyvyzkum.cz/cs/storage/bf5134fec407f6e005288c0e2631ad232c38c013?uid=bf5134fec407f6e005288c0e2631ad232c38c013

[68] https://ec.europa.eu/commission/presscorner/detail/en/IP_22_4595

start-ups. Some of these gains may not be realised if the main GB defence OEMs have to divert resources into shifting part of their manufacturing base outside of the GB.

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, to reiterate 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 GB 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 GB under the NUS, then some proportion of such multiplier effects would be lost to the GB economy. In addition, the ability of the GB to benefit from some of the innovations and technological advances in products ahead of other countries could be lost, if the shift in manufacturing remains permanent and extends to new products.

5.2.5 Summary of economic impacts

Table 5-7 provides a summary of the economic impacts under the non-use scenario.

Table 5-7: Summary of economic impacts under the non-use scenario (12 years, @ 3.5%)

Economic operator	Quantitative	Qualitative
Applicants	• Not assessed	Lost profits to applicants in GB are assessed in the Formulation SEA
A&D companies	• £844 to 1,245 million over 12 years (£87 to 129 million over one year)	Relocation costs, disruption to manufacturing base and future contracts, impacts on supply chain coherence, impacts on future growth in the GB sector (including NI), 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 output/value added 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 use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide to another country (outside GB).

Under this scenario, as noted above, the environmental impacts would be real and the effects enormous. If manufacturing activities using potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide and not using potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide 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 wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide, it would force the manufacturer to go to a site outside the jurisdiction of the EU. 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 site outside the jurisdiction of the EU. Some stranded final products would become obsolete prematurely, due to the paucity of the components needed for their maintenance and repair. This would create excess waste and would go against the principles underlying the Circular Economy and the sustainable use of raw materials, by limiting the ability of the sector to repair and re-use components and assemblies. The industry has been active in trying to decrease buy-to fly ratios (the ratio of material inputs to final component output), and the non-use scenario would significantly undermine these efforts as the more frequent production of new components would increase the waste and scrappage generated. Scrap is material which is wasted during the production process.

Today, the civil aviation industry strives to develop new technologies to reduce the amount of CO_2 emissions by 15 - 20% on each generation of in-service aircraft.

Despite the impact that the COVID-19 pandemic had on air traffic and the whole civil aviation industry, aviation is predicted to double in the next 20 years (see **Figure 5-2**). Consequently, a refused authorisation renewal would lead to aircraft manufacturing and MRO activities involving Cr(VI) uses to move outside the GB. In addition to the socio-economic consequences this would have, the increase in CO_2 emissions would outweigh all the benefits achieved by aviation efforts to reduce fuel consumption and CO_2 emissions of in-service aircraft.

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. Direct job losses will impact on workers at the site involved in use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide and linked processes, as well as workers involved in subsequent manufacturing and assembly steps and related activities (e.g., lab workers, etc.). These are all referred to here as direct job losses (for avoidance with confusion of multiplier effects).

While redundant workers are expected to face a period of unemployment, in line with ECHA's guidance it is assumed that such a period would be only temporary. However, the length of the average duration of unemployment varies greatly across European countries, as do the costs associated with it.

It should be noted that the ECHA methodology has been followed here despite the fact that the impacts across the A&D sector may make it difficult for workers to find another job, especially as there may be a skill mismatch (if there are large scale levels of redundancies).

Estimates of the job losses that would arise at downstream users' sites under the NUS were presented above. For ease of reference, the totals are repeated in **Table 5-8** below. The magnitude of these figures reflects the importance of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide to the manufacture of components, as well as to maintenance and repairs of such components at a subset of MRO facilities. No consideration is given to job losses at those companies providing services that are contracted to provide cleaning and other services to the BtPs, DtBs, MROs, and OEMs.

As context, the civil aeronautics industry alone employees around 405,000 people in the EU, with the defence sector employing more than 500,000 and supporting a further 1.2 million.[69] The figures in **Table 5-8** indicate that approximately 1,900 A&D jobs would be in jeopardy under the NUS, when extrapolated out the estimated 25 sites in GB.

Table 5-8: Predicted job losses in aerospace companies under the NUS

Role	Total job losses due to cessation of manufacturing activities or relocation under the NUS
Build-to-Print	120
Design-to-Build	50
OEM/MROs	1,713
Total	**1,883**

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[70]).

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[71] as a whole that varies according to the mean duration of unemployment. These vary by country, with the mean duration of unemployment

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[69] https://www.eudsp.eu/event_images/Downloads/Defence%20Careers%20brochure_1.pdf

[70] 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

[71] At the time of publication, the UK was still an EU Member State

weighted by the number of employees for each country relevant to A&D sector production sites varying from seven months to 1.6 years.

These figures are combined with the ratio of social costs per job loss provided in Dubourg (2016) and annual wages to calculate the social costs per lost job. For the purposes of these calculations, a figure of £45k has been adopted and applied across all locations and job losses for the average salary per worker. This figure is based on the SIC code data provided by companies but may underestimate the average salary, given that A&D jobs are typically higher paid than those in other industries.

The resulting estimates of the social costs of unemployment are £177 million within GB.

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 GB A&D sector would relocate their activities elsewhere with a partial or full cessation of manufacturing in the GB.

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 5-2** 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[72] quotes an employment multiplier of between 2.2 and 2.4, with this covering both indirect and induced employment effects. The sector is identified as bringing a major contribution to the wider economy.

To successfully compete at a global level, the European A&D industry has formed regional and industry clusters that includes local and national government partners. The clusters are part of the European

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[72] 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

Aerospace Cluster Partnership[73] (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 with 23,000 employees with and a turnover of over £6.5 billion in Wales (See Annex 2).

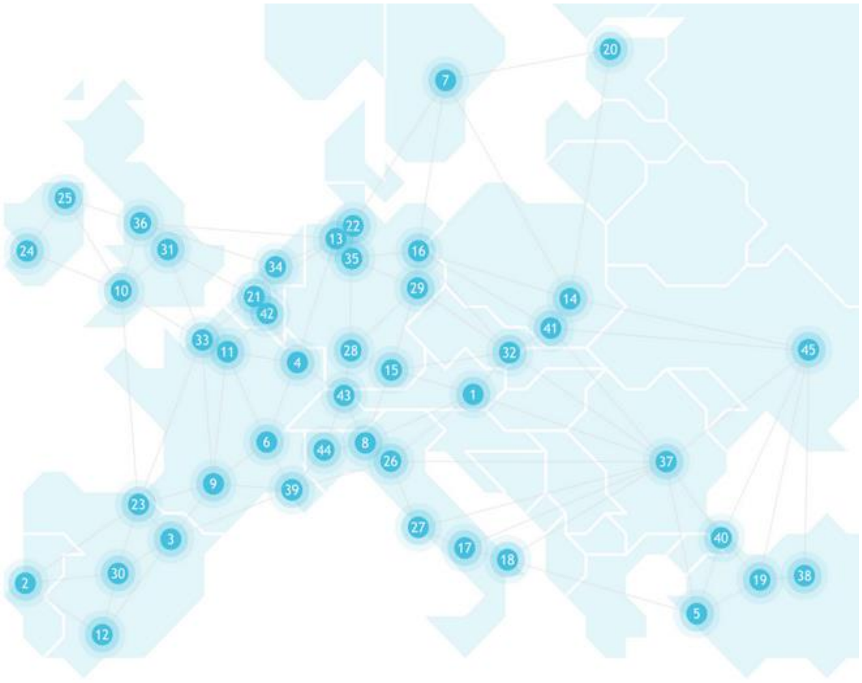

Figure 5-3: Aerospace clusters across Europe

5.4.2.2 Air transport multiplier effects

A 2019 "Aviation Benefits Report"[74] 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

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

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

are directly within the aviation sector, with the remaining 9.6 million arising indirectly from the aviation sector or relating to induced or catalytic effects.

Clearly not all these jobs would be impacted under the NUS, although some impact would be expected should there be reductions in the number of flights, increased delays, and other effects from the loss of GB based MRO activities in particular.

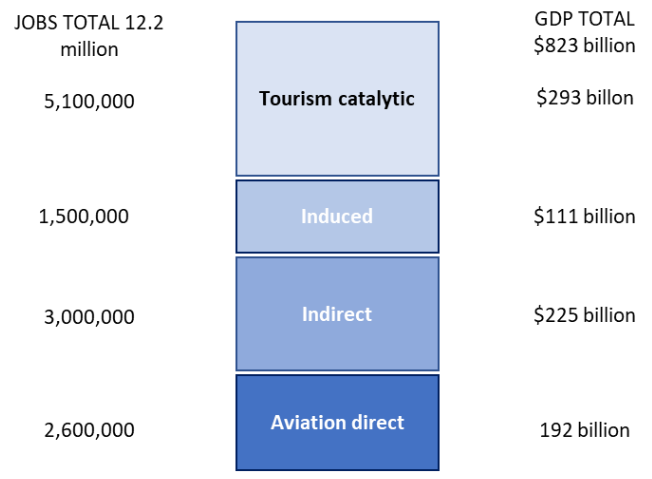

Figure 5-4: Aviation related multiplier effects
Source: Based on: https://www.icao.int/sustainability/Documents/AVIATION-BENEFITS-2019-web.pdf

The potential employment losses associated with a decline in European aviation can be seen by reference to the impacts of COVID-19.[75] A "COVID-19 Analysis Fact Sheet" produced by Aviation Benefits Beyond Borders reports the following:

- A reduction from 2.7 million direct aviation jobs in Europe supported pre-COVID to 2.1 million jobs post-COVID (i.e., at the end of 2021); and
- 13.5 million jobs in supported employment pre-COVID in Europe to 8.1 million at the end of 2021.

Although one would not expect the losses in supported employment (i.e., indirect, induced, and catalytic effects) to be as great due to the loss of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide 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: 1000 GB workers involved in wash primers and linked chromate treatment processes; and 1,900 GB workers impacted by a cessation of other treatment and manufacturing activities;

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

- Social costs of unemployment: economic costs of around £177 million for the GB due to direct job losses;
- 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 5-9 sets out a summary of the societal costs associated with the non-use scenario. Figures are provided as annualised values, and present values over the 12-year review period. Note that the true impacts of non-use are not fully reflected by the monetised impacts of non-use summarised in the table – the monetised costs of non-use are underestimated and many impacts are not monetised.

Table 5-9: Summary of societal costs associated with the non-use scenario

Description of major impacts	Monetised/quantitatively assessed/qualitatively assessed impacts	
Monetised impacts	**£ Present values over the review period**	**£ annualised values**
Producer surplus loss due to ceasing the use applied for[1]: Impacts on applicants - Lost profits GB Impacts on A&D companies[1]: - Lost profits GB	Applicants: Impacts in Pound millions – see Formulation SEA A&D companies £166 to 245 million	Applicants: Impacts in Pound millions – see Formulation SEA A&D companies £17 million to 25 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]	1,883 jobs lost	
	£177 million	£18 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	£343 to 422 million	£35 to 44 million
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 GB	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 Impacts on emergency services and their ability to respond to incidents Impacts on cargo transport	

Table 5-9: Summary of societal costs associated with the non-use scenario

Description of major impacts	Monetised/quantitatively assessed/qualitatively assessed impacts

1) Lower bound figures represent lost profit estimates based on loss of jobs, upper bound based on loss of turnover
2) Estimated using the approach set out in SEAC’s guidance on social cost of unemployment
3) Totals have been rounded

5.6 Sensitivity Analysis

Table 5-10 below shows the scenarios considered as part of the sensitivity analysis. The two profit loss estimates are as discussed in section 5.2 and the average value of monetised human health risks form scenarios 5 and 6, which are given as central estimates in the benefits-to-risks comparison in section 6.3. The additional scenarios (1-4) make use of the upper and lower bound for the human health costs, as discussed in section 4.4. These additional scenarios give a range of benefit-to-risk ratios of 528:1 to 920:1, which further strengthen the conclusion that benefits of continued use outweigh risks of continued use.

Table 5-10: Sensitivity Analysis

Scenario	Profit Losses to the A&D industry	Social Costs due to unemployment	Human Health Risks	Net Present Value	Ratio of societal costs to residual health risks:
1	£25 million	£18 million	67,254.47	€44 million	649:1
2	£17 million	£18 million	67,254.47	€35 million	528:1
3	£25 million	£18 million	47,449.27	€44 million	920:1
4	£17 million	£18 million	47,449.27	€35 million	748:1
5	£25 million	£18 million	57,351.87	€44 million	761:1
6	£17 million	£18 million	57,351.87	€35 million	619:1

Scenario 1 - lost EBITDA/profit, upper bound human health costs
Scenario 2 - GVA-based operating surplus losses, upper bound human health costs
Scenario 3 - lost EBITDA/profit, lower bound human health costs
Scenario 4 - GVA-based operating surplus losses, lower bound human health costs
Scenario 5 - lost EBITDA/profit, average human health costs
Scenario 6 - GVA-based operating surplus losses, average human health costs

6 Conclusion

6.1 Steps taken to identify potential alternatives

When creating a test candidate development plan for substances subject to Authorisation, suitable alternatives to Cr(VI) for wash primers should be "generally available"[76]. At present, this condition has not been met, as there are no alternatives which have met the strict regulatory requirements within the A&D industry for all components onto which wash primers containing Cr(VI) are currently applied.

Alongside the various R&D activities, as described in Section 3.4.1, and information reported in academic literature and patent reports as described in Sections 3.4.3, members of the ADCR have undertaken extensive testing into alternative technologies and processes with many programmes still ongoing. The steps taken by members in the implementation of a substitute for Cr(VI)-based wash primers are shown in **Figure 6-1**:

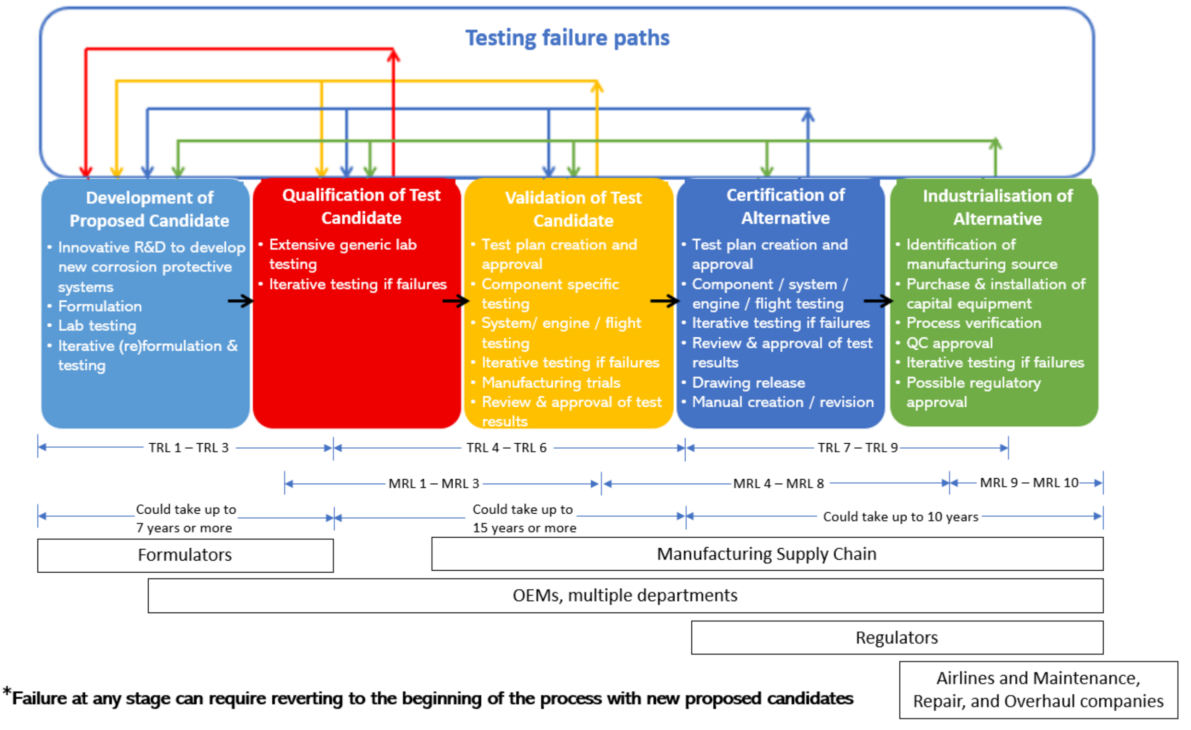

Figure 6-1: Schematic showing the key phases of the substitution process.
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note 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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[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: https://echa.europa.eu/documents/10162/13637/ec_note_suitable_alternative_in_general.pdf/5d0f551b-92b5-3157-8fdf-f2507cf071c1

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 Test Candidate development plan

ADCR member companies have ongoing test candidate development plan in place to develop test candidates with the intent of replacing wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide.

As discussed in Section 3.7.2 and shown in **Figure 6-2** below, of the 20 distinct s test candidate development plans for wash primers assessed in this combined AoA/SEA, 10% of them are expected to have achieved MRL 10 by January 2026. MRL 10 is the stage at which it is expected production will be in operation and it is anticipated wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide will no longer be used for the components covered in that test candidate development plan.

The proportion of development plans that are expected to achieve MRL 10 is then expected to progressively increase to 20% in 2030, 75% in 2033, and 100% in 2038. In 2033 (equivalent to seven years beyond the expiry date for the existing authorisations). many development plans are expected to have successfully progressed to MRL 10. The consortium is also expected to have reduced its potassium hydroxyoctaoxodizincate dichromate, and pentazinc chromate octahydroxide use. A proportion are not expected to have achieved MRL 10 however, are expected to be at the certification stage. For these development plans (which are from several member companies), there is still expected to be a need for the use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide.

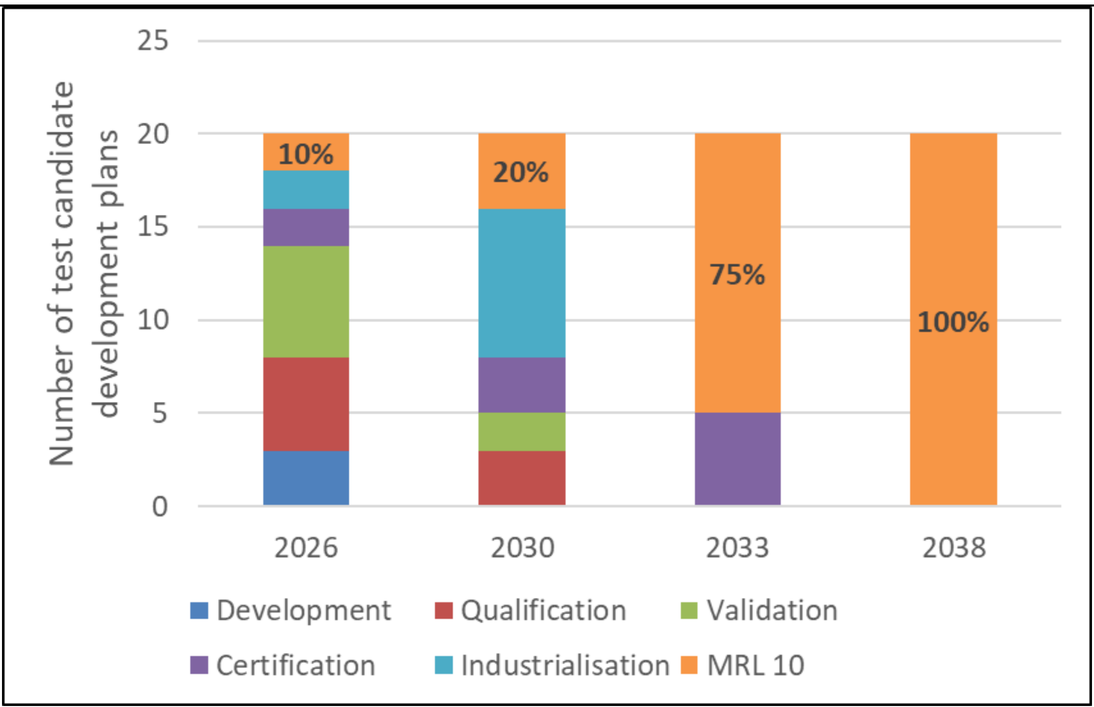

Figure 6-2: Expected progression of test candidate development plans for the use of wash primers containing potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide, by year.
The vertical axis refers to number of test candidate development plans (some members have multiple test candidate development plans for wash primers). The percentage value shown on each of the orange bars indicates the proportion of development plans that are expected to have reached MRL 10 by the date indicated. MRL 10 is the stage at which manufacturing is in full rate production/deployment and it is therefore where it is expected that Cr(VI) will be fully substituted under the relevant plan.
Source: RPA analysis, ADCR member s

As a result of individual members' test candidate development plans summarised above, the ADCR request a review period of **12 years** for the use of wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide.

6.3 Comparison of the benefits and risk

A summary of the societal costs and residual risk comparing non-use scenario and a continued use scenario have compiled in **Table 6-1** below.

Table 6-1: Summary of societal costs and residual risks

Societal costs of non-use (12 years)		Risks of continued use (12 years)	
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	£166 to 245 million	Monetised excess risks to directly and indirectly exposed workers (£ per year over 12 years)	£2,020 to 10,002

Social costs of unemployment	£177 million	Monetised excess risks to the general population (£ per year over 12 years)	£49,558 to 69,203
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 GB; premature redundancy of equipment leading to increased materials use.		
Summary of societal costs of non-use versus risks of continued use	- NPV (societal costs minus residual health risks): ○ £35 to 44 million - Ratio of societal costs to residual health risks: ○ 619:1 to 761:1		

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:

A refused Authorisation would have impacts on the GB formulators and the critical set of key functions provided by wash primers would be lost to A&D downstream users in GB

↓

Due to certification and airworthiness requirements, downstream users in the A&D value chain would be forced to undertake chromate-based wash priming outside GB or shift to suppliers outside of GB

↓

OEMs would shift manufacturing outside GB due to the need for wash priming to be carried out in sequence with other treatments. It would be inefficient and costly to transport components and products outside GB for wash priming only (especially for touch-up repairs)

↓

DtB suppliers may have more flexibility and be able to shift only part their production activities outside GB, resulting in the loss of profits and jobs inside GB

↓

BtP suppliers in GB would be forced to cease chromate-based wash priming, leading to loss of contracts and jobs due to relocation of this and related activities outside GB

↓

MROs, which make up a significant percentage of users, would have to shift at least some (if not most) of their activities outside GB, as wash priming is an essential part of maintenance, repair and overhaul activities

↓

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

↓

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

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

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

Additionally**, the use of the chromates in wash primers is required to ensure the operational capabilities of the military and the ability to comply with international obligations as partner nations including at the UK level, EU level and in a wider field, e.g. with NATO.**

6.4 Information for the length of the review period

6.4.1 Introduction

In a 2013 document, the ECHA Committees outlined the criteria and considerations which could lead to a recommendation of a long review period (12 years) (ECHA, 2013):

1. *The applicant's investment cycle is demonstrably very long (i.e., the production is capital intensive) making it technically and economically meaningful to substitute only when a major investment or refurbishment takes place.*
2. *The costs of using the alternatives are very high and very unlikely to change in the next decade as technical progress (as demonstrated in the application) is unlikely to bring any change. For example, this could be the case where a substance is used in very low tonnages for an essential use and the costs for developing an alternative are not justified by the commercial value.*
3. *The applicant can demonstrate that research and development efforts already made, or just started, did not lead to the development of an alternative that could be available within the normal review period.*
4. *The possible alternatives would require specific legislative measures under the relevant legislative area in order to ensure safety of use (including acquiring the necessary certificates for using the alternative).*
5. *The remaining risks are low, and the socio-economic benefits are high, and there is clear evidence that this situation is not likely to change in the next decade.*

In the context of this combined AoA/SEA, it is assumed that qualification and certification requirements combined with the need for approvals from EASA, the ESA and MoDs are consistent with the requirements under criterion 4 above.

Further discussion was held at the 25th Meeting of Competent Authorities for REACH and CLP (CARACAL) of 15 November 2017. A document endorsed by CARACAL suggests that "*in order to consider a review period longer than 12 years, in addition to the criteria for a 12-year review period established in the document "Setting the review period when RAC and SEAC give opinions on an application for authorisation", two additional conditions should jointly be met*:

6. *As evaluated by the RAC, the risk assessment for the use concerned should not contain any deficiencies or significant uncertainties related to the exposure to humans (directly or via the environment) or to the emissions to the environment that would have led the RAC to 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 required to meet the highest possible safety standards throughout their service life. As noted in Section 4.4, the average life of a civil aircraft is typically 20-30 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[77]. They are a key driver underlying the difficulties facing the sector in substituting the use of potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide in wash primers 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. It requires testing at multiple levels (components, sub-assemblies, assemblies, final aircraft/defence equipment).

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[77] 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.

The ADCR consortium 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 the design of the aircraft itself, but also its use and maintenance history in varied climates and service. An aircraft engine is exposed to massive forces and extremely high stress levels due to high velocities and environmental impacts. Therefore, every single component needs to be designed, manufactured, and maintained with serious attention and care.

In a complex system, change introduces new forms of failure. Any change will bring failures that can be anticipated – and some that are unanticipated. The components in an A&D product need to be adjusted to each other very precisely on the design as well as on the manufacturing level. When in the early design phase for completely new engines, for example, there is an opportunity to consider introducing a material change. Mostly such a material change will be a step improvement on a previous design, in line with the principle of proven engineering. Very rarely is a substantial design change introduced into an existing product, as this would involve substantial cost and risk.

Even where such a small change is considered feasible in principle, the implications are significant and highly complex; time consuming, systematic TRL-style implementation is required to minimise the impact of unanticipated failures and the serious repercussions they might cause. Even when an OEM has been able to undertake the required testing and is in the process of gaining qualifications and certifications of components with a substitute, it may take up to seven years to implement the use of a substitute across the value chain. This is 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 primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide in the production of spare parts and in the maintenance of those spare components and the final products they are used in.

As such, a review period of at least 12 years is warranted and requested for the highly complex systems the ADCR is addressing in this combined AoA/SEA. A 12-year review period in itself may not be sufficient for the aerospace and defence industry to fully replace potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide across all uses of wash primers, 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. The performance of Cr(VI)-based wash primers, due to their extensive performance history, represents the baseline that alternatives must match to demonstrate equivalence.

For example, modern commercial aircraft (including helicopters) consist of between 500,000 and 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)-containing primers 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 billions of flight hours' experience with components onto which Cr(VI)-based wash primers have been applied. Conversely, there is still limited experience with Cr(VI)-free alternatives on components. It is mandatory that components primed using a Cr(VI)-free alternative are demonstrably at least as safe as they had been when primed using a Cr(VI) product. The performance of Cr(VI)-free products can sometimes be demonstrated at the laboratory step but then fail at industrial scale, as it is impossible to replicate all in-service conditions in a laboratory. As a result, the time taken to progress through the TRL process may be increased until it is possible for the performance of the alternative to be demonstrated as per safety requirements at the aircraft level when operating under real life conditions.

Flight safety is paramount and cannot be diminished in any way. Take, for example, a compressor blade that is located in the middle of an engine. If that blade can only survive for a portion of the life of an engine because of service life (and hence maintenance requirement) limitations due to a change in the primer, 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 centre, disassembling the engine and replacing the components at much shorter intervals than previously needed for the remainder of the engine. This would add inherent maintenance time and costs to the manufacturers; operators; and eventually end-use customers.

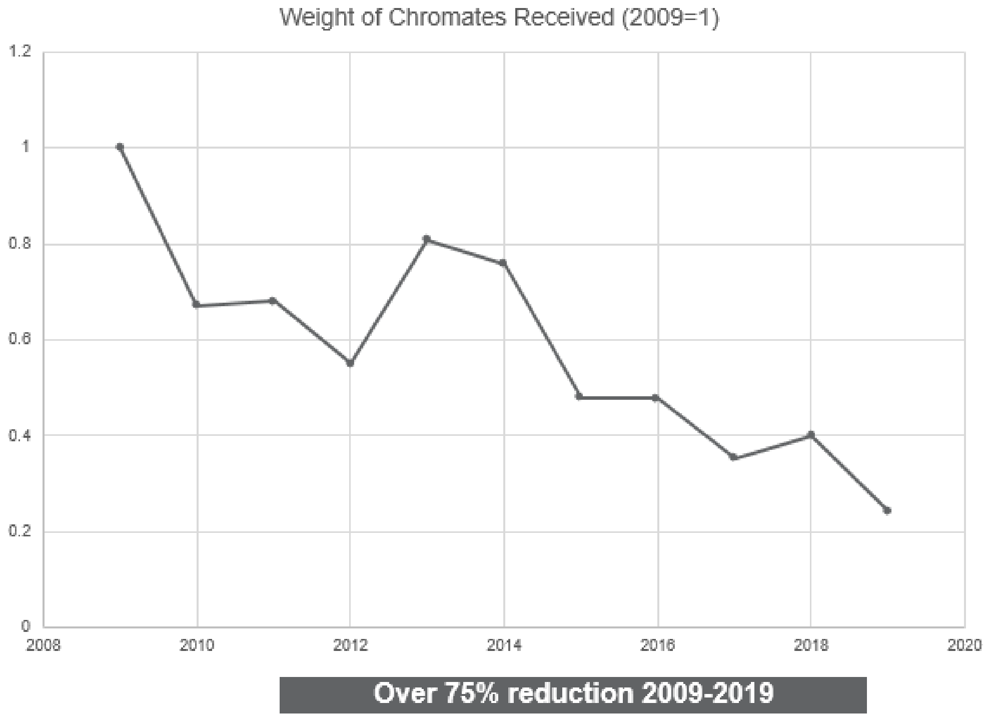
Where possible, and for specific components and final products, some new designs have been able to utilise newly developed alloys that do not require a Cr(VI)-based coating (as typically used to provide corrosion protection on metallic legacy components). However, even in newer designs there may still be a need for the use of Cr(VI)-based wash primers, due to safety considerations and a lack of suitable alternatives available in general.

These technical hurdles are a fundamental reason why the A&D industry requests a review period of 12 years.

6.4.4 Criteria 3 and 7: Results of R&D on alternatives and availability of alternatives over the longer term

Research into the substitution of the chromates has been on-going for several decades. Although use continues, it should be recognised that significant achievements have been made over this period in the substitution of the use of potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide with alternative substances or technologies. This is illustrated by the achievements of one OEM in reducing their use of all chromates (including those listed on Annex XIV which are not covered by this application) by 75% (by weight) (see **Figure 6-3**).

This 75% reduction (by weight) in the use of the chromates reflects the massive efforts and investment in R&D aimed specifically at substitution of the chromates. Although these efforts have enabled substitution across a large range of components and products, this particular OEM will not be able to substitute chromate use in the production of all components and products for at least 12 years. It could even be perhaps longer for those components and products which must meet military requirements (including those pertaining to UK, EEA and US equipment).



Over 75% reduction 2009-2019

Figure 6-3: Reductions in chromate dependency over the period 2009 -2019 as reported by one OEM.

The European aerospace and defence industry is heavily regulated to ensure passenger/operator safety. The consequence is that there are very long lead times and testing cycles before technologies developed from a research project can be implemented into real products. Technologies which are available on the market today are the result of extensive research, including research funded by grants and conducted over the last 25 plus years. In 2020, the European A&D industries spent an estimated €18 billion in Research & Development (with an approximate 40:60 split between civil and military activities, and investment in R&D in the US was roughly four times higher)[78].

A PricewaterhouseCoopers (PwC) study[79] 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 wash primers, it requires testing of changes in a process of corrosion protection, which may include changes in pre-treatments, main surface treatments, and post-primer layers.

Aerospace companies cannot apply a less effective corrosion protection process as aviation substantiation procedures demand component performance using alternatives to be equal or better.

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

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

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 all the components used. The number of configurations of components and final products is immense, and each configuration may differ from the next in terms of its behaviour with a Cr(VI)-free alternative.

As noted previously, there is a complex relationship between each component and its performance requirements within its own unique design parameters, which requires component certification for each individual substitution.

6.4.5 Criterion 4: Legislative measures for alternatives

As discussed in detail in Section 3.1.2, the identification of a technically feasible Cr(VI)-free formulation is only the first stage of an extensive multi-phase substitution process, see **Figure 6-4** 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.

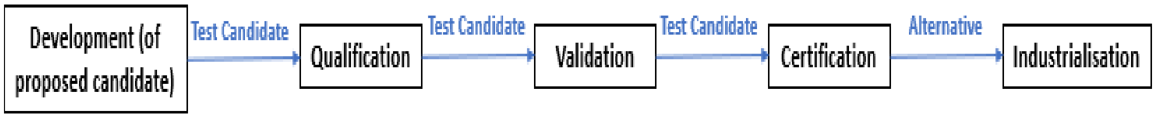

Figure 6-4: Phases of the substitution process

From start to finish, significantly more than 12 years is required to move from Phase 1 to Phase 5 (i.e., to identify, qualify, validate, certify and industrialise alternatives) for all critical A&D applications. The ADCR OEMs and DtBs as design owners are currently working through this process with the aim of implementing Cr(VI)-free wash primers by 2038. Their current test candidate development 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 GB, although there are also international agreements enabling manufacture in partner countries. In contrast to other industry sectors, shifting production to a non-GB territory and import of finished components or products into the GB is more complex, as it could create a dependence on a non-GB 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 priming 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 wash primers 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 GB defence sector requires only small quantities of potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide in wash primers. Based on a defence exemption alone, the quantities demanded would not be sufficient for manufacturers, formulators, and paint applicators to continue to offer their services and products. As a result, application of wash primers on military aircraft and equipment would not continue in GB if other civilian applications were not also possible. This can only be ensured by the granting of an authorisation.

6.4.6 Criterion 5 and 6: Comparison of socio-economic benefits and risks to the environment and effective control of the remaining risks

As demonstrated by the information collected in the SEA questionnaire, A&D companies have invested in monitoring and the installation of additional risk management measures in response to the conditions placed on the continued use of potassium hydroxyoctaoxodizincate dichromate, and pentazinc chromate octahydroxide under the initial (parent) authorisations. This has resulted in both reduced exposures for workers and reduced emissions to the environment. As substitution progresses across components and assemblies and the associated value chains, consumption of potassium hydroxyoctaoxodizincate dichromate, and pentazinc chromate octahydroxide 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[80].

The European and UK 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[81]) 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.

Acknowledged market reports of both 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.[82]

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[80] 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

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

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

Boeing's 2023 Commercial Market Outlook[83] indicates a similar level of increase, noting that the global fleet will increase by around 3.5% through to 2042.

The socio-economic benefits of retaining the key manufacturing base of the 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.

6.5 Substitution effort taken by the applicant if an authorisation is granted

As the AoA shows, where alternatives have been proven as technically feasible – on a component-by-component basis – they have been or are in the process of being implemented. However, there are still some cases where components do not have technically feasible alternatives available. **Figure 6-1** 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 wash primers containing potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide. As illustrated in Section 4, on-going substitution is expected to result in significant decreases in the volumes of the two chromates used in wash primers within the next seven years. However, technically feasible alternatives are still at the development phase (Phase 1 out of the 5 phases) for some components and final products, where alternatives have not been found to meet performance requirements.

6.6 Links to other Authorisation activities under REACH

This combined AoA/SEA is one of a series of applications for the re-authorisation of the use of chromates in primer products carried out by the A&D industry. This series of Review Reports has adopted a narrower definition of uses original Authorised under the CCST and GCCA parent applications for authorisation. Please see the Explanatory Note for further details.

In total, the ADCR consortium will be submitting 4 Review reports covering the following uses and the continued use of strontium chromate, potassium hydroxyoctaoxodizincate dichromate, and pentazinc chromate octahydroxide:

1) Formulation
2) Use of wash primers
3) Use of bonding primers
4) Use of primer products other than wash and bonding primers

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

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8 Annex 1: Standards applicable to wash primers

Table A1-1 lists examples of standards and specifications reported by ADCR members applicable to the use of wash primers. The specifications/standards listed here are test methods and do not define success criteria for alternatives validation.

Table A1-1: Examples of standards applicable to wash primers

Standard Reference	Standard Description	Key function/Standard type
ASTM B117	Standard Practice for Operating Salt Spray (Fog) Apparatus	Corrosion resistance
ASTM 3359	Standard method for measuring adhesion by tape test	Adhesion
EN 3665	Filiform corrosion resistance test on aluminium alloys	Corrosion resistance
ISO 2409	Cross-cut test	Adhesion to subsequent coating or paint
ISO 2808	Determination of film thickness	Layer thickness
ISO 9227	Corrosion tests in artificial atmospheres - Salt spray tests	Corrosion resistance

Source: ADCR members
“Standard description” obtained from https://standards.globalspec.com

9 Annex 2: European Aerospace Cluster Partnerships

Table A2-1: 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 A2-1: 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: Literature search expanded view

Table A3-1: Expanded review of selected scientific publications	
Ref.	**Article Title**
1	Lamprakou et al (2022), "Tannin-based inhibitive pigment for sustainable epoxy coatings formulation" Progress in Organic Coatings, Volume 167, June 2022, 106841 https://doi.org/10.1016/j.porgcoat.2022.106841 Abstract: Calcium tannate was synthesized, characterized, and dispersed into an epoxy coating as an inhibitive pigment. Electrochemical Impedance Spectroscopy (EIS) was employed to monitor the anti-corrosive performance of the coating formulated with the as-prepared pigment after exposure to the salt spray chamber. Reference coatings with the commercial calcium phosphate pigment and unpigmented coating were also evaluated for comparison reasons. EIS results showed that epoxy coating pigmented with calcium tannate has higher coating impedance after 21 days of exposure compared with reference coatings, either unpigmented or calcium phosphate pigmented coatings. XPS analysis was employed for a deeper understanding of the inhibitive action of calcium tannate towards corrosion protection and verified the incorporation of tannate molecules in the protective film formed on the steel substrate under the calcium tannate pigmented coating. **Cr(VI)-Free corrosion inhibitor:** Calcium tannate
2	Indumathi et al (2011), "Cadmium- and chromate-free coating schemes for corrosion protection of 15CDV6 steel" Metal Finishing, Volume 109, Issue 3, April-May 2011, Pages 15-21 https://doi.org/10.1016/S0026-0576(11)00010-9 Abstract: Electrodeposits of cadmium- and chromate-based inorganic inhibitor pigments in paint formulations are extensively used in the aerospace industry to provide long-term corrosion protection for high-strength steel hardware. Due to environmental concerns and worker safety issues, there is a pressing need to identify and adopt alternative eco-friendly coatings with equivalent performance. In this work, an eco-friendly cadmium- and chromate-free coating scheme comprised of zinc nickel alloy plating, trivalent chromium- based passivation, followed by a primer based on polyaniline phosphate, is studied for its anticorrosive properties. Long-term performance evaluation studies of this eco-friendly coating scheme were carried out on 15CDV6 steel, an ultra-high- strength steel used in the aerospace industry. For comparative purposes, two extensively used cadmium- and chromate-based schemes complying to aerospace and military specifications comprised of cadmium plating, hexavalent chromium-based passivation followed by two different chromate-based primers were studied on 15CDV6 steel substrate. Electrochemical impedance spectroscopic studies and salt fog exposure tests were carried out to evaluate the anticorrosive properties of the coating schemes. Cadmium- and chromate-free scheme exhibited excellent performance in the long-term corrosion evaluation studies. The results obtained in accelerated tests show the possibility of replacement of cadmium- and chromate-based schemes for corrosion protection of steels with an eco-friendly option.

Table A3-1: Expanded review of selected scientific publications

Ref.	Article Title
	Cr(VI)-Free corrosion inhibitor: zinc nickel alloy plating, trivalent chromium- based passivation, followed by a primer based on polyaniline phosphate
3	Kamaraj et al (2012), "Electropolymerised polyaniline films as effective replacement of carcinogenic chromate treatments for corrosion protection of aluminium alloys" Synthetic Metals, Volume 162, Issues 5-6, April 2012, Pages 536-542 https://doi.org/10.1016/j.synthmet.2012.01.022 Abstract: Owing to the carcinogenic nature of chromate coatings, alternate coatings with intrinsically conducting polymers such as polyaniline (PANI) and polypyrrole (Ppy) have been developed. Hence a study has been made on the effect of electropolymerised PANI films on corrosion protection performance of epoxy coating on AA 2024 and AA 7075 aluminium alloys. Polyaniline was electropolymerised on both the alloys by galvanostatic method. A post treatment of cecrium was given to seal the pinholes of PANI film. Epoxy coating was applied over these films and their corrosion protection performance was found out by EIS studies in 3% NaCl and salt spray test. EIS studies have shown that the coating resistance (Rc) of PANI with the epoxy coated aluminium alloys has remained above 106 Ω cm2 whereas the alloys coated with epoxy alone have shown the Rc values less than 104 Ω cm2. Besides, the salt spray tests showed a better corrosion protection of PANI with epoxy coated aluminium alloys. **Cr(VI)-Free corrosion inhibitor:** Electrodeposited polyaniline cerium post-treatment
4	Zhang et al (2023), "Study on $CePO_4$ modified PANI/RGO composites to enhance the anti-corrosion property of epoxy resin" Progress in Organic Coatings, Volume 178, May 2023, 107472 https://doi.org/10.1016/j.porgcoat.2023.107472 Abstract: This manuscript presents a modification method by using nanofillers for simultaneously improving the barrier and corrosion inhibition in epoxy coatings. In this method, polyaniline (PANI) nanofibers are first grown on reduced graphene oxide (RGO) using an in situ polymerization reaction, and then cerium phosphate (CePO4) nanograins are directly modified onto polyaniline/reduced graphene oxide (PANI/RGO) composites using a hydrothermal reaction. A new hydrophobic and corrosion-resistant PANI/RGO/CePO4 nanocomposite is successfully prepared. Physical and chemical characterization was performed by Fourier transform infrared spectroscopy (FT-IR), ultraviolet–visible spectroscopy (UV–Vis), X-ray diffractometry (XRD), X-ray photoelectron spectroscopy (XPS), and field emission scanning electron microscopy (SEM). PANI/RGO/CePO4 nanomaterials were compounded into epoxy resin and sprayed on Q235 carbon steel, and their corrosion resistance performance was tested by using AC impedance spectroscopy and salt spray tests. The results show that PANI/RGO/CePO4 nanocomposites improve the barrier properties of epoxy resin. In addition, X-ray photoelectron spectroscopy (XPS) before and after corrosion showed that the cerium ions and phosphate ions released from CePO4 in the composite had a corrosion inhibition effect. It forms cerium oxide and iron phosphate corrosion inhibition films on mild steel and cuts off direct contact between the electrolyte and the substrate. This nanomaterial-loaded epoxy coating can greatly improve the composite's anti-corrosion ability.

Table A3-1: Expanded review of selected scientific publications	
Ref.	**Article Title**
	Cr(VI)-Free corrosion inhibitor: Cerium phosphate modified polianiline/reduced graphene oxide
5	Cao et al (2021), "Bio-based polybenzoxazine superhydrophobic coating with active corrosion resistance for carbon steel protection" Surface and Coatings Technology, Volume 405, 15 January 2021, 126569 https://doi.org/10.1016/j.surfcoat.2020.126569 Abstract: A bio-based benzoxazine, synthesized from cardanol, stearylamine and paraformaldehyde, was utilized to develop a superhydrophobic polybenzoxazine double-layer coating with active protection for carbon steel. This double-layered coating consists of an active anti-corrosive primer and a superhydrophobic topcoat. Halloysite nanocontainers with 2-mercaptobenzimidazole were embedded in the primer to achieve active corrosion resistance. The superhydrophobic topcoat constructed of low-surface-energy polybenzoxazine and amine-modified silica nanoparticles can acquire reinforced passive anticorrosive barrier. The durable double-layer coating could still maintain its superhydrophobicity, even after 60 days of treatment at −20 °C or 100 °C, or 100 cycles of sandpaper abrasion. More importantly, the electrochemical measurement results indicated that the polybenzoxazine superhydrophobic coating maintained outstanding anti-corrosion performance during 90 days immersion in NaCl solution. **Cr(VI)-Free corrosion inhibitor:** Superhydrophobic polybenzoxazine
6	Roselli et al (2013), "Painting rusted steel: The role of aluminum phosphosilicate" Corrosion Science, Volume 74, September 2013, Pages 194-205 https://doi.org/10.1016/j.corsci.2013.04.043 Abstract: Surface preparation is a key factor for the adequate performance of a paint system. The aim of this investigation is to employ a wash-primer to accomplish the chemical conversion of rusted surface when current cleaning operations are difficult to carry out. The active component of the wash-primer was aluminum phosphosilicate whose electrochemical behavior and the composition of the generated protective layer, both, were studied by electrochemical techniques and scanning electron microscopy (SEM), respectively. Primed rusted steel panels were coated with an alkyd system to perform accelerated tests in the salt spray chamber and electrochemical impedance measurements (EIS). These tests were conducted in parallel with a chromate wash primer and the same alkyd system. Results showed that the wash-primer containing aluminum phosphosilicate could be used satisfactorily to paint rusted steel exhibiting a similar performance to the chromate primer. **Cr(VI)-Free corrosion inhibitor:** Aluminium phosphosilicate
7	Li and Buchheit (2017), "Development of zinc ferrocyanide ion exchange compounds for corrosion-inhibiting and sensing pigments" Progress in Organic Coatings, Volume 104, March 2017, Pages 210-216

Table A3-1: Expanded review of selected scientific publications	
Ref.	**Article Title**
	https://doi.org/10.1016/j.porgcoat.2016.11.003 Abstract: The fabrication and application of zinc ferrocyanide ion exchange compounds for use as inhibiting and sensing pigments in protective paints and primers for metals and alloys are described in this paper. A distinctive property of these ferrocyanide pigments is an ability to store corrosion inhibitors and then release them when needed by an ion exchange process. The exchange process is triggered when moisture containing Na+ and K+ ions contacts inhibitor particles embedded in an organic coating. The exchange kinetics were studied by measuring the concentration of released zinc ions in the solution with inductively coupled plasma. The inhibitor storage capacity can be as high as 200 meq/100 g, and it is much higher than that found in other reported ion exchange compounds. Furthermore, structure changes from non-crystalline to crystalline, upon exchange with alkaline ions, can be detected by x-ray diffraction, providing an important indication of activation of the corrosion protection. This is a form of corrosion sensing. The inhibition performance of zinc ferrocyanide in the coating was examined by salt spray tests and electrochemical impedance spectroscopy, and both tests showed that zinc ferrocyanide could provide good protection on aluminum alloy 2024. **Cr(VI)-Free corrosion inhibitor:** Zinc ferrocyanide
8	Shi et al (2017), "Sub-micrometer mesoporous silica containers for active protective coatings on AA 2024-T3" Corrosion Science, October 2017, Pages 230-239 https://doi.org/10.1016/j.corsci.2017.08.030 Abstract: In the present work, the sub-micrometer containers were prepared using mesoporous silica particles (SBA-15) with parallel channels as reservoir and 8-hydroxyquinoline as corrosion inhibitor. Layer-by-layer assembling was used to construct a shell of polyelectrolytes around the silica particles. Release of 8-hydroxyquinoline from sub-micrometer containers was studied in response to acidic or alkaline pH values. The results of electrochemical impedance spectroscopy (EIS) show the improvement of corrosion resistance of epoxy coatings containing sub-micrometer containers. Self-healing ability of the epoxy coatings was provided by sub-micrometer containers, as evidenced by the results of scanning vibrating electrode technique (SVET). **Cr(VI)-Free corrosion inhibitor:** 8-hydroxyquinoline (in mesoporous silica)

11 Annex 4: UK Aerospace sector

11.1 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 2022, as shown in **Figure 10-1**. The Aerospace, Defence, Security and Space Group (ADS) notes that it has over 1,200+ member companies (including over 1,000 SMEs), supporting around 1,000,000 jobs (direct and indirect) across the country.

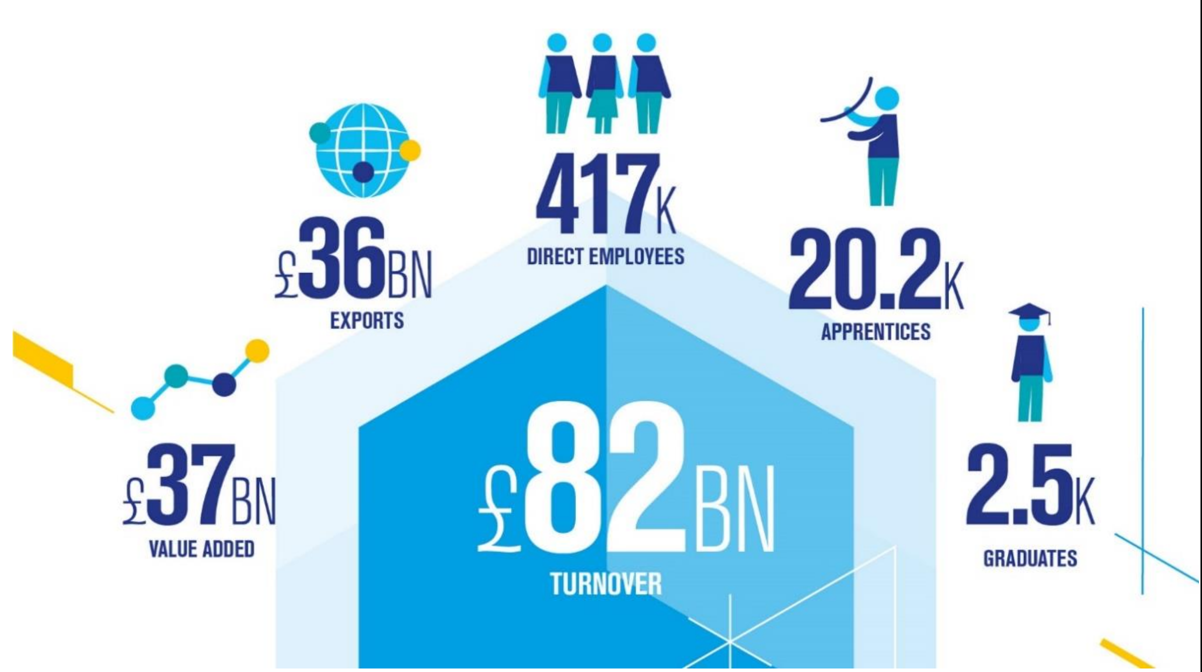

Figure 10-1: Contribution of UK aerospace, defence, security and space sectors to the economy in 2022[84]

The UK aerospace sector is considered by the government to be "hugely important to the UK economy"[85], 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 £82bn, 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)[86]. To date, this co-funded programme has invested £2.6 billion, across all parts of the UK. It is anticipated that the UK aerospace

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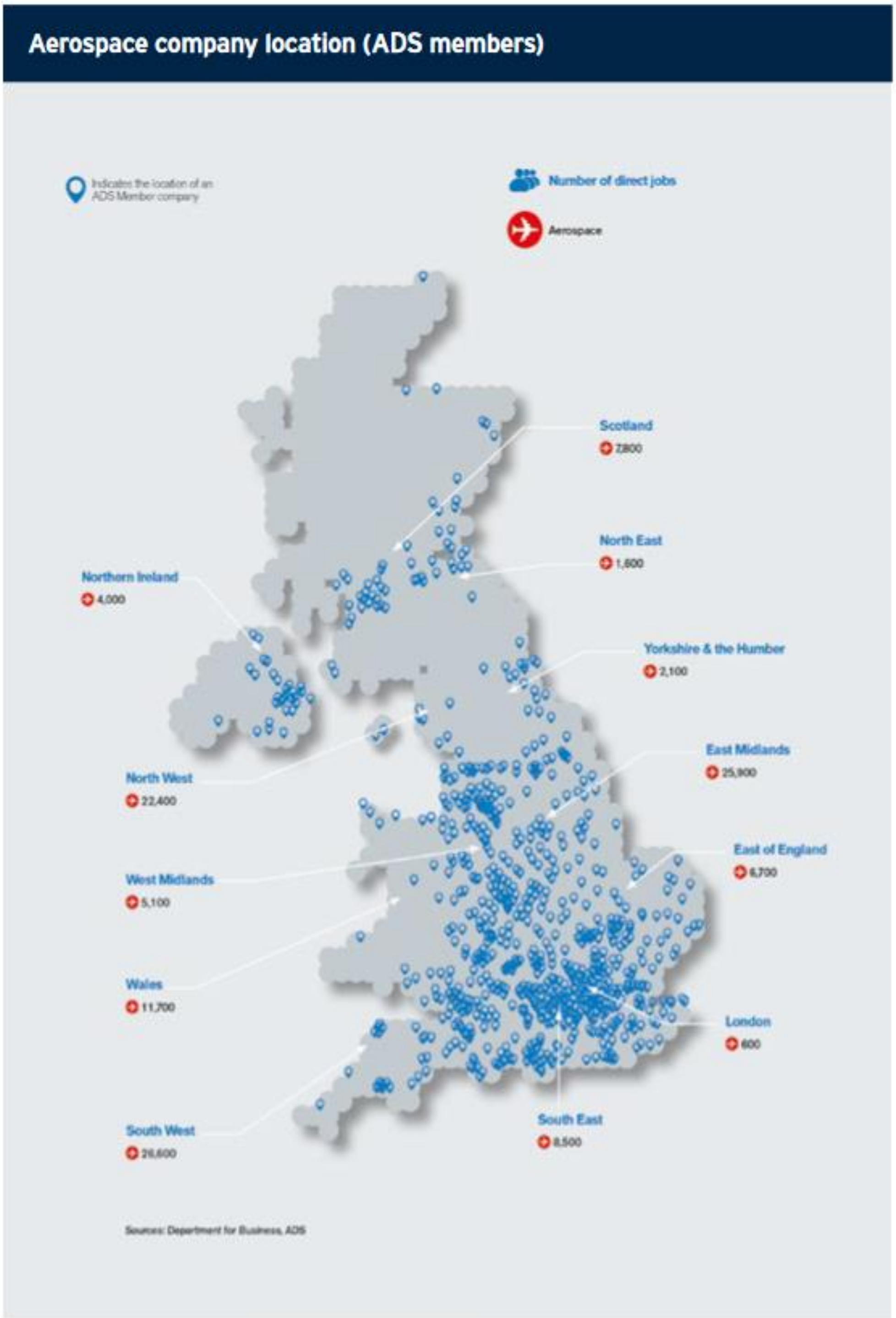
[84] ADS Industry Facts & Figures 2023 - launched! - ADS Group

[85] BEIS, Aerospace Sector Report, undated.

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

sector will continue to grow into the future, due to the global demand for large passenger aircraft, as discussed further below.



Sources: Department for Business, ADS

Figure 10-2: Location of aerospace manufacturing sites and associated jobs in the UK[87]

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

The National Aerospace Technology Exploitation Programme was created in 2017 to provide research and technology (R&T) funding with the aim of improving the competitiveness of the UK aerospace industry, as well as other supporting measures under the Industrial Strategy. The Government's investment in R&T is through the Aerospace Technologies Institute and is programmed at £1.95 billion in expenditure between 2013 and 2026.

This investment will help in maintaining the current expected market development in the UK, which would see a 2.3% per year growth in real terms, leading to direct added value of just over £14 billion in 2035 (compared to £9 billion in 2016). In 2016, the UK aerospace sector employed around 112,500 people, with each direct job in the aerospace industry creating at least one additional job within the aerospace supply chain. This gives around 225,000 people directly and indirectly employed by the aerospace sector in high-value design and high value manufacturing jobs. By maintaining its current direction of growth, the sector is expected to create up to a further 45,000 positions by 2035.

The value of the sectors is also significant in wider economic terms. Investment in aerospace research and technology leads to wider impacts beyond the sector. Every £100 million spent on R&T by the government crowds-in around £300 million of additional private sector investment. Furthermore, every £100 million invested benefits not only UK aerospace GVA by £20 million per year, but also the wider economy by £60 million per year through technology spill overs. These include automotive, marine, oil and gas, nuclear, electronics, composites, metals and other UK industrial sectors. In total, the return on government investment in the sector is estimated as delivering an additional £57 billion of gross value added for the UK aerospace sector and a further £57 billion to the wider UK economy between 2015 and 2035.

11.2 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 11-3**[88]. 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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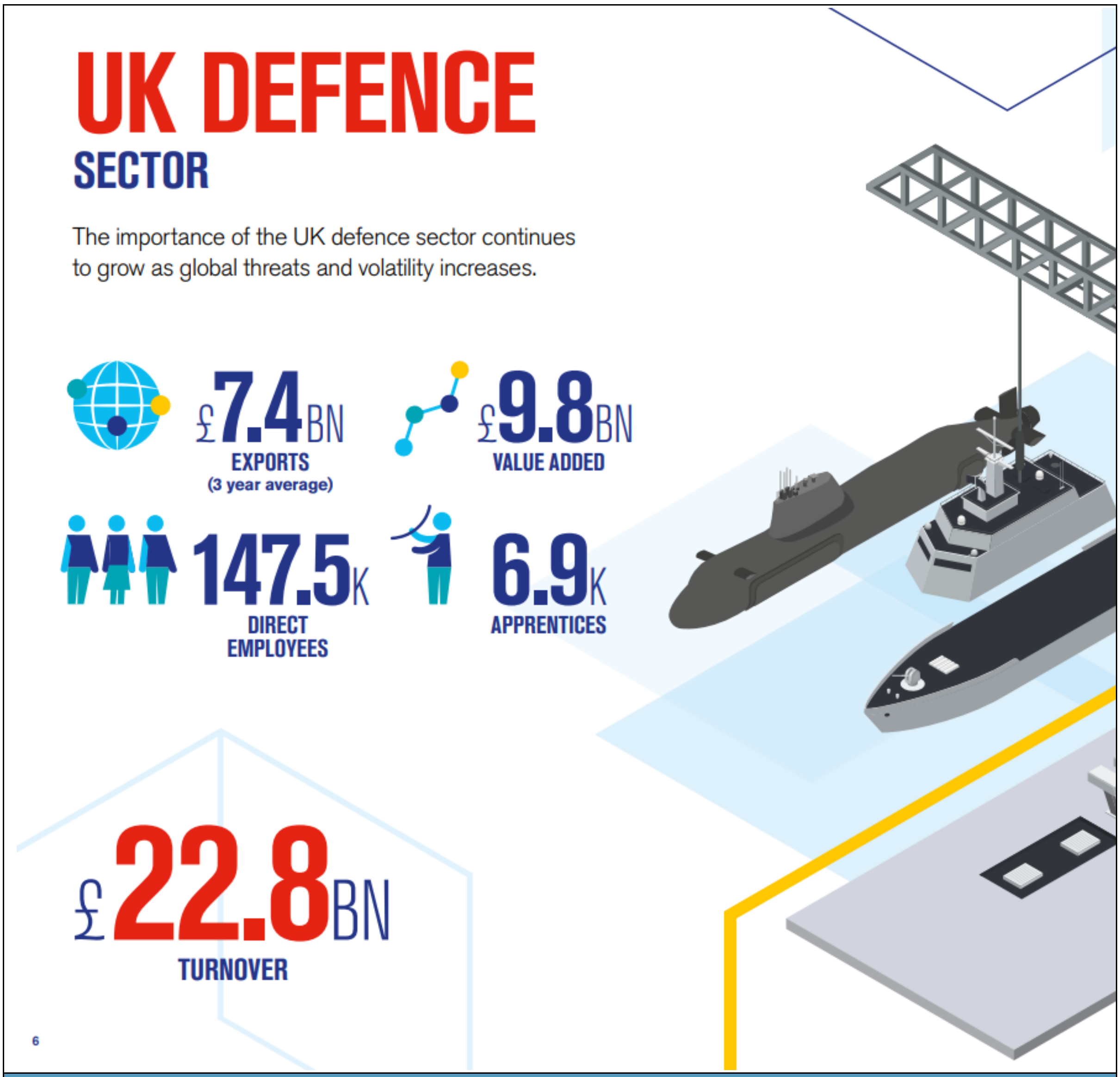
[88] Sources: Industry Facts & Figures 2023 - ADS Group



UK DEFENCE
SECTOR

The importance of the UK defence sector continues to grow as global threats and volatility increases.

£7.4BN
EXPORTS
(3 year average)

£9.8BN
VALUE ADDED

147.5K
DIRECT EMPLOYEES

6.9K
APPRENTICES

£22.8BN
TURNOVER

6

Figure 11-3: UK defence sector contribution to the economy in 2021