ANALYSIS OF ALTERNATIVES

and

SOCIO-ECONOMIC ANALYSIS

Complete version

Legal name of applicant(s):	Akzo Nobel Aerospace Coatings Limited in its legal capacity as only representative for Akzo Nobel Car Refinishes B.V. (StC) Boeing Distribution (UK) Inc. (StC, PCO, PHD) Akzo Nobel Aerospace Coatings Limited in its legal capacity as only representative for Mapaero SAS (StC) Mankiewicz UK LLP in its legal capacity as only representative for Finalin GmbH (StC) Wesco Aircraft EMEA Ltd (PCO, PHD)
Date:	11 July 2024
Substances:	• Strontium Chromate • Potassium hydroxyoctaoxodizincate dichromate • Pentazinc chromate octahydroxide
Use title:	Use of primer products other than wash or bonding primers containing strontium chromate and/or pentazinc chromate octahydroxide and/or 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

BSI – British Standards Institution

BtP – Build-to-Print manufacturer

CAA – Civil Aviation Authority

CAGR – Compound Annual Growth Rate

CCC – Chemical Conversion Coating

CCST – Chromium VI Compounds for Surface Treatment

CF – Carbon Fibre

CFC – Consumption of fixed capital

CMR – Carcinogen, Mutagen or toxic for Reproduction

CRES – Corrosion Resistance Steel

Cr(VI) – Hexavalent chromium

CSR – Chemical Safety Report

CT – Chromium trioxide

CTAC – Chromium Trioxide Authorisation Consortium

DOA – Design Organisational 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

GF – Glass Fibre

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

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

SIC – Standard Industrial Classification

SME – Small and medium-sized enterprises

StC – Strontium chromate

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.
Bond strength	The amount of adhesion between bonded surfaces. It is measured by the stress needed to separate the bonded layers from each other.

Term	Description
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	Fatigue in a corrosive environment. 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. This includes fuel tank coating systems (substrate-fuel tank primer-sealant) to sustain adhesion under cycling mechanical stresses and temperatures while in the presence of fuel.
Embrittlement	The process of becoming degraded, for example loss of ductility and reduction in load-bearing capability, due to exposure to certain environments.
Fatigue	Progressive localised and permanent structural change that occurs in a material subjected to repeated or fluctuating strains at stresses less than the tensile strength of the material. The “permanent structural change” is in the form of microcracks in the crystal structure that can progressively lead to potentially catastrophic macro-cracking and component failure.
Flexibility	The ability to bend easily without breaking or permanently deforming.
Formulation	A mixture of specific substances, in specific concentrations, in a specific form.
Formulator	Company that manufactures formulations (may also design and develop formulations).

Term	Description
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.
Non-nutrients performance	The performance of coating not supporting any microbiological growth in the fuel tank area
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.
Polymer matrix	Organic medium containing corrosion inhibitors, pigments and other fillers
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	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)1841, 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.
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.
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.

Term	Description
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 prior to a primer or topcoat scheme. Where higher corrosion protection is required, 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 primer products other than wash or bonding primers[1] is still required for many components.

Please note, to aid the reader, where contextually appropriate 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 utilisations of this primer use; basic, structural, fuel tank and aluminised.

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 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, including aero derivate use have been searching for alternatives to the three chromates for the ‘use’, primer products other than wash or bonding primers. 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):

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[1] 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.

- Corrosion resistance (including active corrosion resistance); and
- Adhesion promotion

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 protective primers are corrosion inhibiting coatings of liquid consistency which are applied as a thin layer which converts to a solid, adherent and tough film. Corrosion of metal surfaces can be influenced by a broad variety of factors, such as temperature, salinity of the environment, contaminants present in industrial and operating environments. 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 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 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 as they are mandated to continue using the chromate primers if this is specified in Maintenance Manuals provided by the OEMs. This legally obliges them 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 protective primers for the A&D sector. 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 protective primers for the A&D sector.

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

1.3 Socio-economic benefits from continued use

The continued use of the chromates in primers other than bonding and wash 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 the 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 will be able to rely on the use of chromates by their GB suppliers and in their own production activities. The avoided profit losses[2] to these companies under the continued use scenario would equate to between £32 and 3,092 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 £170 to 1,084 million over a 2-year period (PV discounted at 3.5%);

- MRO companies which provide maintenance and repair services to both civil aviation and/or military forces, would be able to continue operating within GB, with the consequent profit losses avoided equating to between £99 to 193 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 primers other than bonding and wash are estimated at £550 million. These benefits are associated with the protection of over 5,000 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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[2] 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 primers other than wash and bonding. 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 130 GB sites where chromate-based protective primers are anticipated as being used, an estimated total of 9360 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 protective priming is considered to take place, an estimated 1.1 million people in GB are calculated as potentially being exposed to Cr(VI) due to chromate-based protective primer activities. Again, these figures are conservative due to the on-going substitution of protective 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[3]:

- 16.39 fatal cancers cases and 9.33 non-fatal cancer cases, at a cost of £30 to £42 million over the 12 year review period (discounted at 3.5%), and £4.4 to £6.2 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:

- 17 to 1 for the lower bound of profit losses and unemployment costs or 96 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 strontium chromate (StC), pentazinc chromate octahydroxide (PCO) and potassium hydroxyoctaoxodizincatedichromate (PHD) in protective 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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[3] 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[4,5]. 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 the use Primer products other than wash or bonding 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 have to be met to ensure airworthiness and safety**. These requirements mandate the need for testing, qualification, and certification of components using the alternative for the use Primer products other than wash or bonding 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 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 the chromates for the use Primer products other than wash or bonding primers, which can be considered to be "generally available" following the European

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[4] https://www.europarl.europa.eu/RegData/etudes/STUD/2022/699651/IPOL_STU(2022)699651_EN.pdf

[5] https://www.easa.europa.eu/en/downloads/17236/en

Commission's definition[6]. The A&D industry has been undertaking R&D into alternatives for the past 30 years. This includes participation in research initiatives partially funded by the European Commission and national governments. Considerable technical progress has been made in developing, validating, qualifying and certifying components for the use of alternatives. However, it is not technically nor economically feasible for the sector as a whole to have achieved full substitution within 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 protective 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 the chromates for the use Primer products other than wash or bonding 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 the chromates is required to ensure the operational capabilities of the military and the ability to comply with international obligations as partner nations at the 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, **the socio-economic benefits from the continued use of strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and pentazinc chromate octahydroxide in primer products other than wash or bonding 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 primer products other than wash or bonding 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. GB A&D sector must ensure not only that it meets regulatory requirements in GB, but also that it meets

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[6] As defined with respect to the "legal and factual requirements of placing on the market" in the EC note of 27 May, 2020, available at: https://echa.europa.eu/documents/10162/13637/ec_note_suitable_alternative_in_general.pdf/5d0f551b-92b5-3157-8fdf-f2507cf071c1

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 for the use ‘primer products other than wash or bonding primers’ by the ADCR consortium members and companies in their supply chain. Primer products other than wash or bonding primers is a term used in this dossier to cover all those primers and speciality coatings currently used under Authorisation decisions C(2020)2076, C(2020)2089, C(2020)6231, and C(2020)1841. Bonding primers and wash primers are outside the scope of this review report[7]. In the parent applications for authorisation, the primer products within scope of this review report were variously described as: basic primers, structural primers, fuel tank primers, and aluminised primers. All primer products other than wash or bonding primers provide corrosion resistance/active corrosion inhibition and promote adhesion to subsequent layers. Additionally, they exhibit compatibility with a broad range of substrates, due to the inclusion of strontium chromate, potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide.

Although bonding primers and wash primers are outside the scope of this review report, the interrelationship between different primers types, pre-treatments and subsequent coatings strongly influences the performance of individual primers, and in turn the performance of any Cr(VI)-free alternative. The multi-faceted treatment system, also described in the other ADCR dossiers, is essential to the successful delivery of the respective primer functions described in this review report. Other primer uses; wash and/or bonding can be intentionally used together, or unintentionally come into contact with this primer use as a consequence of the production process. Therefore, it is essential that due regard is made for different elements of the treatment system coming into contact with one another, and that compatibility is ensured where this is the case.

The use of the chromates in primer products other than wash or bonding 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, particularly those relating to airworthiness set by the 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

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[7] These two primer types are the subject of other review reports submitted by existing authorisation holders on behalf of the ADCR consortium.

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 using all primer types, with data for 38 of those sites using protective primers that are anticipated to undertake use of primer products other than wash or bonding 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 strontium chromate, potassium hydroxyoctaoxodizincatedichromate and/or pentazinc chromate octahydroxide in primer products other than wash or bonding primers 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 strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and pentazinc chromate octahydroxide in primer products other than wash or bonding 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 strontium chromate, potassium hydroxyoctaoxodizincatedichromate and pentazinc chromate octahydroxide, which does not compromise the functionality and reliability of the components to which primer products other than wash or bonding 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 strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and pentazinc chromate octahydroxide in primer products other than wash or bonding primers. These research efforts include UK 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 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:

• Strontium chromate	EC 232-142-6	CAS 7789-06-2
• Potassium hydroxyoctaoxodizincatedichromate	EC 234-329-8	CAS 11103-86-9
• Pentazinc chromate octahydroxide	EC 256-418-0	CAS 49663-84-5

Strontium chromate (StC; Entry No. 29), 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 three chromates were previously granted authorisations for use in primer products other than wash or bonding primers across a range of applicants. **Table 2-1** summarises the parent AfA:

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

Application ID	Substance	CAS #	EC #	Applicants	Use name
0117-01 33UKREACH/20/12/0 34UKREACH/20/12/2	Strontium chromate	7789-06-2	232-142-6	Various applicants (GCCA consortium)	Use of strontium chromate in primers applied by aerospace and defence companies and their associated supply chains
0046-02 30UKREACH/20/7/13 31UKREACH/20/7/17	Strontium chromate	7789-06-2	232-142-6	Various applicants (CCST consortium)	Application of paints, primers and specialty coatings containing Strontium Chromate in the construction of aerospace and aeronautical parts, including aeroplanes / helicopters, spacecraft, satellites, launchers, engines, and for the maintenance of such constructions.
0047-02 27UKREACH/20/6/5	Potassium hydroxy-octaoxodi-zincate-dichromate	11103-86-9	234-329-8	PPG Industries (UK) Ltd (CCST consortium)	Use of potassium hydroxyoctaoxodizincate-dichromate in paints, in primer, sealants, and coatings (including as wash primers)

2.3 Scope of the analysis

2.3.1 Brief overview of uses

2.3.1.1 Process description

Cr(VI)-based primer products other than wash or bonding primers are corrosion inhibiting coatings which are applied as a thin layer which converts to a solid, adherent and tough film (CCST, 2015a). These coatings are generally provided to the downstream user as multi-part kits. The first part of the kit is the base, composed of an epoxy, alkyd or polyurethane resin, in which the chromate its dispersed and held in suspension. The second part is a catalyst, which controls the rate of cross-linking of the base, and the third part is a thinner, controlling the viscosity of the dispersion. The thinner may be an organic solvent, water, or a combination of both (CCST, 2015a).

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 or biological growth (CCST, 2017). Although the main function of Cr(VI)-based primer products other than wash or bonding primers is corrosion protection and active corrosion inhibition, they may provide additional protection from the environment, functional fluid resistance, and adhesion properties. They must provide adhesion to both the substrate(s), and any previous (e.g. wash or bonding primers) or subsequent layers (e.g. coatings or sealants) (GCCA, 2017b).

Many primer products other than wash or bonding primers are referred to as ‘basic primers’ and are selected for their universal applicability to many substrates, compatibility with many subsequent coatings, and ability to provide corrosion protection to both interior and exterior surfaces (CCST, 2015b). However other primer products other than wash or bonding primers will be more specialised and have additional performance criteria which makes them suitable for specific applications. The four primer types defined in the parent AfA and collectively covered by the term ‘protective primer’ in this dossier are described below:

- Basic primers (also referred to as paint primers) are applied as a base layer of a paint or coating system. Their main purpose is corrosion protection although they must simultaneously provide good adhesion between the metal surface and further coating layers.

- Structural primers (also known as commercial exterior aerodynamic structure primers) are used on aerodynamic components and structures that protrude from the fuselage. They provide extended corrosion protection and enhanced adhesion, and are able, for example, to withstand erosion from impingement of rain at the leading edges of an aircraft (CCST, 2015a).

- Fuel tank primers provide not only corrosion resistance but also electrostatic control and must not support microbial growth. They also ensure the adhesion of sealants (CCST, 2015a). The fuel tank cells and fuel tank components to which these primer products other than wash or bonding primers are applied are exposed to extreme environmental conditions which include cold temperatures, dynamic loading, and the presence of water, fuel and microbes (CCST, 2017).

- Aluminised primers (also known as metallised epoxy coatings) are applied to various areas of an aircraft including seat tracks, cargo floor fittings and cargo handling equipment. They provide corrosion protection, via the inclusion of chromate, in an environment that is routinely exposed to moisture and fluids originating from the passenger and cargo department. They are often applied in these areas, to provide an aluminium appearance (where the appearance requirement is met by the presence of aluminium particles in the primer formulation, and not the chromate). Additionally, aluminised primers may be applied to the engine inlet and thrust reverser flow surfaces providing UV protection and temperature resistance (CCST, 2017).

All the above-mentioned protective primers are used during the manufacturing of A&D components and final products but also during MRO activities. Spraying, using hand-held or automated spraying guns, is the most common and cost-effective technique to cover large surfaces with a uniform layer of primer products other than wash or bonding primers. Spray guns with an integral paint container may be used for small areas, however brushing rolling or pen sticks may also be used for small repair work or on surfaces which are not suitable for the spraying process (CCST, 2015b).

After application, protective primers are cured at room temperature, in an oven, or using another heat source. The sensitivity to temperature and relative humidity is dependent on the formulation and will determine the curing method used (CCST, 2017). Whilst basic primers are commonly cured at both room temperature and at elevated temperatures, components primed with fuel tank or aluminised primers are routinely heated to accelerate the cure of the coating (CCST, 2017).

Protective primers are applied onto components made of a wide range of substrates, such as aluminium and its alloys, titanium, steel (Corrosion Resistance Steel (CRES), stainless steel), nickel, magnesium (CCST, 2017), plated coatings and composites (GCCA, 2017b). The A&D sector primarily uses Cr(VI)-based protective primers with lightweight metals and alloys such as aluminium and magnesium (CCST, 2015a).

For reference, substrates identified by the ADCR members as relevant to primer products other than wash or bonding primers are:

Basic primers:

- Aluminium and its alloys (including Metallic Matrix Composites MMC);
- Composites (carbon fibre (CF)/glass fibre (GF));
- Copper and its alloys;
- Magnesium and its alloys;
- Nickel and its alloys (including Nickel Cobalt);
- Steel and its alloys (including plated steel and stainless steels);
- Titanium and its alloys;
- Tungsten alloys; and
- Tedlar Foils.

Structural primers:

- Aluminium and its alloys;
- Bronze;
- Composites (CF/GF);
- Copper alloys;

- Magnesium alloys;
- Steel and its alloys (including plated steel); and
- Titanium and its alloys.

Fuel tank primers:

- Aluminium and its alloys;
- Composites (CF/GF);
- Copper and its alloys;
- Nickel alloys;
- Stainless steel; and
- Titanium and its alloys.

Aluminised primers:

- Aluminium and its alloys; and
- Composites (CF/GF).

As indicated above, substrates may be plated. For example, cadmium or zinc may be used to plate a substrate.

2.3.1.2 Choice of chromate

Strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and pentazinc chromate octahydroxide are all selected for use as corrosion-inhibitors in primer products other than wash or bonding primers because they are extremely effective at low concentrations, and their low solubility enables them to release corrosion inhibitors over a long period of time to protect adjoining material. Although all three of these chromates are selected for use in primer products other than wash or bonding primers due to their low solubility, the solubility of pentazinc chromate octahydroxide is considerably lower than the other two chromates.

2.3.1.3 Relationship to other ADCR applied for chromate uses

Surface treatment of metals is a systematic process composed of various treatment steps, and only the combination of these steps will lead to a well-prepared surface. Although single process steps can be assessed individually, they are not standalone processes and the entire coating system must be considered (GCCA, 2017a).

Prior to application of the primer types within this use, the substrate may undergo a surface treatment, such as anodising or chemical conversion coating, to support successful adhesion of the primer and enhance corrosion resistance. As described in Section 3.4.4, Identification of alternatives, the performance of the treatment system as a whole is dependent upon the compatibility of the primer step with the preceding surface treatments such as anodising and conversion coating. For areas where enhanced erosion resistance is also required (such as structures which protrude from the fuselage), electroplating techniques, such as cadmium and functional chrome plating, may be used before the protective primer is applied. Where chemical surface treatments cannot be performed, adhesion will be improved via a mechanical treatment such as sanding or grit/abrasive blasting. In addition to, or more often in place of, the surface treatment, a wash primer may also be applied prior to application of the protective primer product.

The treatment undertaken prior to application of a protective primer will be dependent upon the substrate as well as size, shape and location of the component. In re-work/repair it is particularly common for a wash primer to be used prior to application of the protective primer, as this is significantly easier than, for example, repeating the anodising process. Only a limited number of protective primers can be applied 'direct to metal' with no prior treatment – the use of such primers is again more common in MRO. On occasion, a primer product other than wash or bonding primers may also be applied on top of a bonding primer.

The protective primer may be applied without a topcoat, such as in fuel cells or, for dry interior structural applications where the primer provides sufficient chemical resistance on its own and will not be exposed to the external environment. However the final layer of the system will most commonly be a polyurethane or epoxy-based paint. This topcoat layer provides additional chemical resistance, mechanical resistance and a barrier function (particularly required in the presence of electrolytes which may increase the risk of corrosion). In the case of fuel cells and fuel tank components, some primed areas (such as junction areas, joints and other crevices in the integral fuel tank structure) will be overcoated with a silicone or polysulphide-based sealant.

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

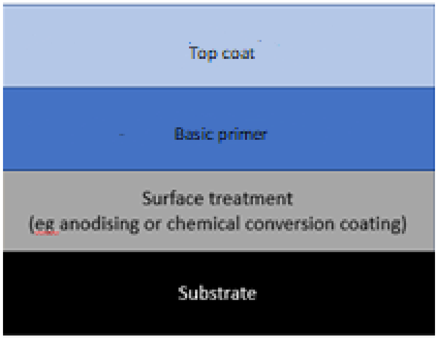

Figure 2-1: Coating system valid for basic primer
Adapted from (CCST, 2017)

2.3.2 Temporal scope

Because of the lack of viable and qualified alternatives for the use of strontium chromate, potassium hydroxyoctaoxodizincatedichromate and pentazinc chromate octahydroxide in primer products other than wash or bonding 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 consortium 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.

As can be seen from **Table 2-3**, almost all of the larger ADCR members (21 of 24) support the use of chromates in primer products other than wash or bonding 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 primer products other than wash or bonding primers to ensure it is available to their suppliers as well as for their own use. The most supported substance by members is strontium chromate (21 members) followed by potassium hydroxyoctaoxodizincatedichromate (11 members).

Table 2-3: Number of ADCR members supporting each substance for use in primer products other than wash or bonding primers for their own activities or for their supply chain

	strontium chromate	potassium hydroxyoctaoxodizincate dichromate	pentazinc chromate octahydroxide
No. of members	15	6	5

2.3.3.2 Downstream users of primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincate dichromate, or pentazinc chromate octahydroxide

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[8] (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[9]. 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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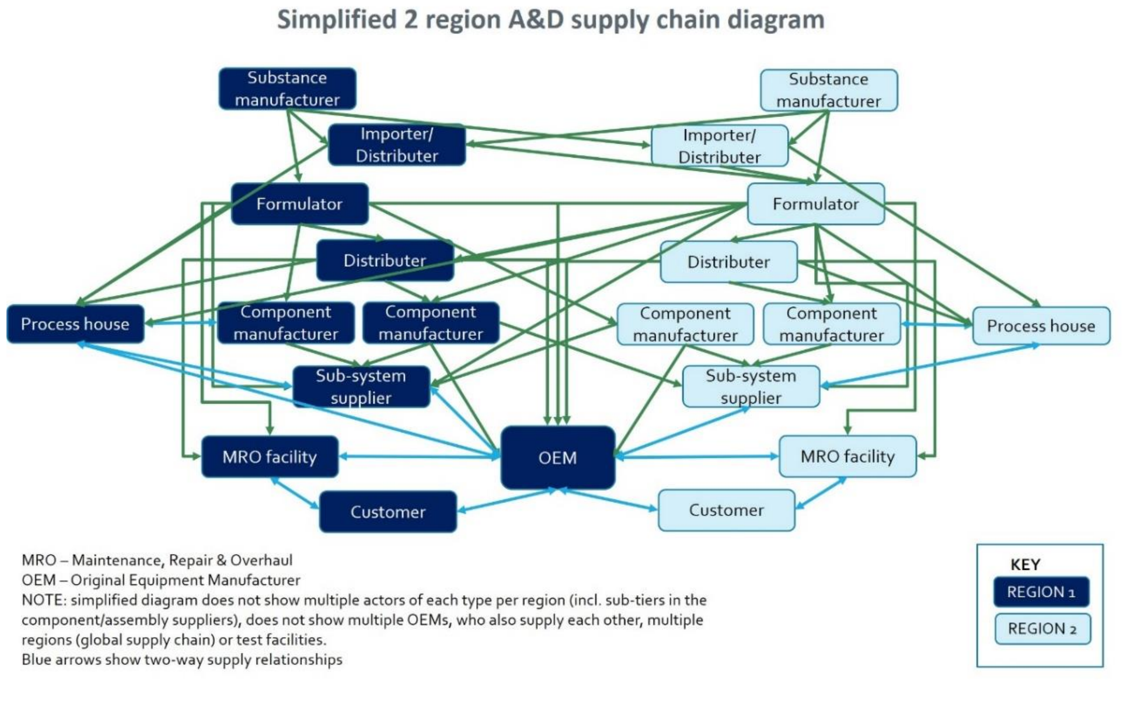
[8] Also referred to as "design and make" or "design responsible" suppliers

[9] 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 primer products other than wash or bonding 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 contributing to the dossier for primer products other than wash or bonding primers.

Table 2-4: Numbers of companies providing SEA information on primer products other than wash or bonding primers

Role	Number of companies
OEMs	5
Design-to-Build	7
Build-to-Print	11
MRO mainly (civilian and/or military)	2
Total	**25**

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 primer products other than wash or bonding primers themselves, as part of their own manufacturing activities, the primers are also used by a range of companies within the supply chain. The OEMs operate at the global level, and therefore may have facilities 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 and defence systems, service lives typically comprise 30-40 years. MRO shops (including those servicing MoDs) carry out the maintenance, repair, and overhaul activities involved in ensuring that A&D final products continue to meet airworthiness and safety requirements. This includes use of Cr(VI)-based primer products other than wash or bonding 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.

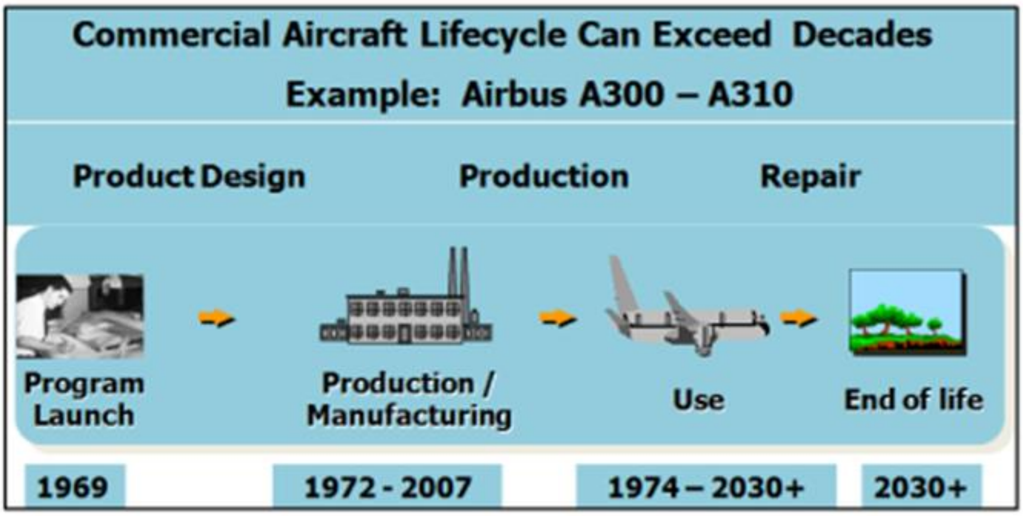


Figure 2-3: Commercial Aircraft Service Life, from ECHA & EASA (2014)[10]

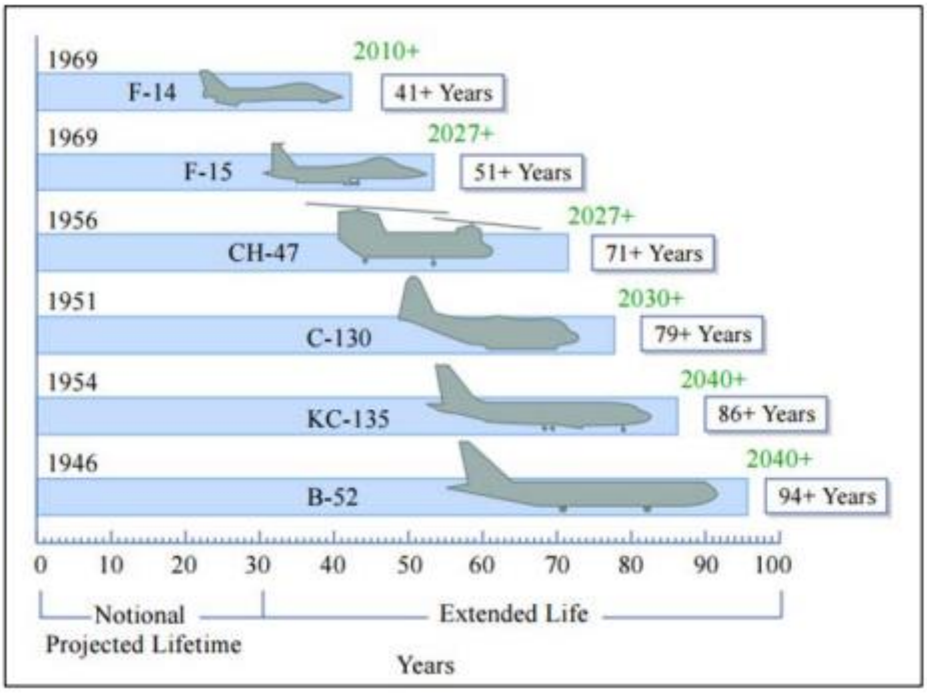


Figure 2-4: Life cycles of defence aircraft, from A Haggerty (2004)[11]

Even if new designs/components – coming onto the market in the short to medium term – might succeed in dispensing with the need for use of primer products other than wash or bonding 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

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

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

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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincate dichromate 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 primers other than bonding or wash has been taken to be 130.

2.3.3.6 Customers

The final actors within this supply chain are the customers of A&D final products to which primer products other than wash or bonding 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[12]. 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[13]. These benefits cannot be realised without the ability to undertake regular maintenance works and to repair and maintain aircraft as needed with replacement components manufactured in line with airworthiness approvals.

In 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,[14] part of this expenditure is related to military aviation, with an uncertain but significant proportion also spent on non-aviation defence products that rely on the use of protective primers.

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

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

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

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 primer products other than wash or bonding 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. 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 35 sites operated by the ADCR OEMs and their DtB and BtP suppliers using primers other than wash or bonding 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

Although there have been successes and levels of use have decreased significantly, the specific use of hexavalent chromium compounds in protective primer is still required for many components. As described in Section 1.1 the term "primer products other than wash or bonding primers is condensed to "protective primer" in this report. This is a collective term used to describe those primers and speciality coatings currently used under Authorisation decisions C(2020)2076, C(2020)2089, C(2020)6231, and C(2020)1841, excepting bonding primers and wash primers[15]. In the parent applications for authorisation, the primer products within scope of this combined AoA/SEA were variously described as: basic primers, structural primers, fuel tank primers, and aluminised primers.

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

• Strontium chromate	EC 232-142-6	CAS 7789-06-2
• Potassium hydroxyoctaoxodizincatedichromate	EC 234-329-8	CAS 11103-86-9
• Pentazinc chromate octahydroxide	EC 256-418-0	CAS 49663-84-5

3.1.1.1 Process steps and overview of key functions

Cr(VI)-based protective primers are corrosion inhibiting coatings of which are applied as a thin layer which converts to a solid, adherent and tough film (CCST, 2015a). These coatings are generally provided to the downstream user as multi-part kits. The first part of the kit is the base, composed of an epoxy, alkyd or polyurethane resin, in which the chromate its dispersed and held in suspension. The second part is a catalyst, which controls the rate of curing of the base, and the third part is a thinner, controlling the viscosity of the dispersion. The thinner may be an organic solvent, water, or a combination of both (CCST, 2015a)

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 or potential for biological (microbial) growth (CCST, 2017). Although the main function of Cr(VI)-based protective primers is corrosion resistance and active corrosion inhibition, they may provide additional protection from the environment; functional fluid resistance, and adhesion properties. They must provide adhesion to both the substrate(s), and any previous (e.g. wash or bonding primers) or subsequent layers (e.g. topcoats or sealants) (GCCA, 2017b).

Protective primers are used in the manufacture of A&D components, final products and in MRO activities. Spraying, using hand-held or automated spray guns, is the most common and cost-effective technique to cover large surfaces with a uniform layer of protective primer, however dipping or immersion of the component in a tank filled with the primer may also occur in large facilities or repair stations (CCST, 2015b). Spray guns with an integral paint container may be used

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[15] These two primer types are the subject of other review reports submitted by existing authorisation holders on behalf of the ADCR consortium.

for small areas, however brushing rolling or pen sticks may also be used for small repair work or on surfaces which are not suitable for the spraying process (CCST, 2015b).

After application the protective primer is cured at room temperature, in an oven, or using another heat source. The sensitivity to temperature and relative humidity is dependent on the formulation and will determine the curing method used (CCST, 2015b). Whilst basic primers are commonly cured at both room temperature and at elevated temperatures, components primed with fuel tank or aluminised primers are routinely heated to accelerate the cure of the coating (CCST, 2017).

Although a number of key functions are attributed to protective primers in the parent AfA, the key functions of the SVHC (strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and pentazinc chromate octahydroxide) in protective primers (supported by the information on mode of action provided in the parent AfA and through member consultation) are:

- Corrosion resistance (including active corrosion inhibition); and
- Adhesion promotion

Corrosion resistance

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) arising from the dissolution of primer pigment particles when in sufficient concentration, retained in the passivation layer. Should the oxide layer be damaged locally to reveal bare metal then, after the initial formation of a thin metal oxide layer, this residual 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** and **Figure 3-2** below.

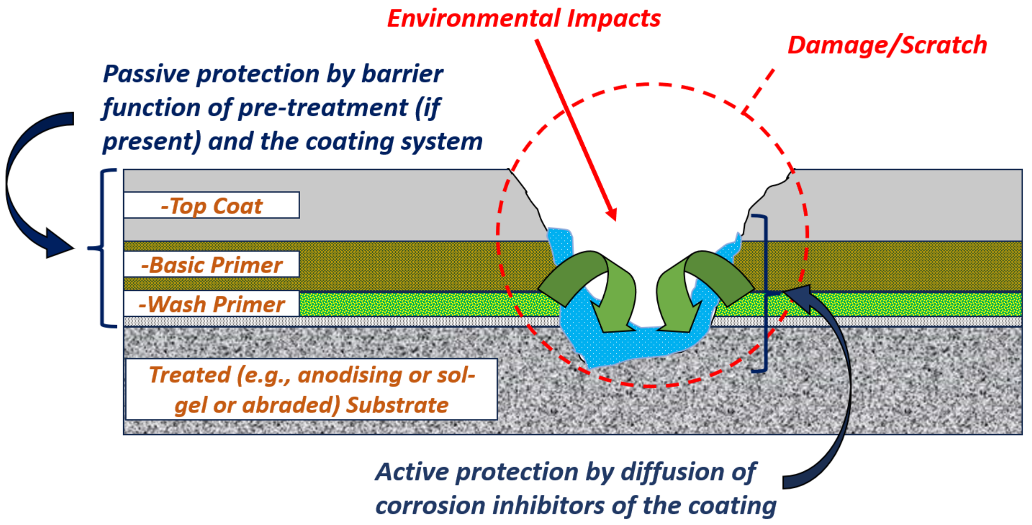

Figure 3-1: Basic functions of an example of a surface protection system (Adapted from CCST, 2015b)

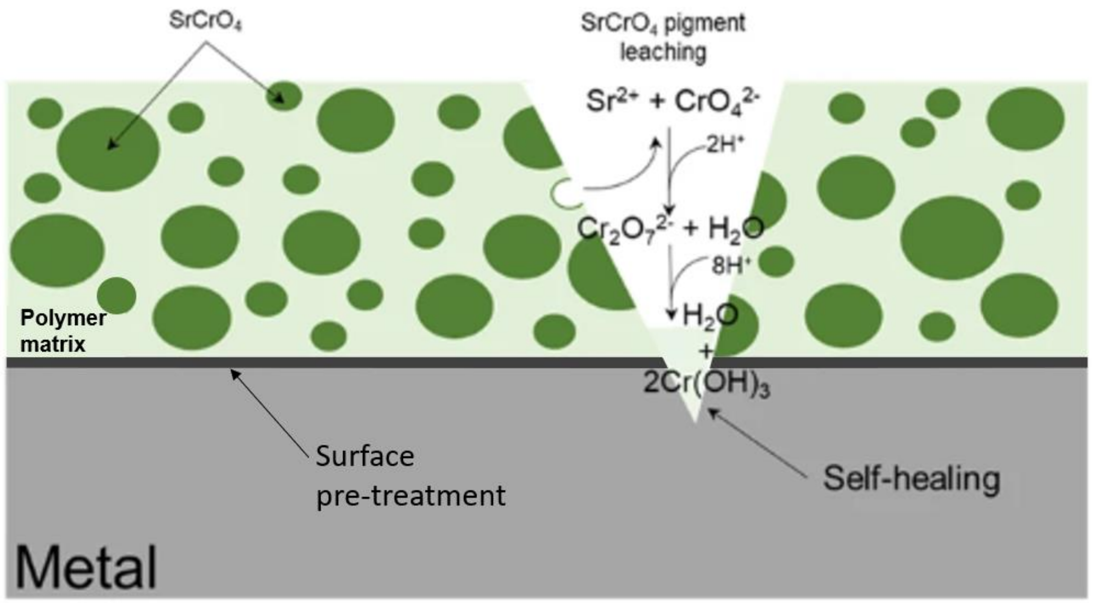

Figure 3-2: $SrCrO_4$ leaching mechanism and self-healing illustration
Source: ADCR member

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 chemical 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, Guo and Jiang, 2016).

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 from adjoining primer pigment particles provides a mechanism for Cr(VI) ions from 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 3-3** below:

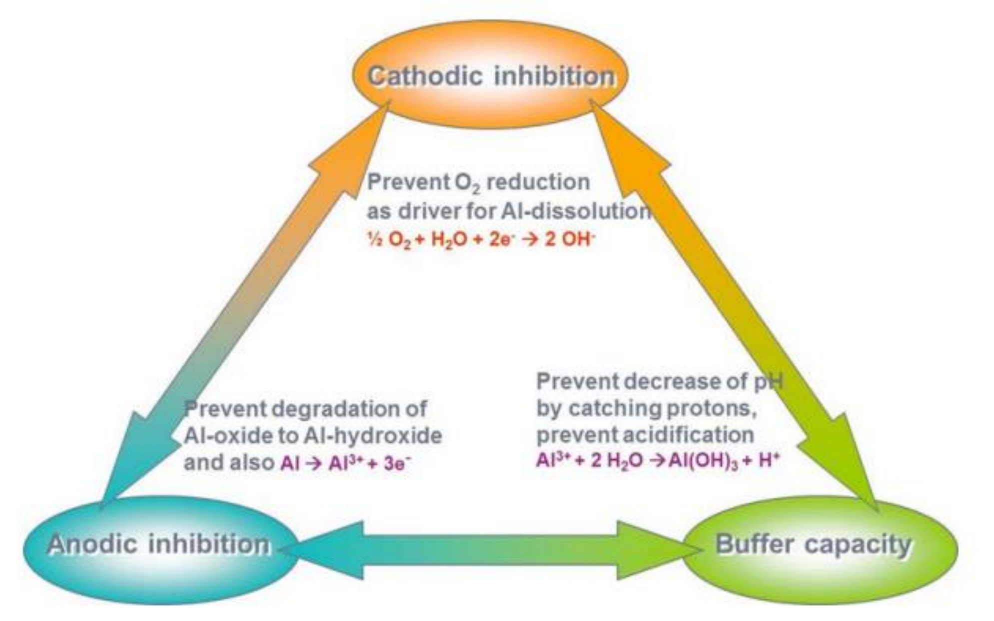

Figure 3-3: Key Cr(VI) functionalities illustrated with aluminium substrate (CCST, 2015a)

Adhesion promotion

The presence of Cr(VI) substances in the primer layer allows for a suitable concentration of Cr(VI) close to the primer-substrate interface, which in turn stabilises the aluminium oxide or aluminium chromium oxide-hydroxide layer which is essential to maintaining adhesion between the substrate and subsequent coatings.

As described in the 'corrosion resistance' section above, the interior of the 'active' layer is composed of Cr(III) oxy-hydroxide, which forms a chemical bond. The bonding of Cr-OH groups in the presence of oxygen also plays an important role in the adhesion, whilst the chromates also stabilise the aluminium oxide layer enabling long term adhesion promotion.

3.1.1.2 Usage

Components that may be treated with the Annex XIV substance

As detailed above, primer products other than wash or bonding 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. Components may be located throughout an assembly or final A&D product. By way of example, **Table 3-1** is divided into four categories to illustrate the diversity of applications where chromates are used. This is by no way an exhaustive list; however, it does help to demonstrate to some extent the diverse applications of chromates in the A&D sector.

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, 2017b)

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, 2015a):

- 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 3-4**) and can occur either in the presence of impurities in the grain boundaries or to the local enrichment of one of the elements;
- Galvanic corrosion can occur at locations where there is contact between dissimilar conductive materials;
- Filiform; localised corrosion under painted surfaces including beneath organic coatings, where the actively-corroding head of the filament is sustained by acidification resulting from oxygen deprivation;
- 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;
- Fretting corrosion occurs when overlapping metallic joints are subject to repeated or cyclic relative movement; and
- Pitting corrosion; found in areas such as forgings, landing gear, structural and engine components and fuel systems (Civil Aviation Authority, 2017)

The corrosion types, crevice corrosion and filiform corrosion, are caused by the “oxygen cell” effect created by occluded geometries that produce differential aeration. This leads to acidification and increased corrosion rates in air-deprived regions. Crevice corrosion can occur in overlapped or butted regions between pieces of the same material. Bond-line corrosion is an example of crevice corrosion between similar materials. Filiform corrosion is a special case of surface corrosion occurring beneath organic coatings, where the actively-corroding head of the filament is sustained by acidification resulting from oxygen deprivation.

Intergranular corrosion (IGC) commonly results from a lack of uniformity in the alloy structure. This could be caused by alloy composition and various processing conditions (heating, cooling, deformation, etc. during the manufacturing process. Due to non-uniformity/segregation of alloying elements at grain boundaries, these areas become more reactive compared to the matrix. IGC is especially detrimental in high stress areas like fuselage, wing fold areas, rotary components of engine, etc. Presence of impurities in the grain boundaries, local enrichment or depletion of one of the elements, can be contributing factors.

Fretting can be present in various parts of an aircraft structure (e.g. engines, aircraft primary and secondary structure, and landing gear components) in which small amplitude cyclic slip between adjacent contacting materials is possible. Rivets and mechanically fastened joints can be particularly susceptible to fretting and fretting fatigue multiple-site damage (Charles B Elliott, Moesser and Hoeppner, 1994).

Pitting corrosion is a type of localized corrosion that is initiated by breakdown of passive film. Intermetallics, inclusions, second phase particles or grain boundaries are common pit initiation sites. As the pits are localized and the initiation stochastic, it is hard to predict the local chemistry changes that may lead to formation of pits. As such, most applications of aluminium alloys in corrosive conditions (in presence of anions like chlorides) could potentially lead to pitting corrosion due to formation of local corrosion cells.

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 where moisture can become entrapped (like a joint) is also highly susceptible to corrosion.

Examples of corrosion types are illustrated in the images below.

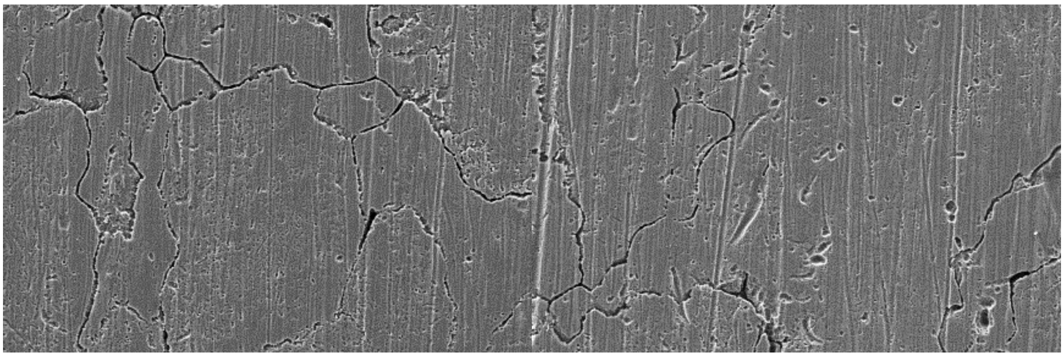

Figure 3-4: Early stage of dissolution of intergranular zinc precipitations in high strength aluminium-zinc alloy AA7050
Source: ADCR member

Figure 3-5: Galvanic corrosion of aluminium alloy fitting
(Civil Aviation Authority, 2017)

Figure 3-6: Filiform corrosion
(Civil Aviation Authority, 2017)

Figure 3-7: Exfoliation corrosion
(Civil Aviation Authority, 2017)

Figure 3-8: Pitting corrosion on vintage aircraft crankshaft
(Civil Aviation Authority, 2017)

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, 2017a). 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, 2017a).

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

3.1.2.1 Introduction

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

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

- High utilisation rate (around 16 hours per day for commercial aircraft, whilst critical defence systems must operate continuously for extended periods);
- Environmental and service temperatures ranging from below minus 55°C at cruising altitude to in excess of plus 200°C (Depending on substrate and location on final product);
- Wide ranging and varying humidity and pressure;
- High and varying loads;
- Fatigue resistance under varying modes of stress;
- 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[17] in the EAA. Similar airworthiness requirements exist in all countries where aeronautical products are sold. These regulations require a systematic and rigorous framework to be in place to qualify all materials and processes to meet stringent safety requirements that are subject to independent certification and approval through the 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.

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

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

Identification and implementation of feasible, suitable, and available alternatives in the A&D industry is a time consuming and complex process that can involve multiple stages of performance testing in laboratory trials, manufacturing trials and during inflight/in operation testing. Once a proposed candidate is identified, it must be shown that implementing it will maintain the stringent safety requirements that govern the sector. Not only this but, due to the potential implications of inadequate corrosion 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 3-9**).

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.

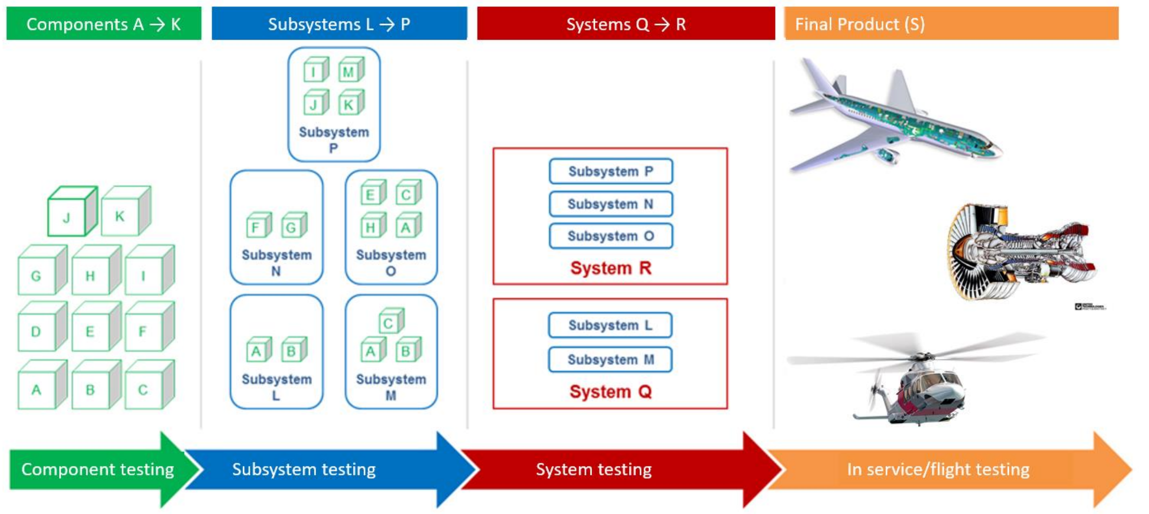

Figure 3-9: Assessment requirements in the implementation of alternatives
Source: Adapted from GCCA white paper

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

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

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

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

TRL	Definition	Description
	demonstration in a relevant environment	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 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

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

MRL	Definition	Description
		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 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 3-10**, 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.

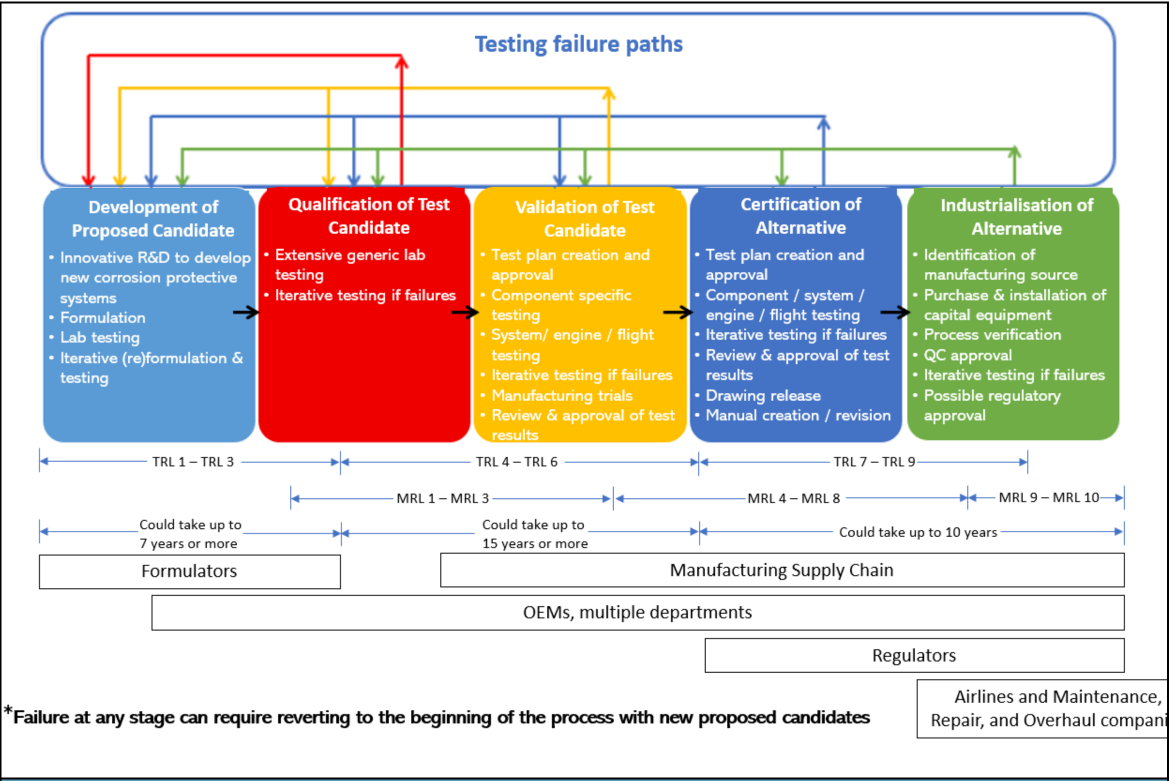

Figure 3-10: Schematic showing the key phases of the substitution process.
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note 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 **(GCCA, 2017b)**

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[18].

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[18] GCCA

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 3-10** above).

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

Validation of test candidate

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

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

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

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

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

Some of the components impacted by the substitution of a 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 3-11** 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[19], each of these components will need to be approved individually:

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

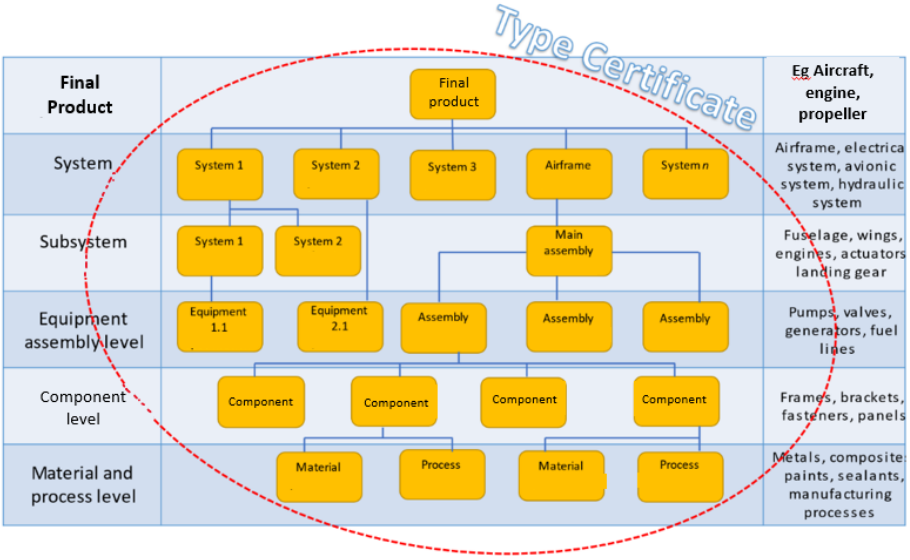

Figure 3-11: System hierarchy of a final product showing the interconnection of each level in the system hierarchy, and how changes at a lower level have impacts on higher levels.
Source: ADCR member

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.

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[19] Application for Authorisation 0117-01 Section 5.3 available at https://echa.europa.eu/documents/10162/b61428e5-e0d2-93e7-6740-2600bb3429a3 accessed 06 June 2022.

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

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 3-12** below.

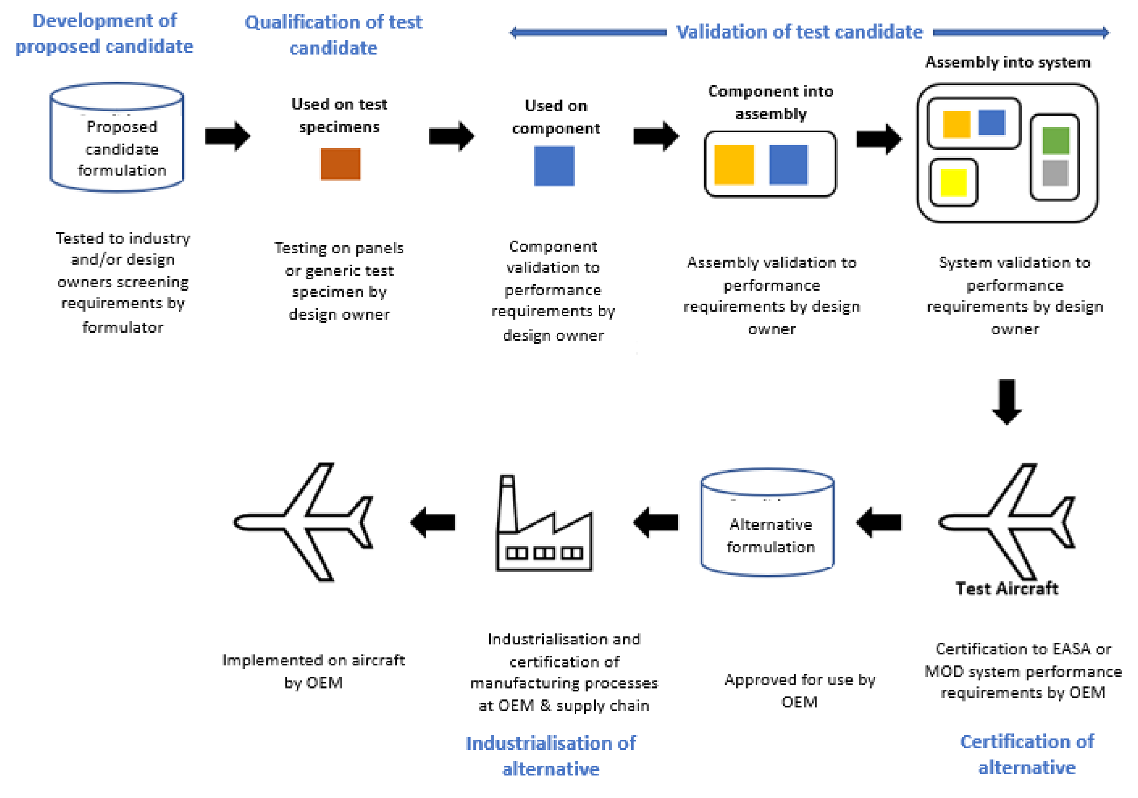

Figure 3-12: Process to Certify a Formulation for use on Aircraft.
Formulations used in production have completed this process. New or reformulations must follow same process for use in production.
Source: ADCR member

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 primer products other than wash or bonding primers

3.2.1.1 Introduction

The development of technical feasibility criteria for proposed candidates to replace the use of Cr(VI) in primer products other than wash or bonding 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 primer products other than wash or bonding primers.

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

- Corrosion resistance (including active corrosion inhibition);
- Chemical/fluid resistance;
- Adhesion promotion;
- Compatibility with substrate, sealant and coatings;
- Layer thickness;
- Temperature resistance (including thermal cycle resistance);
- Mechanical properties (including flexibility, impact resistance, scratch resistance);
- Surface appearance;
- Compatibility with different application methods;
- Repairability;
- Low infrared reflectance;
- Dynamic performance;
- Does not support bacterial/fungal growth;
- Electromagnetic effects/lightning (EME) performance;
- Erosion resistance; and
- UV radiation protection.

Not all of these criteria will be relevant in every development plan, for example dynamic performance, not supporting bacterial/fungal growth and EME performance will generally only be a consideration for primers applied to fuel tank cells and fuel tank components, whilst erosion resistance may only be a requirement when substituting those primers applied to leading edges.

3.2.1.2 Technical feasibility criterion 1: Corrosion resistance (including 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 deterioration, which could lead to failure if not detected soon enough, by chemical reaction with its environment. Examples of corrosion failure are described in Section 3.1.1.2 and include galvanic, filiform and crevice corrosion.

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 and 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. However, use of copper impacts the corrosion resistance of this alloy as copper is a conductive element acting as a built-in corrosion driver. To ensure long-term corrosion stability, inhibition of the copper is mandatory (GCCA, 2017b).

The corrosion resistance requirements vary within the A&D sector and are dependent on the metal substrate (aluminium alloy, steel type etc.,) and location of the component. Corrosion inhibiting co-formulants can be categorised according to inhibitive efficiency, versatility, in terms of potential areas of use, and hazard profile. Ideally, the corrosion inhibitor is applicable in all surface treatment processes, compatible with subsequent layers and performs effectively on all required substrates. In addition it must ensure product stability (chemical and thermal) and reinforce coating properties (GCCA, 2017b).

The ability of a material to spontaneously restore corrosion protection following damage to the original coating is known as active corrosion inhibition, or self-healing, and is described in detail in **Figure 3-1** and **Figure 3-2** (see above). It is reported that the solubility of Cr(VI) delivered by the primer matrix is sufficient to supply an adequate number of inhibitive ions to support diffusion and the self-healing mechanism (GCCA, 2017b). This characteristic is particularly important for those systems which will have long service lives, in harsh environments, where abrasion and localised mechanical damage to surfaces can sometimes occur, compromising the protective layer (GCCA, 2017b).

The images in **Figure 3-13** show one type of corrosion after exposure to artificial salt spray for 1500 hours using test method ISO9227. This test is used to screen test candidates in the early stage of the development cycle prior to bespoke testing. The full testing programme will vary according to the design to be treated and what is prescribed within the substitution process.

The image on the left exhibits corrosion products, white material, in the scribe. The right hand image is the reference test coupon treated with the chromated primer. The test candidate must match or exceed the performance of the reference.

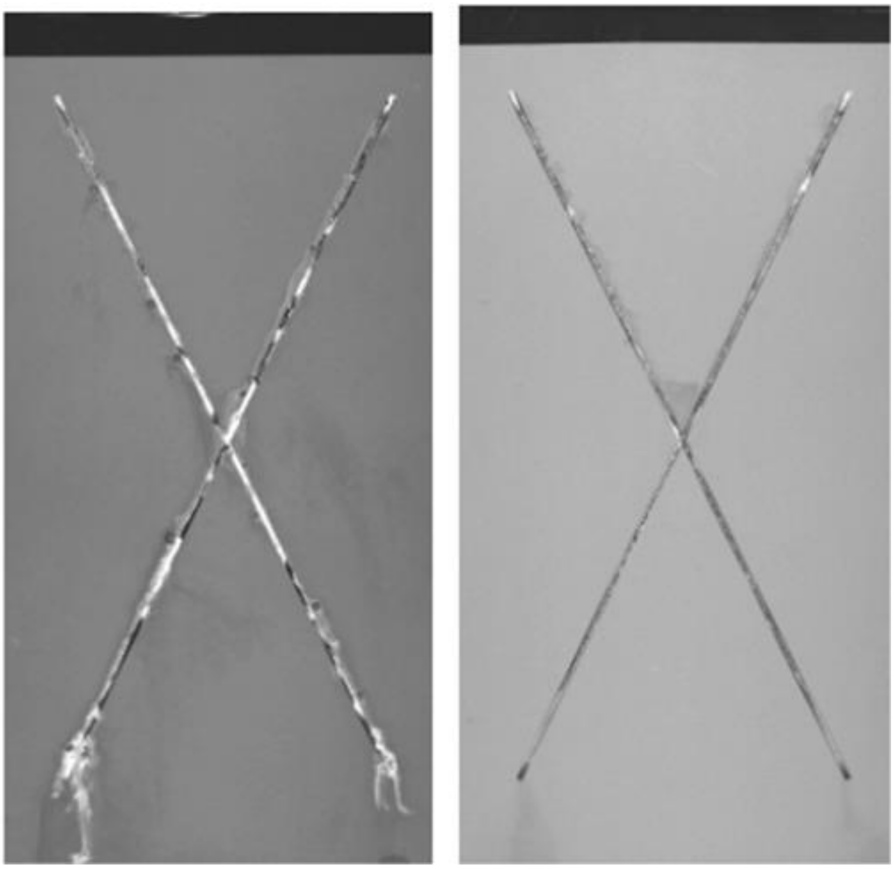

Figure 3-13: Scribed test coupons; test method reference: ISO9227, artificial salt spray, duration 1500h.

Left image: Test candidate primer coating

Right image: Chromated primer reference coating

Source: ADCR member (test candidate coating undisclosed)

3.2.1.3 Technical feasibility criterion 2: Chemical/fluid resistance

Materials used in aerospace and defence applications must be resistant to damage caused by chemical/fluid exposure. Contact with various chemicals, for example de-icing fluids, greases, oils and lubricants, or aggressive fire-resistant aviation hydraulic fluids, may occur in the service environment of the part. Without adequate resistance, deterioration of the protective coatings or metal components via chemical interaction could increase maintenance costs (CCST, 2015a). For those primer products other than wash or bonding primers applied within the fuel tank or to fuel tank components, the sustained resistance to highly combustible jet fuel is a key requirement.

3.2.1.4 Technical feasibility criterion 3: Adhesion promotion

Depending on the functions of the components, they may be coated with additional 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 its 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 7: Mechanical properties (see Section 3.2.1.8). It is of note, that, whilst the Cr(VI) plays a role in adhesion promotion, as described in Section 3.1.1.1, the adhesion properties of a primer product other than wash or bonding primers formulation, are influenced by different factors including the complex interplay between corrosion inhibitor, matrix and other additives. Any alternative corrosion inhibitor must therefore be compatible with the variety of different resin matrices which may be used in the different primer products other than wash or bonding primers. Where Cr(VI) cannot be substituted with another universally compatible corrosion inhibitor, it must be noted that different inhibitors may be used in combination with different resin matrices which can add complexity and consequently time to the substitution process.

For those protective primer products applied to fuel tank components, adhesion to sealants in extreme environmental conditions, for example cold temperatures, dynamic loading, and the presence of water in fuel for fuel tank primers, must be assured (CCST, 2017).

3.2.1.5 Technical feasibility criterion 4: Compatibility with substrate, sealant and coatings

Compatibility with a wide range of substrates (refer to Section 2.3.1.1), other primers, and subsequent layers is a key performance characteristic within the aviation sector. This includes not only a wide range of ferrous and non-ferrous metals, but also non-metallic substrates such as composites. A key advantage of Cr(VI)-containing primers is their ability to be applied across the range of substrates used within the sector. This universal applicability is unlikely to be found with alternative corrosion-inhibitors, which will ultimately lead to a number of different alternatives needing to be implemented within each organisation. It must be ensured that alternatives are industrialised which are suitable for each substrate used.

Protective primers applied to aerodynamic components and structures that protrude from the fuselage (commonly marketed as ‘structural primers’) often require additional corrosion resistance and are therefore applied in combination with wash primers. Compatibility with wash primers is therefore an essential requirement for protective primers (CCST, 2015a).

3.2.1.6 Technical feasibility criterion 5: Layer thickness

The thickness of the various coating layers on the substrate, specified in nanometres or micrometres, is critical for optimum performance of all parts of the aircraft. The objective is to achieve maximum performance with minimum thickness, which in turn equates to minimum weight, as weight is critical to the fuel efficiency of an aircraft. Layer thickness impacts 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. For protective primer products, a thickness between 7-50 µm is typically specified (CCST, 2017).

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 insufficient corrosion and chemical resistance, inadequate adhesion of adhesives to the substrate or decreased cracking resistance. Due consideration must be paid to the application process of Cr(VI)-free primer systems in order to ensure reproducible and even coverage of components with complex geometries (CCST, 2015b).

3.2.1.7 Technical feasibility criterion 6: Temperature resistance (including thermal cycle resistance)

This parameter describes the ability of a coating or component 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 (CCST, 2015b).

3.2.1.8 Technical feasibility criterion 7: Mechanical properties (including flexibility, scratch resistance, impact resistance)

Like most coatings, all protective primers require a degree of flexibility. For example structural primer applied to leading edges/control surfaces, or components that may expand in use, may have increased requirements for flexibility to accommodate a degree of movement in use and prevent the risk of coating detachment or damage (Indestructible Paint Ltd., 2017).

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.

3.2.1.9 Technical feasibility criterion 8: Surface appearance

Protective primers should have a smooth and uniform appearance. Additional appearance inspection criteria may include; no blushing, bubbling, cracking, cratering, floating, foreign contamination, large particulates, pin-holing, popping, sagging, streaking or other indicators that the coating may not meet performance requirements (CCST, 2017). This is particularly important for those primer products other than wash or bonding primers, containing aluminium (marketed as ‘aluminised primers’), designed for application to exterior surfaces without a topcoat in order to provide a metallic appearance.

Surface appearance also includes visibility/inspectability. When the primer product other than wash or bonding primers is being applied to the substrate, visibility of the primer is an important factor in ensuring full coverage of the area to be primed is achieved. Inspection for defects is made less complicated with Cr(VI)-based primers as they are naturally given a yellow/green colouration making them easily visible to the naked eye. An alternative primer product other than wash or bonding primers with a colourless/ near colourless Cr(VI)-free corrosion inhibitor would require the addition of a dye to allow current inspection processes, and therefore current production rates, to be maintained.

3.2.1.10 Technical feasibility criterion 9: Compatibility with different application methods

A suitable alternative to the use of chromates in primer products other than wash or bonding primers must have the ability to be processed/implemented at elevated temperature as well as room temperature, (particularly when applied in MRO or touch-up activities).

It must also be capable of being spray applied for the initial coating of large areas, but also of brush/roller/swab application for touch-up/repair. Such touch-up activities will often take place with the worker underneath the component, so it must be ensured that the alternative is suitably viscous to prevent the primer dripping onto the worker.

3.2.1.11 Technical feasibility criterion 10: Repairability

A suitable alternative to the use of chromates in protective primers must have the ability to be repaired. The primer should be easily removed by existing approved stripping techniques that do not affect the substrate. Also, as mentioned above, compatibility with different application methods is one of the requirements for repairability.

Since the alternative primer product may be applied over or adjacent to chromated primer in repairs, compatibility of the two systems is a key requirement for repairability. Corrosion inhibition and adhesion (and other performance requirements) should not be compromised in any way at the interface between the new and legacy primers. Also, in those components where the surface treatment prior to primer application is any type of anodising, for repair applications where touch-up is being performed, wash primers, touch-up conversion coating or sol-gel may be used as the surface treatment. In this scenario, the alternative primer must meet all technical feasibility criteria.

Such coating materials must have the ability to be repaired in service by qualified materials, which are not necessarily the exact same products as the original coating. In consequence the alternative to the chromated primer must be compatible to materials used during MRO activities.

3.2.1.12 Technical feasibility criterion 11: Low infrared reflectance

Primer products with low infrared reflectance may be applied in certain areas of the aircraft. The criterion is relevant for special military applications and requires an adjustment of a conventional primer pigmentation for this purpose.

3.2.1.13 Technical feasibility criterion 13: Dynamic performance

Fuel tank coating systems (substrate-fuel tank primer-sealant) must be able to sustain adhesion under mechanical stresses while in the presence of fuel. Stresses arise from mechanical movement due to flexing of parts and under changing loads experienced during flight cycles as well as from expansion and contraction due to changing temperatures.

For those protective primer products that are applied to fuel cells and fuel tank components (commonly marketed as ‘fuel tank primers’), dynamic performance is the system requirement for the combination of resistance to chemicals and mechanical cycling at high and low temperatures. Under these conditions there should be no loss of adhesion to the substrate, no coating cohesive failure and no adhesive failure to the sealant (CCST, 2017).

3.2.1.14 Technical feasibility criterion 14: Does not support bacterial/fungal growth (non-nutrients performance)

Microbiological growth can occur in aircraft fuel tanks due to moisture/contamination in fuel and cause severe corrosion. Debris from corrosion products has the potential to dislodge from the fuel tanks, migrate through the fuel system, and lead to an in-flight engine shutdown (CCST, 2015b).

3.2.1.15 Technical feasibility criterion 15: Electromagnetic effects/lightning (EME) performance

The presence of charged thin dielectric coatings in contact with grounded conductors (such as fuel tank primer on fuel tank surfaces) can result in propagating electrical discharge, potentially with enough energy to ignite fuel vapours. Metallic fuel tanks have extensive history with existing designs that have been shown to be safe via in service history. Materials, such as composites, require a greater amount of analysis and rigor to show that they are acceptable for electrostatic requirements. Fuel tank surfaces and any applicable coatings, including but not limited to primer, levelling compound, sealant, epoxy, resin etc. must be designed to not hold electrostatic charge, or be applied in a manner that does not accumulate enough charge to support ignition.

3.2.1.16 Technical feasibility criterion 16: Erosion resistance

Primer products other than wash or bonding primers exposed to high-speed air streams need to maintain adhesion to the substrate and cohesive integrity. Erosion resistance is required in the presence of solid particles e.g. sand or ice, or liquid droplets, such as rain, impacting the primer surface (GCCA, 2017b). This is a particular requirement for aerodynamic components and structures that protrude from the fuselage (commonly marketed as ‘structural primers’).

3.2.1.17 Technical feasibility criterion 17: UV radiation resistance

Those primer products other than wash or bonding primers applied at the engine inlet lipskin (often marketed as ‘aluminised primers’ due to their aluminium content) require UV radiation resistance (CCST, 2017).

3.2.1.18 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. 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 3-14**. 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 3-14: 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. 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 3-15**. Consequently, the industry requires a diverse range of metal alloys to fulfil all performance requirements that these various applications demand. Whilst primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate 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 3-15: 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 aircraft in service. The demanding nature of service environments in the aerospace and defence sector, and potential for serious consequences if only one component should fail, dictate that very stringent measures are adopted and enforced when developing and qualifying Cr(VI)-free test candidates.

Various R&D activities were reported within the two parent applications for authorisation relating to primer products other than wash or bonding primers. Proposed candidates for the replacement of Cr(VI) in primer products other than wash or bonding 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)[21].

Table 3-4: Cr(VI)-free proposed candidates for the replacement of StC, PHD and PCO in primer products other than wash or bonding primers reported in parent AfA as 'protective primers'

Proposed candidate	Implementation status (TRL level) reported in parent AfA	AfA ID
Cr(VI)-free inhibitors (confidential)	Not equivalent to Cr(VI)-based products. At least 15 years required for implementation after a viable candidate is developed.	0046-02
Calcium-based corrosion inhibitors	Technically not equivalent. Questionable if they will qualify for further R&D efforts.	0046-02 0118-02
Magnesium-based corrosion inhibitors	Technically not equivalent. Questionable if they will qualify for further R&D efforts.	0046-02 0118-02
Molybdate-based corrosion inhibitors	Technically not equivalent. Questionable if they will qualify for further R&D efforts.	0046-02 0117-01 0118-02
Organic corrosion inhibitors	TRL 2. At least 15 years required for implementation after a viable candidate is developed.	0046-02 0117-01 0118-02
pH-buffering additives (Calcium carbonate, calcium hydroxide, magnesium hydroxide, magnesium oxide)	Technically not equivalent.	0117-01
Phosphate-based corrosion inhibitors	TRL 2/3. At least 15 years required for implementation after a viable candidate is developed.	0046-02 0117-01 0118-02
Rare earth-based corrosion inhibitors (Praseodymium trihydroxide, praseodymium oxide)	Technically not equivalent. Questionable if they will qualify for further R&D efforts.	0046-02 0117-01 0118-02
Sacrificial metal-based	Not equivalent to Cr(VI)-based products. At least 15 years required for implementation after a viable candidate is developed	0117-01
Silane-based coatings	TRL 2. At least 15 years required after development of viable candidate for implementation into supply chain.	0046-02
Silicate-based corrosion inhibitors	Technically not equivalent.	0117-01
Zinc-based inhibitors	TRL 2. Questionable if these systems will qualify for further R&D.	0046-02 0117-01 0118-02

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

Electrocoat primer technology	Technically not equivalent. Questionable if they will qualify for further R&D efforts.	0046-02 0118-02
Source: (CCST, 2015b, 2017; GCCA, 2017b)		

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.

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 corrosion inhibitors listed within **Table 3-4**, or other chemistries known only to the formulators. This category of test candidates comprises potential alternatives where a proprietary mixture of corrosion inhibitors has been formulated to achieve greater functional performance than the individual test candidates used in isolation. The specific composition of inhibitors used in these mixtures 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.

Formulators reported that research into **calcium-based corrosion inhibitors**, **magnesium-based corrosion inhibitors**, and **molybdate-based corrosion inhibitors** continued for a period after submission of the parent AfA. However, it was halted as insufficient scribe protection was seen in the tested products. In the case of **molybdate-based corrosion inhibitors**, OEMs/DtBs reported similar results. However, it was reported that implementation of a basic primer containing a calcium-based corrosion inhibitor has progressed for more than one OEM and is currently being industrialised for one component family. This progression is discussed further in Section 3.5. For magnesium-based corrosion inhibitors, some OEMs/DtBs reported that the primer products presented to them had failed to meet corrosion resistance requirements or demonstrated an incompatibility with other parts of the treatment process. Whilst other OEMs/DtBs reported that research is still ongoing with a number of proposed candidates for use as basic, structural and fuel tank primers. This work is also further discussed in Section 3.5.

Research into **organic corrosion inhibitors** was reported by formulators to be ongoing, whilst some OEMs/DtBs reported promising results in their own trials with this proposed candidate – although compatibility issues with certain topcoats have been encountered. These trials are further discussed in Section 3.5.

Although reported in the parent AfA to be technically not equivalent to Cr(VI)-based corrosion inhibitors, formulators continue to undertake research into **pH-buffering additives** and members reported that such additives are included in the inhibitor packages of a number of primer products currently under investigation. Further information is provided in Section 3.5.

Primers containing **phosphate-based inhibitors** were reported to have entered limited use by one OEM, and formulators reported that research on this proposed candidate remains ongoing. See Section 3.5 for further information.

A number of OEM's/DtBs reported testing of a basic primer containing praseodymium trihydroxide, and whilst one found that the product did not meet corrosion resistance requirements another reported that the same primer had been qualified for some programs. Continued testing of a fuel tank primer containing yttrium oxide was also reported. Research and qualification of primer products other than wash or bonding primers containing **rare-earth based corrosion inhibitors** is discussed further in Section 3.5.

Sacrificial metal-based primers containing zinc-magnesium pigments were reported to have been tested by one formulator, however due to the high amount of pigment required, they were considered not to be suitable for most basic primer uses. Solutions which can be used for repair remain in development however and are discussed further in Section 3.5.

Most members who had tested **silane-based products** reported that they had only done so as potential alternatives for chemical conversion coating or wash primer applications, and not as a replacement for the use primer products other than wash or bonding primers, however some OEMs/DtBs did report ongoing R&D with one proposed candidate within this group. This R&D is further discussed in Section 3.5.

Formulators reported that research into **silicate-based corrosion inhibitors** had continued in the period since the original AfA. However they reported that this research had subsequently ceased due to insufficient corrosion performance. No non-formulating members reported any further research into this group.

Multiple members reported ongoing research into **zinc-based corrosion inhibitors**, and trials of 'protective primer' products containing them. One OEM reported that TRL 4 had been achieved for one such product in one development plan. The progression of this test candidate is further discussed in Section 3.5.

Multiple members also reported ongoing trials with **electrocoat primer technology**, with one proposed candidate having been tested on a number of substrates including 2xxx, 6xxx and 7xxx series aluminium, steel and titanium. The results of this testing against the technical feasibility criteria described above are discussed further in Section 3.5. To further highlight the significant efforts being made by the aerospace and defence sector to substitute chromates, examples of internal R&D projects and ongoing R&D collaborations are identified below. It is noted that multiple projects and 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 primer products other than wash or bonding 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.

- **Airbus Chromate-Free project** aims to progressively develop new, environmentally friendly, Cr(VI)-free alternatives to qualified products and processes used in aircraft production and maintenance. At the time of submission of the parent AfA, the project was ongoing and reported to be organised into several topics, specifically addressing applications where chromates are used in production or applied to aircraft. Protective primers were reported to be within the remit of the project. Since 2016, ADCR members have reported that the development of Cr(VI)-free primers has moved to the **Basic Primer Acceleration Project**. This goal of this internal project is to push and support the development of Cr(VI)-free products through collaboration with relevant formulators.

- Multiple sub-projects under the **Highly Innovative Technology Enablers for Aerospace (HITEA)** project with partners including Innovate UK (part of UK Research and Innovation) and the Engineering and Physical Sciences Research Council (EPSRC). HITEA was initiated in 2012, with phase one ending in 2015 and two subsequent phases running (total funding £1.06 million). The project identified some proposed candidates for the replacement of basic primers containing Cr(VI).

- **OptiComp** was referenced by an ADCR member as being linked to HITEA and HITEA3 and considered alternatives to strontium chromate in basic primers and fuel tank primers. The project was reported as starting in October 2019, and was reported by members to remain ongoing. The project has identified 2 Cr(VI)-free protective primer products for application to composites, whilst screening of candidates for use on metallics are still to be completed.

- **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. Three priority projects identified in the report involve the assessment of non-chromate primers. ADCR members were included within the alternative technology related efforts listed in the report.

- The **International Aerospace Environmental Group (IAEG)** Replacement Technologies Working Group (WG2), formed in 2011 provides a global framework for aerospace and defence manufacturers, including a number of companies within the ADCR, to collaborate on widely applicable, non-competitive alternative technologies. It was reported that interested member companies have worked on a collaborative project on corrosion-preventive primers which was focused on gathering information from formulators and developing a report on the proposed candidates available for testing.

- **PICASSO** is an R&T collaborative project partially financed by the French DoD (DGA). Its aim is the development of basic and wash primers which are free of substances of very high concern, for aeronautics. The Partners are the primer Formulator, a French Institute/University for corrosion inhibitors design and production and an OEM, as potential end-user, to give the requirements and perform the relevant technological tests on most promising formulations.

Two further projects, VIEWS and AnEdOCAM, funded by IUK[22] were also reported. These involved the assessment of electrocoat technologies on aluminium alloys and titanium/CRES respectively.

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 primer products which have shown varying degrees of success.

In addition to those proposed candidates listed in the parent AfA, one member also reported that they had investigated a lithium-based complex. This is discussed further in Section 3.5.

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[22] Innovate UK

3.4.2 Consultations with customers and suppliers of alternatives

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

3.4.3 Data Searches

3.4.3.1 High level patent review

A non-exhaustive patent search was performed with the aim of identifying examples of potential technologies related to primer products other than wash or bonding primers. The search was performed using Espacenet[23], the European Patent Office (EPO) open access search portal. Espacenet contains over 120 million patent documents held by patent offices around the world, including North America and Asia (EPO, 2020).

Keyword search terms, with Boolean Operators, were used to help identify patents potentially within the scope of the different primer types within the 'primer products other than wash or bonding primers' category.

Search criteria

Fuel tank primer key word search: Fuel AND tank AND free AND coating OR primer [NOT Sealant OR Sealants] AND chromate AND aerospace.

Structural primer key word search: Structural AND [coating OR primer] NOT [Sealant OR Sealants] AND chromate AND free AND aerospace.

Search date 29 March 2023

Note: A key word search for aluminised/aluminized or 'metallised' chromate free primer failed to yield any patent results relevant to the A&D or general engineering sectors.

Patents were 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.

Fuel tank primer search returned seven results of which three were deemed potentially relevant to aerospace and defence applications, summarised in **Table 3-5** below.

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

Table 3-5: Patent search technology summary: Fuel tank primer

Title	Patent publication reference	Summary
Process for preparing a fuel tank of polyurethane laminate having contiguous contrasting layers (Publication 1987)	US4668535A	The invention is suitable for use as a coating and for the preparation of various in situ articles or enclosures, for example a fuel tank, such as commercial and military aircraft. Constituents: Fuel resistant polyurethane formed into an article or applied directly to structure via brushing, spraying, dipping.
Coating composition comprising an amide group containing macromolecular compound usable as primer for a fluororesin layer (Publication 2005)	EP1564270A1	A coating composition free from hexavalent chromium to serve as a binder component but having adhesion comparable to the primer based on chromate phosphate even if baked at elevated temperature for a long time. It is another object according to the present invention to provide a composition in which the heat resistance of resin having an amide group is improved. Aerospace uses include parts of fuel system. Constituents include: Fluororesin, polyamide-imide, poly(arylene sulfide), nitrogen containing compound e.g. benzothiazole-base, zinc based antioxidant.
Corrosion resistance adhesive Sol-gel (Publication 2020	US2020115561A1	Sol-gel promotes adherence between a metal substrate and secondary layer e.g. sealant or paint. Metal substrate includes structural or mechanical components including a fuel tank. Constituent: Reaction product of a hydroxy organosilane, a metal alkoxide, an acid stabilizer, and a corrosion inhibitor.

The 'Structural primer' search returned 24 results. Of these, six are summarised below in **Table 3-6.** These describe systems that may impart similar properties to structural primer containing chromates and/or be relevant to aerospace and defence applications.

Table 3-6: Patent search technology summary: Structural primer		
Title	**Patent publication reference**	**Summary**
Chromate free corrosion resistant coating (Published 2005)	US2005151120 A1	Corrosion resistant chromate free fastener coating for example applied via spraying, dipping or brushing. Constituents: Suspension in phenol-formaldehyde thermosetting resin of inorganic salt (zinc or calcium cation, silicate, phosphate, carbonate, or oxide anion), 1-(Benzothiazol-2-ylthio) succinic acid, (2-benzothiazolylthio) succinic acid (BTTSA) amine complex. The suspension is dissolved in a suitable solvent e.g. isopropyl alcohol, methyl ethyl ketone, xylene. Polytetrafluoroethylene (PTFE) may also be included as a functional additive.
Primer compositions for adhesive bonding systems and coatings (Publication 2009)	WO2009036790A1	Adhesive bonding systems and coatings applied to underlying structures. Constituents: Aqueous dispersion of at least one thermosetting, self-emulsifying epoxy resin,- at least one thermosetting, non-self-emulsifying resin; water,- and at least one curative (polyamine), anodic and cathodic corrosion inhibitors (non-chromate) selected from at least one organic zinc salt, copper complexing agents, phosphates, wolframate (tungstate), zirconate, iron, molybdate, or cyanamide
Integral resin-silane coating system (Publication 2006)	WO2006083656	Coating composition containing a resin; a curing agent; a catalyst; and a hydrolyzed bis-amino silane provides excellent adhesion between the substrate and the coating. Corrosion-resistant organic coating system having excellent adhesion between the substrate and the coating and therefore minimal delamination. Constituents include: Epoxy resin, or mixture of at least one (meth)acrylate and at least one epoxy resin. Curing agent; mixtures of at least one silane and at least one polyisocyanate, catalyst; such as acetic acid, formic acid, propionic acid, butanoic acid, or nitric acid, and a bis-amino silane.

Table 3-6: Patent search technology summary: Structural primer		
Title	**Patent publication reference**	**Summary**
Coating compositions exhibiting corrosion resistance properties, related coated substrates, and methods (Publication 2008)	CN101287784A	A primer and/or pre-treatment coating composition comprising: (a) an adhesion promoting component; and (b) corrosion resisting particles selected from: (i) magnesium oxide particles having an average primary particle size of no more than 100 nm; (ii) particles comprising an inorganic oxide network comprising one or more inorganic oxides; and/or (iii) chemically modified particles having an average primary particle size of no more than 500 manometers. Constituents include: Magnesium oxide particles not more than 100nm, inorganic oxide, film forming resin (polyvinyl butyral resin), phosphorylated epoxy resin.
Coating composition comprising an alkali salt of graphene oxide and coating layers produced from said coating composition (Publication 2022)	WO2022084119A1	Comprises at least one graphene oxide containing at least one monovalent metal ion selected from the group consisting of lithium, potassium and mixtures thereof (GO-M), at least one binder B and/or at least one silane compound SC and at least one solvent S1. The inventive coating composition is therefore preferably a liquid coating composition at 23 °C Binders selected from poly(meth)acrylates, polyurethanes, linear or branched polyester polyols, polyether polyols, polyepoxides, phenoxy resins, copolymers of the stated polymers, and polyepoxides. Silane compound, (3-(2-aminoethylamino) propyltrimethoxy silane. Solvent; preferred organic solvent selected from xylene and/or methoxypropanol or aliphatic hydrocarbons and methoxypropyl acetate and butyldiglycol acetate and dibasic esters.

As with all patents, those listed in **Table 3-5** and **Table 3-6** 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.

As described in Section 3.1.2.2 it is the role of formulators to incorporate these novel chemistries into viable proposed candidates for design owners to screen. Of those technologies listed above all are understood to include at least one alternative described in Section 3.4.1.1 above with the possible exception of graphene oxide salt as described in patent WO2022084119A1. It is claimed that the inclusion of graphene oxide salt in a coating containing at least one binder and silane compound provides corrosion resistance, is easily applied using conventional processes, e.g. spray gun, or roller application, with good adhesion characteristics rendering it suitable as a primer. It was reported by members however that graphene oxide can pose major formulation challenges when used in practice, whilst one member also reported that the use of graphene oxide may be prohibitively expensive if a viable proposed candidate based on this patent was presented.

Proposed candidates containing graphene oxide have not been presented to members by formulators at this time, which may be because initial investigations by formulators have concluded that they would not meet performance requirements of customers' designs or could be because other more mature test candidates are already available for which development plans are being progressed. If qualification, validation, 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 the novel method described in this or other patents if the necessary licencing agreements could be reached.

3.4.3.2 High-level literature review

A non-exhaustive technical literature review was carried out using Science Direct (Journals and Books)[24] on-line service using the keyword search terms below. The purpose was to identify examples of alternatives to Cr(VI) for different applications of primer products other than wash or bonding primers that have been investigated in the academic field or within other industry sectors. Although it is acknowledged that technical requirements for primer products other than wash or bonding 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 searches are tabulated below.

Fuel tank primer

Table 3-7: Literature search for fuel tank primers in Science Direct

Search term	Time period	Research articles	Review articles	Open access
Chromate-free "corrosion resistant" fuel tank primer	2000- 2023	7	6	1

The title and abstracts of the two open access 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 primer products other than wash or bonding primers. An expanded review is presented below for the review article available via open access, refer to **Table 3-8.**

Table 3-8: Expanded review of selected scientific publications: Fuel tank primer search

Ref.	Article Title
1	Aiman, N et al (2022) "Potential Application of Plant-Based Derivatives as Green Components in Functional Coatings: A Review"

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

Table 3-8: Expanded review of selected scientific publications: Fuel tank primer search	
Ref.	**Article Title**
	Cleaner Materials, Volume 4, June 2022 https://doi.org/10.1016/j.clema.2022.100097 Abstract: The conventional coatings are generally unsustainable in harsh environments and offer limited protection to the intended infrastructures. Recently, the emergence of plant-based components to enhance coatings has attracted significant attention due to their characteristics of anticorrosion, antifouling, antimicrobial, self-healing, and ultraviolet (UV) shielding. Almost all plant parts can be utilized as a potential material of interest, including leaves, flowers, oils, seeds, and fruits. The reason is that the extract from these parts possesses many phytochemicals that contribute to the properties stated above. In the coating industry, plant extract is introduced as a green additive and is said to share similar functions as synthetic additives, which is to enhance the protection ability of the coating. Moreover, they are non-toxic, safe to use, abundant, and environmentally- friendly. **Cr(VI)-free corrosion inhibitor:** Plant extracts

Other primer types

Search term 'chromate-free primer coating' was used to broaden the search due to the relatively small number of open access sources available for review. This search term returned 1,442 results of which 45 were open access. A summary of the results for research articles, review articles and open access sources is given in **Table 3-9.**

Table 3-9: Literature search for structural primers in Science Direct				
Search term	**Time period**	**Research articles**	**Review articles**	**Open access**
Chromate-free primer coating	2000- 2023	613	97	45

Table 3-10 provides a review of five selected open access sources, detailing potential Cr(VI)-free alternatives, taken from the literature search summarised above in **Table 3-9**.

Table 3-10: Expanded review of selected scientific publications	
Ref.	**Article Title**
1	Lamprakou, Z et al (2022) 'Tannin-based inhibitive pigment for sustainable epoxy coatings formulation' Progress in Organic Coatings, Volume 167, June 2022 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

Table 3-10: Expanded review of selected scientific publications	
Ref.	**Article Title**
	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	Zhang, T et al (2022) 'Corrosion and aging of organic aviation coatings: A review Chinese Society of Aeronautics and Astronautics & Beihang University https://doi.org/10.1016/j.cja.2022.12.003 Abstract: Organic anticorrosive aviation coatings are an effective guarantee for aviation structure since aircraft corrosion can lead to great economic losses. Whether it is during ground parking or air cruises, organic aviation coatings are important barriers to the corrosion of aviation structure. With the vigorous development of the aviation industry, organic aviation coatings continue to meet the challenges of diverse, complex, and harsh service environments. This review analyses and summarises the research status of the types and development of organic aviation coatings, influencing factors and mechanisms, experimental methods, calendar life research methods, and modification methods. It also summarizes the research results that have been achieved to date. The current research deficiencies in the equivalence relationship between atmospheric exposure and artificial acceleration, failure criteria and life prediction were pointed out, and nano-modification technology, and future research strategies and directions that need breakthroughs are discussed. **Cr(VI)-free corrosion inhibitors**: Nano-cerium oxide, carbon nanotubes, graphene / graphene oxide.
3	Zhang, F et al (2018) 'Self-healing mechanisms in smart protective coatings: A review' Corrosion Science, Volume 144, November 2018, pp 74-88 https://doi.org/10.1016/j.corsci.2018.08.005 Abstract: A Self-healing coatings inspired by biological systems possess the ability to repair physical damage or recover functional performance with minimal or no intervention. This article provides a comprehensive and updated review on the advantages and limitations associated with common autonomous and non-autonomous self-healing mechanisms in protective organic coatings used for anti-corrosion purposes. The autonomous healing mechanisms are often enabled by embedding polymerizable healing agents or corrosion inhibitors in the coating matrices. For non-autonomous mechanisms, the healing effects are induced by external heat or light stimuli, which trigger the chemical reactions or physical transitions necessary for bond formation or molecular chain movement. **Cr(VI) free corrosion inhibitors**: Graphene oxides in polyurethane coatings. Other examples cited; phosphates, nitrites, molybdates, tungstates, vanadates, borates, rare earth, benzotriazole (BTA),

Table 3-10: Expanded review of selected scientific publications	
Ref.	**Article Title**
	mercaptobenzothiazole (MBT), imidazoline, 8-hydroxyquinoline (8-HQ) and aliphatic amines. (Section 2.2)
4	Soufeiani, L et al (2020) 'Corrosion protection of steel elements in façade systems – A review' Journal of Building Engineering, Volume 32, November 2020 https://doi.org/10.1016/j.jobe.2020.101759 Abstract: Corrosion of steel elements in a façade system may cause failure that can adversely affect building performance. In this paper we review and synthesize the scientific literature in order to provide practical guidance for engineers, designers and material/product specifiers to avoid or minimize the corrosion of steel elements in façade systems as well as to identify the challenges for future research. The review covered different types of corrosion such as atmospheric, galvanic or bimetallic, embedded, and cut-edge corrosion and how different factors affect the corrosion rate of steel. **Cr(VI)-free corrosion inhibitors**: Organic conducting polymer coatings (e.g. polyacetylene, polypyrrole, polyaniline, and polythiophene), polyaniline/nanotube-TiO_2 composite.
5	Karanika, A et al (2018) 'Development of new environmentally friendly anticorrosive surface treatments for new Al-Li alloys protection within the frame of Clean Sky 2' Procedia Structural Integrity, Volume 10, 2018, pp 66-72 https://doi.org/10.1016/j.prostr.2018.09.010 Abstract: Innovative, last generation Al-Li alloys were evaluated in terms of mechanical performance and corrosion protection in order to be used in aircraft structures. Involved alloys are AA2060 and AA2198, where tensile, fatigue, rolling and formability tests were performed and compared against the respective of AA2024. Corrosion protection on the above substrates involves thin film sulphuric acid anodizing or sol-gel technologies. Above aspects are within the technological interests of Hellenic Aerospace Industry that is participating in ecoTECH project under Clean Sky 2 platform for the seven years core project (2016-2022). **Cr(VI)-free corrosion inhibitors**: Water based epoxy primer.

Whilst most of the Cr(VI)-free corrosion inhibitors identified in **Table 3-8 and Table 3-10** are described in some form in the parent applications, there are corrosion inhibitors that appear to be outside the scope of past research described in Section 3.4. Corrosion inhibitors derived from plant extracts and graphene/graphene oxide require further analysis to determine their novelty outside the scope of those alternatives described in the parent analysis of alternatives. The potential limitations of graphene oxide are already described in Section 3.4.3.1, and formulating members further reported that the corrosion inhibitors stated in the Zhang et al (2022) paper do not provide sufficient corrosion protection for us in the A&D sector. Formulating members of the consortium also reported that plant extracts had not been presented as a corrosion inhibitor in primer product other than wash or bonding primers due to a failure to meet a number of the requirements of the A&D sector.

3.4.4 Identification of alternatives

Proposed candidates for the replacement of Cr(VI) in primer products other than wash or bonding primers are shown in **Table 3-11** below. This list comprises all the alternatives that were reported in the parent AfAs, as well as any further proposed candidates identified during the above data searches.

Table 3-11: Proposed candidates for the replacement of Cr(VI) in primer products other than wash or bonding primers

Proposed candidate
Cr(VI)-free inhibitors (confidential)
Calcium-based corrosion inhibitors
Magnesium-based corrosion inhibitors
Molybdate-based corrosion inhibitors
Organic corrosion inhibitors
pH-buffering additives (Calcium carbonate, calcium hydroxide, magnesium hydroxide, magnesium oxide)
Phosphate-based corrosion inhibitors
Rare earth-based corrosion inhibitors (Praseodymium trihydroxide, praseodymium oxide)
Sacrificial metal-based
Silane-based coatings
Silicate-based corrosion inhibitors
Zinc-based inhibitors
Electrocoat primer technology
Graphene/graphene oxide/graphene oxide salts
Plant extracts
Lithium-based 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 protective primers which must show equal or better performance compared to the incumbent protective primers are:

- Corrosion resistance (including active corrosion inhibition);
- Chemical/fluid resistance;
- Adhesion promotion;
- Compatibility with substrate, sealant and coatings;
- Layer thickness;
- Temperature resistance (including thermal cycle resistance);
- Mechanical properties (including flexibility, scratch resistance, impact resistance);
- Surface appearance;
- Compatibility with different application methods;

- Repairability;
- Low infrared reflectance;
- Dynamic performance;
- Does not support bacterial/fungal growth (non-nutrients performance);
- Electromagnetic effects/lightning (EME) performance;
- Erosion resistance; and
- UV radiation resistance.

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.

For primer product other than wash or bonding primers applications, corrosion resistance may be tested according to ASTM B117 or ISO 9227 (both salt spray tests), or EN 3665 (filiform corrosion test in combination with a top coat). In general, adhesion is tested according to ISO 2409, or ASTM 3359. 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). Chemical resistance can be tested using ISO 2812 and fluid resistance using MIL-PRF-5606, whilst compatibility with substrates and coatings is also tested according to ISO 2409 and compatibility with sealants is tested according to ISO 4628-2 or internal test methods. To ensure requirements for mechanical properties are met, scratch resistance is tested according to ISO1518-1, flexibility is tested according to ISO 1519 and impact resistance is tested according to ISO 6272-1 or ISO 4628-4.

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**.

Not every proposed candidate will be tested according to all the standards listed above for a number of reasons. Firstly, not all criteria will be relevant to every development plan, for example dynamic performance, not supporting bacterial/fungal growth and EME performance will generally only be a consideration for primers applied to fuel tank cells and fuel tank components, whilst erosion resistance may only be a requirement when substituting those primers applied to leading edges. Additionally, in most cases corrosion testing (according to ASTM B117 or other appropriate standards) is used as the first screening test as it is the most critical requirement to be met in any alternative for this use. More complex and specialised tests are usually only conducted on proposed candidates that exhibit acceptable corrosion resistance.

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

When considering technical feasibility criteria, in many instances these are strongly interrelated in the delivery of the product performance, and it is not possible to consider one criterion independently of the others when assessing proposed candidates. For example, the layer thickness and chemical resistance of primer products other than wash or bonding primers are both directly related to the performance of the corrosion inhibitor.

Cr(VI) salts are mobile and able to easily leach from the primer matrix to offer effective corrosion protection even in low concentration and in thin primer layers. A Cr(VI)-free proposed candidate must provide an equal or better performance with the same film thickness. If it cannot be achieved with the same thickness and requires a higher film thickness then it will affect the weight of the component, and thus the final product, which in the case of an aircraft is critical for fuel consumption. Increased film thickness may also affect several properties such as paint cohesion, adhesion on the substrates and crack formation.

There is also a link between corrosion inhibition and chemical resistance. The chemical resistance provided by a primer can be increased by the degree of cross-linking within the primer matrix, however increased crosslinking decreases leaching of the corrosion inhibitor. Due to the effective corrosion prevention / inhibition provided by Cr(VI) in protective primers , formulators are less reliant upon leaching of high concentrations of corrosion inhibitors from the matrix. If a Cr(VI)-free proposed candidate contained a less effective corrosion inhibitor, leaching would need to be higher than in the incumbent product. This may only be achievable by reducing the cross-linking in the primer matrix, and in doing so decreasing the chemical resistance of the product.

The GCCA application for authorisation (GCCA, 2017a) 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 parameters are listed below[25]:

- Hardware[26] base alloy(s);
- Contact or mating surfaces with other components;
- Exposure to fluids (e.g., de-icer, lubricants, salts, 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[27], 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

Based on the ongoing assessment of those proposed candidates listed in **Table 3-11** against the technical criteria listed in Section 3.4.4, the following proposed candidates have been progressed to test candidate status:

- Magnesium-based corrosion inhibitors;
- Silane-based coatings;
- Electrocoat primer technology;
- Calcium-based corrosion inhibitors;
- Organic corrosion inhibitors;
- pH-buffering additives;
- Phosphate-based corrosion inhibitors;
- Rare-earth based corrosion inhibitors;

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

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

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

- Sacrificial metal-based corrosion inhibitors;
- Zinc-based inhibitors (including zinc molybdate);
- Lithium-based corrosion inhibitors; and
- Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors.

These are discussed in more detail in Section 3.5.

There are many reasons why multiple proposed candidates have been shortlisted for the applied for use, not least the number of companies who have contributed to the consultation exercises used in producing this combined AoA-SEA, but also the number of different performance requirements which must be met across the different test candidate development plans for this use. A key consideration also is the compatibility with different substrates currently seen with primer products containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, or pentazinc chromate octahydroxide. A significant benefit associated with Cr(VI) inhibitors is that they show wide substrate compatibility, whilst most Cr(VI)-free inhibitors are more specific regarding suitability for different substrates. This means that even within individual member organisations, multiple primer products based on different corrosion inhibitor chemistries are being implemented in place of each protective primer type containing strontium chromate, potassium hydroxyoctaoxodizincate dichromate, or pentazinc chromate octahydroxide currently in use.

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.

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 protective 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 chromated 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.

Another aspect adding to the complexity of substitution with an alternative is the frequent need to use more than one corrosion inhibitors in the form of a stable proprietary mixture referred to above as 'Proprietary mixtures of Cr(VI)-free corrosion inhibitors'. Test candidate refers to any of the corrosion inhibitors or technologies listed in 'Shortlist of alternatives' above. Mixtures or 'formulations' are understood to contain one or more corrosion inhibitors as well as other ingredients that facilitate the delivery and function of the mixture. It is recognised that many test candidates are proprietary formulated mixtures containing more than one of the corrosion inhibitors listed in this

AoA, and that these proprietary mixtures are subject to the same substitution process described in Section 3.1.2.

Continuous innovation and development of test candidates, in the period since the parent authorisations were granted is a consequence of the need to replicate the key functions and performance requirements delivered by chromated primers used across a wide range of substrates and in-use conditions. Mixtures containing multiple corrosion inhibitors illustrates their inherent limitations when used in isolation. The frequent need to combine one or more corrosion inhibitor to reproduce the performance of chromated primers for all substrates used in the A&D sector illustrates one of the challenges with replacing the incumbent chromated primer system.

This review report does not refer to the short-listed test candidate category of 'Cr(VI)-free confidential' reported in the parent authorisations. Instead, where appropriate, reference may be made to mixtures of corrosion inhibitors used within proprietary formulations. As proprietary formulations are often confidential business information, their full composition either cannot be reported or is unavailable. This category of test candidate is discussed in Section 3.5.13 Proprietary mixtures of Cr(VI)-free test candidates.

When considering the hazard profile of each test candidate versus the chromated primer system, additional consideration may be required depending on the composition of the proprietary mixture to avoid the potential for regrettable substitution. A test candidate used in isolation may constitute a reduction in hazard profile, although may not meet all performance requirements. Therefore, due regard should be made to the hazard profile of the proprietary mixture if used to increase the performance threshold of the test candidate. As stated, full formulation disclosure is often not possible for reasons of confidential business information. Formulation hazard profiles are also likely to vary depending on their composition. For these reasons they are not presented in this review report. Where a hazard profile assessment is made, it is for the test candidate compared to the incumbent chromate substances.

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[28] 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;

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[28] 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

- 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[29], 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[30]. Changes to design of a product are subject to certification and can only be made following approval from the Regulator and compliance with the requirements of the appropriate Airworthiness Regulation, such as (EU) 2018/1139 (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'.

Note that in the following sub-sections we refer to different "corrosion inhibitors" to retain consistency with the parent applications but it should be recognised that these test candidates should not be assumed to always provide corrosion protection only.

3.5.2 Test candidate 1: Magnesium based corrosion inhibitors

3.5.2.1 Introduction: Summary of status reported in parent applications

Parent analyses of alternatives report the evaluation of magnesium-based corrosion inhibitors, also referred to as magnesium rich primer, as test candidates for use in various primer types including basic, fuel tank, structural and aluminised primers. In general, magnesium-based corrosion inhibitors were reported as failing to meet the technical requirements due to insufficient corrosion performance and lack of active corrosion inhibition.

For basic primer applications following preparatory steps of tartaric-sulphuric acid (TSA) or conversion coating, magnesium-based corrosion inhibitors were reported to not provide minimum corrosion resistance. Salt-spray performance was unacceptable with corrosion occurring after 1000 hours using test methods ISO 7253 and ISO 9227[31](CCST, 2015b).

The non-exhaustive list below gives examples of minimum pass thresholds for salt-spray exposure testing for different protective primer applications versus test method ASTM B117:

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[29] EASA (2022), available at Airworthiness Directives - Safhttps://www.easa.europa.eu/en/domains/aircraft-products/airworthiness-directives-adety Publications | EASA (europa.eu) accessed 18 October 2022

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

[31] Corrosion tests in artificial atmospheres – Salt spray tests, available at https://www.iso.org/obp/ui/#iso:std:iso:9227:ed-5:v1:en, accessed 27 December 2023

- Basic: 1000-3000 hrs;
- Fuel Tank: 1000 hrs;
- Structural: 500-3000 hrs; and
- Aluminized: 3000 hrs[32]

Where ranges are permitted, as shown above, there may be scope for tailoring pass thresholds within the range on a case-by-case basis depending on the expected service environment. In addition to the above, ADCR members report other requirements associated with the assessment of corrosion resistance. These include no visible corrosion of the metal beyond 1/8 inch from scribe marks and no blisters in the primer layer after 3000 hours exposure, according to ASTM B117. A general minimum requirement applied to all testing is to achieve equal or better corrosion performance, no regression, compared to the legacy chromated primer.

An example specification is MIL-PRF-23377K[33]. Section 4.5.8 in the specification specifies a minimum of 2000 hours in accordance with ASTM B117. Internal specifications commonly extend this to 3000 hours as an approximate to the performance of many chromated primers for this test.

Filiform corrosion resistance using test method EN 3665 was reported as within specification achieving 960 hours for structural primer applications. However, performance against salt spray test method ISO 9227 only achieved 2000 hours with an expectation of >3000 hours. Corrosion resulting in the formation of water blisters was reported. Water blister formation indicates loss of adhesion to the detriment of primer performance.

In contrast to Cr(VI) primers, magnesium based inhibitors were reported to not deliver the benefit of active corrosion resistance.

Minimum adhesion requirements were reported as met for dry adhesion, although performance varied depending on the primer type. Basic primers exhibited slightly inferior adhesion compared to structural primers. Chemical resistance requirements were reported as meeting minimum requirements (CCST, 2015b).

An alternative must also be compatible with all relevant substrates; refer to Section 2.3.1.1 for a list of substrates relevant to this application. (CCST, 2015b) reported the evaluation of an electrochemical active magnesium inhibitor added to an orthophosphate-based basic primer system to treat steel plate. Salt spray corrosion results (ASTM B117 and ISO 9227) were below expectation with corrosion appearing after 550 hours.

Magnesium-based primers were reported to be sensitive to the pre-treatment used as they require electrical contact with the base metal. Chemical conversion coatings electrically isolate the primer. Anodised surfaces were reported to exhibit poor compatibility with magnesium-based primers. As a consequence of the above, OEMs were reported to not have qualified magnesium-based primers.

In addition to compatibility with the pre-treatment process, the primer must also be compatible with topcoats as applicable. (CCST, 2015b) reported the successful application of topcoats producing visually immaculate surfaces with sufficient hardness (scratch resistance > 1500 grams as specified in

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[32] Values supplied by ADCR member

[33] Available at, https://chemsol.com/wp-content/uploads/2013/10/MIL-PRF-23377.pdf, accessed 5 April 2024

ISO 1518[34]. Processing was acceptable with curing at room temperature possible, and application across the whole aircraft also reported to be feasible.

3.5.2.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of Magnesium based corrosion inhibitors

Delivery of the key function of corrosion resistance was reported to be unacceptable by some members for this test candidate. A further reported issue was the performance requirement of surface appearance as a consequence of excessive generation of corrosion reaction products from a magnesium-based basic primer. As reported in the parent applications magnesium-based primer were observed to swell and cause blistering over time resulting in adhesion failure at the blister sites.

An aspect of the mode of action of Cr(VI)-free magnesium rich primer is to corrode sacrificially thereby protecting the substrate. However, an unintended consequence of this mechanism is the formation of magnesium corrosion products. These were observed to be excessive, invasive in some situations visible around treated component or assembly perimeters. Where this occurred the residual magnesium product had to be removed as it could not be distinguished from component/substrate corrosion. This negative consequence affecting surface appearance; potentially masking corrosion of the substrate, was deemed unacceptable. For example, it could interfere with future inspection and maintenance procedures. Other members reported ongoing work to assess the repairability of the alternative, another key consideration for future MRO activities.

Technical readiness levels for this magnesium based reached advanced stages; TRL 6-9 in some cases prior to the above reported issues leading to its rejection. Application is as a basic primer.

As discussed above, proprietary formulations may contain combinations of one or more of the suite of Test Candidates listed in Section 3.4.5. Members have reported testing proprietary formulations containing magnesium based and calcium-based test candidates. Another variable affecting technical feasibility of the test candidate and/or its rate of progression is the nature of adjacent processes in the treatment system. For example, in some cases testing is in combination with other chromated primers such as bonding primers where specified for a given design. Where this is the case, further work is required to evaluate the compatibility of the two primer types, basic and bonding, in a Cr(VI)-free form. Another member reported compatibility issues with the use of magnesium-based corrosion inhibitors and pre-treatments. A reported example combining a magnesium and calcium based basic primer test candidate with a Cr(VI)-free bonding primer is relatively less mature; reported to be at TRL 3. This demonstrates the interrelationship of primer uses and how one may impact the other. A bonding primer is typically applied on all the treated surfaces. After the assembly bonding step, the complete assembly is painted with basic primer. This includes any overlapping excess bonding primer not in the original bonded area. Expectation is that this work will progress to first production and industrialisation trials by 2030. Where Cr(VI) free bonding primer is not used, for repair activities, this test candidate failed corrosion testing Note, bonding primers are not covered by this use.

It is also reported that magnesium based test candidates are typically thicker than Cr(VI) primers. Significantly this adds weight to the aircraft which may be detrimental to operation of the design. For this reason, some members have rejected or not prioritised development of magnesium-based test candidates.

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[34] ISO 1518-1:2023: Paints and varnishes: Determination of scratch resistance

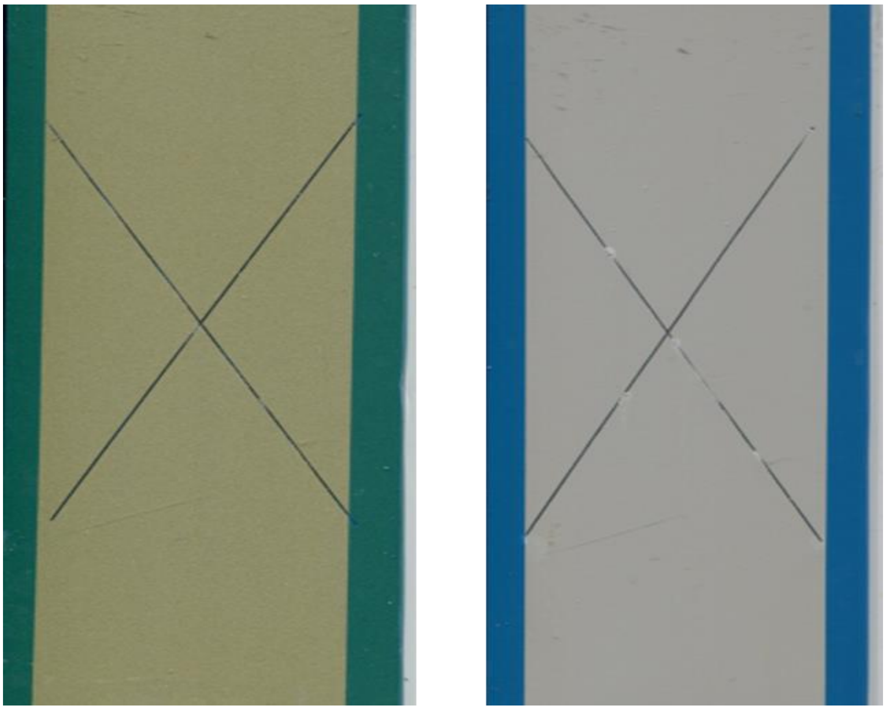

Figure 3-16: Scribed test coupons. Substrate AA2060 neutral salt spray test, 2000h.
Left image: Control with Cr(VI) basic primer
Right image: Cr(VI)-free basic primer (magnesium & calcium based test candidates in proprietary mixture)
Source: ADCR member

Figure 3-16 illustrates corrosion products in the scribed area of the right-hand coupon treated with a proprietary mixture containing magnesium based and calcium based test candidates.

Suppliers of specialist designs where there is a need to implement Cr(VI)-free basic and bonding primer candidates, as described above, to deliver the performance requirements of the overall system , need to achieve dual qualification of two new primer processes. This places logistical constraints on the supplier due to the need to maintain production schedules, thereby impacting the rate of progression to full industrialisation.

Economic feasibility of Magnesium based corrosion inhibitors

In general the cost of the test candidate is higher than the incumbent Cr(VI) primer ranging up to 50% higher. In addition to the cost of the raw materials other cost impacts are reported associated with the adoption of magnesium-based test candidates. Considering that the test candidate would be applied using mostly the same equipment as the incumbent primer systems, it is predicted that additional capital investment in new application equipment will be low to moderate. Although a detailed assessment of this is not available.

The costs attributed to the screening, development, staff training, certification and industrialisation of a test candidate primer system range widely with estimates of in excess of €70 million over a period of 12 years in some cases. These costs incorporate all investments. They serve as a guide to achieve industrialisation of the test candidate in the supply chain; R&D, testing and certification costs, up to MRL10. Additional costs attributed to infrastructure changes for example, may also be incurred on a case by case basis.

Health and safety considerations related to the use of Magnesium based corrosion inhibitors

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. However, the inherent risk is from VOC exposure and air emissions Due to the reactivity of magnesium particles with water, these primers are solvent based and as a consequence flammable. When present within a mixture with organic solvents and binders as supplied to the applicator, however, the risk of spontaneous combustion is largely mitigated.

Subject to meeting all performance requirements, under due diligence, appropriate risk assessment of magnesium based primers may be conducted. An elevated fire risk resulting from the presence of highly flammable high-surface area magnesium metal applied over a surface has the potential to be evolved into the air via removal and/or machining operations. Measures may need to be implemented to mitigate conditions that could elevate risks of auto-ignition, for example from friction or moisture, of dry magnesium powder present in the operational environment whether this is at the primer formulation or primer application stages of the process.

However, proprietary formulations utilising magnesium based test candidate do not exhibit the same hazard profile as with Cr(VI) based primers and therefore represent a clear reduction in hazard profile compared to Cr(VI).

Availability of Magnesium based corrosion inhibitors

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 primers for the use. 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, availability of magnesium-based primers is governed by their technical feasibility and in turn capacity to deliver all key functions and performance requirements in order to achieve certification as required for A&D purposes. As described above, not all applications, for example where impact on weight, surface appearance or repairability are important criteria required by the treated design, can be assumed to be able to meet the aforementioned certification requirements. Consequently magnesium based corrosion inhibitors are not viewed as ‘generally available’ across the whole sector.

Suitability of Magnesium based corrosion inhibitors

As summarised in Section 3.5.1 an alternative must be assessed against defined criteria to determine if it can be viewed as ‘suitable’. Magnesium based corrosion inhibitors are at a mature state of technical readiness for use in applications were surface appearance or presence of magnesium corrosion products is not an issue within the production process. Another limitation is where repair processes are required which cannot, or do not, also include a bonding primer step within the repair process. Where this step is lacking, corrosion resistance is reported to be compromised. Although proprietary basic primer formulations containing magnesium-based test candidates are at mature stages, and industrialisation is underway, they are not a suitable alternative for other applications including some MRO activities. In some cases they are reliant on the qualification of Cr(VI)-free bonding primers before the test candidate can be introduced at the system level. Until other programme work is complete, certification and full industrialisation is prevented.

A reduction in hazard profile for human health is achieved. Economically there are some impacts associated with raw material cost and initial costs from implementing the test candidate. However application equipment is broadly similar and does not represent a significant cost impact.

As described above, the test candidate is available on the market in proprietary formulations, however it is not certified across all existing applications of the use and therefore cannot be considered as 'generally available'. Therefore, noting all the above current limitations, this is not a suitable test candidate for all component designs for the 'use' of primer products other than wash or bonding primers.

3.5.3 Test candidate 2: Silane-based processes including sol-gel coatings

3.5.3.1 Introduction – summary of status reported in parent applications

Parent AoAs report the evaluation of test candidate systems utilising silane-based processes including sol-gel coatings. These include sol-gel chemistries, which are a group of processes in which a solvent is evaporated leading to the formation of a transparent gel film.

It was reported sol-gel chemistries do not provide significant corrosion resistance in their own right – and are unable to replicate the function of a primer. Their mode of action is aligned with conversion coatings and not primers. Additives are needed, and/or subsequent coatings are required to provide corrosion resistance comparable to that expected from a chromated primer. At present no known additives were reported to provide the necessary stand-alone corrosion performance (CCST, 2015b).

Corrosion resistance arises from the physical barrier provided by the sol gel film, rather than through electrochemical mechanisms. Consequently, sol gel coatings do not provide active corrosion inhibition. Their corrosion performance is linked to the thickness of the applied layer, sufficient corrosion performance can only be achieved by thicker layers. Thicker layers give problems related to embrittlement, which itself compromises corrosion protection.

It was reported (CCST, 2015b) that sol-gel coatings when combined with a Cr(VI)-free primer could be used on steel and aluminium for the exterior of aircraft / helicopters in situations where the corrosion inhibition requirements are less demanding.

The SOL-GREEN project, an initiative between the University of Toulouse and the aerospace industry has developed corrosion resistant sol-gel coatings for use in conjunction with aluminium alloys. Results from the SOL-GREEN project were reported; hydroxyapatite – silicon dioxide composite ("hybrid") coatings were deposited on AA2024-T3 and reported to show a salt spray resistance > 500 hours at layer thicknesses > 4 µm. This barrier effect could be increased by the addition of cerium and boehmite nanoparticles to the coating, which provided active corrosion protection and inhibited the corrosion propagation into the substrate; corrosion performance was improved up to 1400 hours. It was reported the minimum corrosion requirements for aerospace applications are often much higher, especially with regard to long-term corrosion which can be much greater than 6000 hours (ISO 9227) (CCST, 2015a).

Suitable application of a relevant pre-treatment (for example, pickling) is important to ensure sufficient adhesion of the sol-gel coating to the substrate, to avoid issues such as bond-line corrosion (CCST, 2015a) (CCST, 2015b).

It was reported that the industrial application method for sol-gel is complex and consequently had limited reproducibility (which is essential for a manufacturing process). Furthermore, due to the application method it was reported there was limited ability to coat complex parts. Novel methods to overcome this limitation such as electrophoresis were reported as not yet developed or still undergoing testing.

3.5.3.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of Silane based processes including sol-gel coatings

Silane based process test candidates used in basic primer applications were reported in some cases to deliver insufficient corrosion protection, poor mechanical properties; failing flexibility tests, and to be unsuitable for heat sensitive components for example where the primer curing temperature in excess of 120°C is required. Corrosion resistance was reported by one member to not exceed 168 hours for salt spray exposure with a minimum requirement in excess of 3000 hours. Other technical feasibility criteria reported to have failed testing for some basic primer applications include:

- Chemical resistance;
- Layer thickness;
- Surface appearance; and
- Does not form a coating on or adhere to non-metallic substrates

Progression for silane based corrosion inhibitors for this primer use is reported to be variable. As described in Section 3.5.3.1 complexities encountered with the industrialisation of the sol-gel process coupled with a limited ability of the test candidate to coat complex designs, inhibited rapid implementation for some applications. Industry R&D collaborations have resulted in limited progression achieving maturity of TRL 3 – 4. However, testing ceased after failing to meet certain performance requirements, as outlined above.

In contrast, performance requirements were reported to have been met for a narrow range of aluminium alloys, 2XXX series substrate reaching a maturity of TRL 9, allowing progression to the industrialisation phase. However, this performance improvement was achieved with a proprietary mixture utilising silane based process with zinc-based corrosion inhibitor. Testing across all substrates subject to treatment with Cr(VI) based primers within the sector is required before sector wide implementation is possible. The more successful development programme assessed the viability of the test candidate with the most challenging substrate series first. Therefore, testing of other relevant substrates is still required before the proprietary mixture can be industrialised across all relevant component designs.

Economic feasibility of Silane based processes including sol-gel coatings

In general the cost of the test candidate is neutral to higher than the incumbent Cr(VI) primer. In addition to the cost of the raw materials other cost impacts are reported associated with the adoption of the test candidate. The test candidate can be applied using existing equipment on the whole. It is predicted that additional capital investment in new equipment will be low although a complete and detailed assessment is not available.

Costs attributed to this primer test candidate to the screening, development, staff training, qualification, certification and industrialisation is considerable ranging up to several million euros for one company alone. For the entire process, there are examples of costs of more than €100,000 to progress beyond TRL 6. However, final costs encompassing testing of all substrates is difficult to estimate at the current state of maturity of the test candidate.

Where the Sol-gel solvent system is aqueous based, it is reported that some application difficulties may need to be resolved in the industrialisation of the test candidate, with associated costs. However, as the application method is similar for the test candidate no significant investment in training or increase in energy costs are foreseen.

Health and safety considerations related to the use of silane based processes including sol-gel coatings

For the purposes of understanding the risks associated with the test candidate, the key identifiers of the constituent elements of proprietary mixtures containing silane based corrosion inhibitors was assessed and reported to demonstrate a reduction in hazard profile compared to legacy Cr(VI) based primer systems. To maintain confidentiality, hazard classes for proprietary mixtures are not disclosed. By way of example, the hazard profiles of methyl trimethoxysilane (EC 214-685-0)[35] and vinyl trimethoxysilane (EC 220-449-8)[36] provide useful oversight of hazard profiles of silanes available for use in proprietary blends. Both represent a reduction in hazard profile compared to Cr(VI) substances.

Availability of Silane based processes including sol-gel coatings

While silane based corrosion inhibitor formulations are available on the EU market, limitations in technical feasibility and regulatory constraints prevent their application as an alternative to Cr(VI)-based primers for the use primer products other than wash or bonding primers. If technically feasible and regulatorily compliant silane-based corrosion inhibitor primer formulation(s) were to be identified suitable for all incumbent applications, 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, availability of silane-based processes is governed by their technical feasibility and in turn capacity to deliver all key functions and performance requirements in order to achieve certification as required for A&D purposes. As described above, not all performance criteria are currently met for all design certification requirements. Therefore silane-based processes including sol-gel coatings are not considered ‘generally available’.

Suitability of Silane based processes including sol-gel coatings

To be considered as suitable to substitute Cr(VI) based primers, the test candidate must fulfil the requirements discussed in Section 3.5.1. Each of the above sections discusses the elements of suitability in turn. It is apparent that a variety of technical challenges remain to be resolved. These include corrosion resistance, adhesion, and application for more complex geometries. Layer thickness and mechanical properties; flexibility, are other performance attributes to be managed for some applications of primers where silane based corrosion inhibitors are under investigation. However, due to the above non-universal adoption and technical feasibility deficiencies preventing certification, the

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[35] Hazard profiles of methyl trimethoxysilane, available at: https://echa.europa.eu/brief-profile/-/briefprofile/100.017.986

[36] Hazard profiles of vinyl trimethoxysilane https://echa.europa.eu/brief-profile/-/briefprofile/100.018.591

test candidate is not considered as 'generally available'. Therefore, noting all the above, it is not a suitable test candidate for all component designs for the 'use' of primer products other than wash or bonding primers.

3.5.4 Test Candidate 3: Electrocoat primers

3.5.4.1 Introduction – summary of status reported in parent applications

Evaluation of electrocoat test candidates was reported in some of the parent Applications. In general corrosion resistance was reported as having mixed results, and overall, not meeting the requirements for aerospace applications. It was also observed that the processing temperature needed to apply the electrocoat was too high for most aerospace-relevant alloys.

Additional issues reported were that the electrocoat layer is not conductive and does not provide active corrosion resistance. Adhesion was reported as being insufficient.

Insufficient corrosion performance on aluminium alloys was reported; for example, scratch length > 3 mm after 3000 hours (ASTM B117) and 720 hours (EN 3665) respectively. Filiform corrosion testing (according to EN 3665) showed average blister length of 1 mm on clad 2024 T3 aluminium alloy and 0.25 mm on bare 2024-T3 alloy after 3000 hours exposure and the neutral salt spray test (ISO 9227)(CCST, 2015b).

After 6000 hours in the neutral salt spray test, it was reported results were in line with civil aviation requirements. Additionally, it was reported that initial results from the aerospace/helicopters sector (civil and military) for corrosion resistance after beach exposure (atmospheric corrosion) and accelerated aging exhibited inferior performance than the reference (chemical conversion coating with Cr(VI)-containing primer)(CCST, 2015b).

While it was reported that electrocoat can be used to coat complex parts and can be coated uniformly, a limitation of electrocoat is that it can only be applied using a dip-coating process, and therefore can only be applied in MRO operations where the part can be removed from the aircraft during overhaul. It is not suitable for in-situ touch-up. In these situations it is reported only Cr(VI)-based primers can be used.

3.5.4.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of Electrocoat primers

To deliver the coating system, multi-stage processes are used comprising of separate formulated mixtures. These mixtures may consist of a pigment paste element, and separate resin mixture which are utilised according to manufacturers' instructions.

Performance of electrocoat primer test candidate for basic, structural and fuel tank primer types has been reported, with variable results across the spectrum of performance requirements. Adhesion, in basic primer applications is reported to be deficient in some instances when followed with certain subsequent layers and sealants. As a consequence, evaluation as a test candidate for some basic primer applications has been discontinued.

Including the above examples, key functions and performance requirements reported in some instances to have failed at some point in early evaluation when used for basic primer applications include:

- Chemical resistance;
- Compatibility with different application methods;
- Adhesion promotion;
- Mechanical properties; and
- Repairability.

The above list does not represent all observed performance attributes; however it does illustrate the potential vulnerability of the test candidate to failure when tested in combination with different component designs subject to different service environments. In order to mitigate performance attribute failures, examples of which are identified above, it may be necessary to implement a change in design. If these design changes are too numerous for a given certified aircraft, this may not be a feasible option for many OEMs.

Testing is reported as mature in some cases and ranges up to and including TRL 5. Positive results have been reported for key functions of corrosion resistance and adhesion. In addition, the performance requirements layer thickness, flexibility (mechanical properties), and ultra-violet protection were reported as acceptable by other members for basic, structural and fuel tank primer applications. However, challenges remain concerning compatibility with sealants and topcoats where further development work is required. Where this test candidate is most advance, at TRL 5, it is estimated to reach TRL 9, and subject to successful production trials, full industrialisation by 2038. It must be recognised that Electrocoating is a novel process and therefore precedent may not exist in all situations. Therefore, there is a high degree of risk of setbacks occurring at some point in the industrialisation phase hence the extended projected timeline for successful industrialisation reported in some cases.

As primers are the last stage in a multi-step treatment system where adjacent steps in the process are inter-dependent the development of substitutes cannot be conducted in isolation. A factor governing the progression of Cr(VI)-free primer test candidates including Electrocoat, is the need to industrialise performant, reproducible and compatible pre-treatments, for example anodising and chemical conversion coating. These pre-treatments may also utilise chromates and be subject to their own substitution processes; not a subject of this dossier. Resources, including human and specialised test facilities have to be prioritised accordingly. In some test programmes, development of pre-treatments has been prioritised over the Electrocoat test candidate to ensure a stable and robust treatment system is developed and certified suitable for industrialisation.

Economic Feasibility of Electrocoat primers

This technology is removed from conventional epoxy primers and therefore is not the focus for all primer users seeking to continue using conventional application methods and pre-existing facilities due to costs associated with new equipment or logistical constraints restricting viable locations for installation for example.

Implementation of this test candidate is reported to require significant changes to existing infrastructure and facilities these include:

- Bespoke treatment tanks;

- Specialised filtration system;
- Rectifiers with control panel;
- Curing oven upgrades as required; and
- Waste management infrastructure for coating treatment and disposal.

The specialised nature of this test candidate will require extensive staff training including line operators and quality control personal each with associated cost implications.

Estimated costs vary depending on the size of the facility. For example ~ €300,000 to install a pilot 500 litre test tank. Costs for full implementation post pilot stage testing are reported to be in the range of €1.2M per tank. Reorganisation of existing facilities, as highlighted above, will add additional cost impacts from implementation of this test candidate. Any such costs will be on a case by case basis; by way of example costs of up to €1.1M in addition to the above are reported. Ongoing factors with potential economic impact include costs attributed to charging the process tanks with the primer, cost of the primer, compared to the incumbent chromated version, and an ongoing risk of spoilage.

Health and Safety considerations related to the use of Electrocoat primers

This test candidate is available as a proprietary system and therefore the hazard profile will be determined by specific formulation used. To deliver the coating system, a multi-component process can be used comprising of separate formulated proprietary elements.

These elements may consist of a pigment paste, and separate resin component which are utilised according to the manufacturers' instructions. Analysis of an example of this proprietary system demonstrates a reduction in hazard profile compared to Cr(VI) based primer. An example of an electrocoat multicomponent mixture classification; worst case scenario is reported for one of the components of the system R36/38, irritating to eyes and skin.

Availability of Electrocoat primers

Proprietary multicomponent systems are available on the market. This technology requires specialised equipment. This is summarised in the Economic feasibility section above and reported to be available on the market. Limitations in technical feasibility and regulatory constraints, certification, prevent its application as an alternative to Cr(VI)-based primers for the use of primer products other than wash or bonding primers. Reported progression has reached TRL 5 status for most advanced application scenarios. As a consequence of not meeting all performance requirements for all affected component designs and limited progression of substitution, Electrocoat test candidate is not considered 'generally available' for A&D purposes.

Suitability of Electrocoat primers

To be considered as suitable to substitute Cr(VI) based primers, the test candidate must fulfil the requirements discussed in Section 3.5.1. The technical feasibility of Electrocoat primer systems is reported to only be acceptable for the range of performance requirements across a limited range of component designs. Due to the specialised nature of the technology, some suppliers need to adapt existing infrastructure and install a host of new equipment. This contributes to inhibiting it rate of progression and in some cases can be a factor preventing or delaying development of this test candidate. Proprietary formulations are available on the market, however as described above they cannot be readily introduced without significant capital expenditure in both pilot trials and then full industrialisation.

Electrocoat proprietary formulations reported demonstrate a considerable reduction in hazard profile compared to incumbent Cr(VI) based primers, supporting this aspect of their suitability as an alternative.

Although this test candidate is reported to have given positive results with an advanced maturity for some design owners, due to the relatively immature sector wide TRL status and reported technical feasibility weaknesses for some component designs, Electrocoat cannot currently be considered ‘generally available’ to the sector as a whole. Therefore, it is not considered a suitable test candidate for all component designs for the ‘use’ of primer products other than wash or bonding primers.

3.5.5 Test Candidate 4: Calcium-based corrosion inhibitors

3.5.5.1 Introduction – summary of status reported in parent applications

Evaluation of calcium-based test candidates was reported in some of the parent Applications. Examples include, calcium carbonate, calcium hydroxide, calcium metasilicate, and calcium borosilicate (CCST, 2015b).

Evaluation of calcium based corrosion inhibitors either standalone or in a proprietary formulation combined with other inhibitors is reported to have been predominantly on steel substrates with far less data attributed to aluminium substrates. Corrosion resistance and adhesion promotion performance were reported as insufficient for aerospace applications. Screening at laboratory scale concluded all failed to meet minimum corrosion resistance requirements versus salt spray testing (ISO9227). Due to not meeting minimum technical feasibility requirements, calcium based inhibitors were not progressed for further testing, and considered unsuitable as an alternative to Cr(VI)-based primers (CCST, 2015b)

As stated above the majority of testing is reported to have been performed on steel plate. Performance on high strength aluminium alloy substrates, prevalent in aerospace and defence applications, could not be readily transferred. At the time of reporting exploration of calcium based inhibitors in combination with other compounds including magnesium, molybdenum, and phosphates in proprietary formulations had been conducted. Results for adhesion promotion were poor; insufficient for aerospace requirements. Also, tests were with a limited range of substrates; aluminium substrate data was unavailable. No in-depth data was available therefore extensive further testing would be required if these test candidates were to be progressed (CCST, 2015d).

3.5.5.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of Calcium-based corrosion inhibitors

Members reported examples of calcium compounds including calcium metasilicate (Wollastonite)[37] and calcium sulphate cited as examples used in combination with other corrosion inhibitors. As stated above, calcium-based corrosion inhibitors were considered unsuitable to be used as standalone options. Other inhibitors such as magnesium based are reported to be used in combination within blends (proprietary formulations) in an attempt to deliver the performance attributes required from the primer system.

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[37] CAS 10101-39-0 https://echa.europa.eu/substance-information/-/substanceinfo/100.030.214

For small areas of repair, a bonding primer is not used therefore the repair is reliant on the basic primer to provide corrosion resistance. It is reported that proprietary Cr(VI)-free basic primer using a including calcium based corrosion inhibitors for small repairs, failed corrosion resistance tests if a Cr(VI)-based bonding primer is not also used.

Where used in combination with a chromated bonding primer, calcium-based corrosion inhibitor in a proprietary blend demonstrated sufficient performance with high strength aluminium alloys. Testing has progressed to TRL 6. Testing of Cr(VI)-free basic primer in combination with Cr(VI)-free bonding primer is at a less mature TRL 3 status.

Economic feasibility of Calcium-based corrosion inhibitors

The costs attributed to the screening, development, staff training, certification and industrialisation of a test candidate primer system containing calcium-based inhibitors for TRL 3 to industrialisation is reported to be up to €1.4M for one supply chain example. These costs will increase where other primer types, such as bonding primers, need to be developed in unison to allow the adoption of a Cr(VI) free primer system.

Health and safety considerations related to the use of Calcium-based corrosion inhibitors

This test candidate is available as a proprietary system as it is considered unsuitable to be used as a standalone inhibitor. Therefore the hazard profile of any formulation should also be considered.

Examples of calcium-based inhibitors used in proprietary formulations reported by members are given below in **Table 3-12**

Table 3-12: Hazard profiles of selected calcium based corrosion inhibitors

Calcium-based corrosion inhibitor	CAS Number	Hazard Classification and Labelling
Calcium metasilicate[(a)]	10101-39-0	Eye Irrit.2; H319, STOT SE 3; H335 May cause respiratory irritation
Calcium sulphate[(b)]	13397-24-5	Not classified

Source
(a) https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/129760
(b) https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/64219

Availability of Calcium-based corrosion inhibitors

Calcium-based corrosion inhibitors are not technically feasible options as standalone alternatives, therefore, the only current scenario of use if within proprietary formulations.

Although proprietary formulations containing calcium based corrosion inhibitors are commercially available is it reported that bonding primers are used in combination. Testing with non-chromated bonding primers is at an earlier stage of development, TRL 3.

Implementation with one component family using high strength aluminium is more advanced and entering the industrialisation phase, however this is not representative of the wider array of aluminium alloys treated with basic primers.

As a consequence of the above, calcium based inhibitors are not considered ‘generally available for A&D purposes.

Suitability of Calcium-based corrosion inhibitors

To be considered as suitable to substitute Cr(VI) based primers, the test candidate must fulfil the requirements discussed in Section 3.5.1. This section outlines each element that together constitute suitability of the test candidate to be an alternative to the incumbent chromate.

Calcium based corrosion inhibitors are not considered a technically feasible option when used in isolation. Development as a component within proprietary formulations is ongoing with positive results to date, however further work is required to assess compatibility with Cr(VI)-free bonding primers for example.

Economic feasibility and hazard profile of substances assessed within this test candidate category are not barriers to use. However due to the ongoing testing required to determine key functions, performance requirements, including compatibility with other primer types, is completed across all required designs, the test candidate cannot be considered suitable for the substitution of Cr(VI) base primer products.

3.5.6 Test Candidate 5: Organic and organometallic corrosion inhibitors

3.5.6.1 Summary of status reported in parent applications

Evaluation of organic test candidates was reported in some of the parent Applications (CCST, 2017) (CCST, 2015b). Discussion in the parent Applications relating to wash primers only has been excluded from this analysis. In general, corrosion resistance was reported as insufficient.

Test candidates typically comprise benzotriazole (BZT) derivatives such as 5-methyl-1H-benzotriazol (5-BZT) and triazol thiol. BZT is reported as used in basic primers and coatings on aluminium alloys alloyed with elements including, magnesium, manganese, zinc, and copper. Organo-zinc pigments are reported although these were subject to R&D within formulators.

BZT does not provide active corrosion inhibition (CCST, 2017) as release of BZT from the primer is hindered (CCST, 2015b).

Different corrosion results were obtained by formulators for a formulation with 5-BZT in epoxy basic primers on aluminium alloys (AA2024-T3 pre-treated with either TSA anodising or Cr(VI)-free conversion coatings). Corrosion protection did not meet the requirements in salt spray tests according to ISO 9227 and ISO 7523 (3000-6000 hours). Here, corrosion pitting appeared after 2000 hours with creepage within the range of 2 mm. After 168 hours exposure (test according to ISO 9227) corrosion pitting was observed in the scratch. In addition, active corrosion resistance was reported to not be supported. It is proposed that this was a consequence of hindered release of BZT from the primer matrix(CCST, 2017) (CCST, 2015b).

BZT was reported to show blisters on the surface of the substrates due to osmotic effects. It was proposed that nitrogen in the BZT molecule may take part in the curing process of the primer/paint matrix, either being consumed, or interfering with the curing process itself. If so, this could result in blistering following exposure to water and also negatively impact resistance to hydraulic fluids (CCST, 2015b).

A coordination complex test candidate comprising a 9:1 combination of zinc calcium strontium aluminium orthophosphate silicate hydrate and zinc-5-nitroisophthalate in solvent-borne acid-cured epoxy DTM (direct-to-metal) coating was tested. It demonstrated only slight corrosion after 2218 hours on bare aluminium. However, these results still did not meet the corrosion requirements (3000-6000 hours, as discussed above).

Chemical resistance was tested on the alloys above, pre-treated with TSA anodising, chromate conversion coatings or Cr(VI)-free passivation. BZT in epoxy basic primers showed sufficient chemical resistance (ISO 1518, ISO 2409 and ISO 2812) after water immersion for 14 days and 1000 hours immersion at 70°C in hydraulic fluid (grade 0 to 1 in both tests). However, in other testing it was reported BZT failed hydraulic fluid and water resistance tests, indicating insufficient chemical resistance when applied on Al alloys (CCST, 2017)(CCST, 2015b).

Layer thickness was found to be sufficient; 7-20 µm for Fuel Tank Primer and 20-50 µm for Aluminised Primer (CCST, 2017). Adhesion (ISO 2409) was reported as sufficient – GT0[38] for dry adhesion (CCST, 2017) (CCST, 2015b).

It was found that thiol-based inhibitors such as triazol thiol reacted with epoxy functional groups, affecting the physico-chemical properties of the formulation which made it difficult to formulate them into epoxy primers for aeronautic applications (CCST, 2017).

Cr(VI)-based corrosion inhibitors provide an important buffering capacity, preventing acidification on aluminium surfaces. BZT's buffering capacity had still to be evaluated (CCST, 2015b).

It was reported that stability issues were consistently highlighted by paint manufacturers when using organic substances in test candidates, and that additional studies were needed (CCST, 2015b)

3.5.6.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of Organic and organometallic corrosion inhibitors

Benzothiazole-containing proprietary mixtures

A number of members have reported their development of benzothiazole-containing proprietary mixtures, which also contain inorganic corrosion inhibitors (for example, metal phosphates). These are discussed below. Benzothiazole is a structural analogue of benzotriazole (BZT).

One member reported progression is currently at TRL 1-2, with the hope that this will progress to TRL 3 in 2024.

A member reported that for basic and fuel tank primers, benzothiazole-containing proprietary mixtures have achieved TRL 4 for a limited number of substrates. An equivalent level of end-product performance compared to the Cr(VI)-free alternative is required.

A member reported progression to TRL 4. After exposure to a warm and moist atmosphere for a variety of test times (up to 42 days), the test candidate caused degradation of sealants applied on the

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[38] GT0: ISO2409 Adhesion Test results classification: The edges of the cuts are completely smooth: none of the grid squares are separated, available at https://www.neurtek.com/descargas/neurtek_master_paintplate_en.pdf accessed 24 January 2024

surface. Single lap-shear tests showed a significant decrease in shear strength as well as loss in adhesion. This was observed after an exposure duration of 84 days.

Other proprietary mixtures containing organic corrosion inhibitors

A member reported evaluating a two-part proprietary mixture comprising a base containing C18 fatty acids, and separate curing agent for structural primer application. This mixture exhibited poor compatibility with certain topcoats impacting corrosion resistance.

Economic feasibility of Organic and organometallic corrosion inhibitors

One member expects costs associated with raw materials and investment in new equipment needed to implement benzothiazole-containing proprietary mixtures will increase compared to the incumbent Cr(VI) based primer. Other impacts on costs have not yet been fully assessed by this member.

Another member observed that while in general Cr(VI)-free products are more expensive, implementation of these organic primers is at present thought to be neutral to Cr(VI)-primers, or with a limited increase in cost. They noted that implementation costs are difficult to assess at this stage due to e.g., the uncertainty relating to the final number of design configurations requiring treatment.

Health and safety considerations related to the use of Organic and organometallic corrosion inhibitors

A benzothiazole compound reported as a component in some organic blends has a harmonised classification as hazardous to the aquatic environment and skin sensitising, however no SVHC concerns have been raised.

It is therefore to be expected that benzothiazole represents a reduction in hazard profile compared to Cr(VI)-containing primers. As discussed in Section 3.5.1, due regard should still be given to the hazard profile of any formulation used that contains organic corrosion inhibitors to mitigate potential for regrettable substitution.

Availability of Organic and organometallic corrosion inhibitors.

In the event that this test candidate can be successfully developed to MRL 10, it is expected that benzothiazole proprietary mixtures will be available in sufficient quantities with a supply chain expected to be developed or in place. A phased transition from Cr(VI)-based primer may be necessary to accommodate the ramp-up in volume required.

One member noted that their strategic procurement department is an integral part of the qualification process and that no major issues have been identified with benzothiazole-containing proprietary mixtures from a supply chain point of view. However, they expect a phased transition from Cr(VI) primers to Cr(VI)-free primers due to e.g. type of substrate and associated performance attributes, or military versus civil applications. As reported above, development of this test candidate is at a relatively immature stage and has not completed testing required to certify its use for all A&D applications, therefore it is not considered ‘generally available’.

Suitability of Organic and organometallic corrosion inhibitors

Technical feasibility of the test candidate is reported to be subject to its use in proprietary formulations. By their nature these will vary in performance depending upon their composition and nature of use; substrates, design, and service environment. Those proprietary formulations reported above are at a relatively immature TRL status; up to TRL 4. A significant performance issue affects adhesion promotion as a consequence of degradation of sealants used in combination with the test candidate present within a proprietary formulation. This occurred after exposure to warm and humid conditions.

Economic feasibility is broadly comparable to other test candidates with potential for expenditure on new equipment. Cost of proprietary formulations vary therefore it is difficult to summarise if there would be a long-term cost increase as a result of a transition to this test candidate compared to incumbent Cr(VI)-based primers. Overall any cost impact from the test candidate, excepting costs associated with testing and implementation, is expected to be neutral or moderate.

The test candidate represents a reduction in hazard profile versus Cr(VI)-based primer. However, due to the limited technical feasibility and relatively immature development status, TRL 4, the candidate is not considered ‘generally available’. Therefore, this does not represent a suitable test candidate for the substitution of Cr(VI) based primer products.

3.5.7 Test Candidate 6: pH-buffering additives

3.5.7.1 Introduction – summary of status reported in parent applications

Evaluation of pH-buffering candidates was briefly discussed in one of the parent Applications, but with limited technical details. This groups of substances is captured under the generic term of classical corrosion inhibitors. As such proprietary formulations containing these substances were reported to be available on the market. It was reported that commercially available products did not have sufficient technical performance, for example corrosion inhibition, for basic or bonding primer aerospace applications. A minimum of 15 years was forecast to be required to industrialise a viable test candidate.

Such additives contain substances such as magnesium oxide, magnesium hydroxide, calcium carbonate, and calcium hydroxide that neutralize acidic conditions that support corrosive attack (GCCA, 2017b).

3.5.7.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of pH-buffering additives

This category of test candidate is reported to generally not be a standalone solution and must be considered as part of a mixture composed of several distinct components one of which is pH-buffering additives with different modes of action. Therefore, it is not possible or relevant to provide an analysis of this test candidate category in isolation. The current reported convention is to use them in their capacity as additives to supplement the mode of action of proprietary formulations and other test-candidates.

Economic feasibility of pH-buffering additives

No cost impact is reported for the use of pH buffering additives for protective primer applications.

Health and safety considerations related to the use of pH-buffering additives

Examples of pH-buffering additives include those listed in the introduction e.g. magnesium oxide magnesium hydroxide, calcium carbonate, and calcium hydroxide. As discussed above these substances are typically not intended to be used in isolation. All represent a reduction in hazard profile compared to the incumbent chromate substances. The examples of pH-buffering additives provided in Section 3.5.7.1 are tabulated below in **Table 3-13.**

Table 3-13: Hazard profiles of selected pH-buffer additives

pH-buffer additive	CAS Number	Hazard Classification and Labelling
Magnesium oxide[(a)]	1309-48-4	H319; Eye Irrit.2
Calcium carbonate [(b)]	7440-70-2	H318; Eye Dam.1, H315; Skin Irrit.2, H335; STOT SE 3
Calcium hydroxide [(c)]	1305-62-0	H318;Eye Dam.1; H315; Skin Irrit.2, H335; STOT SE 3

Source
(a) https://echa.europa.eu/fi/information-on-chemicals/cl-inventory-database/-/discli/details/14963
(b) https://echa.europa.eu/fi/brief-profile/-/briefprofile/100.006.765
(c) https://echa.europa.eu/fi/brief-profile/-/briefprofile/100.013.762

Availability of pH-buffering additives

As stated in the introduction, proprietary formulations containing pH buffering additives are available on the market.

Suitability of pH-buffering additives

To be considered as suitable to substitute Cr(VI) based primers, the test candidate must fulfil the requirements discussed in Section 3.5.1. In terms of its technical feasibility, when used in isolation, pH-buffering additives are reported to not offer key functions and performance requirements necessary to the function of the primer. It is reported that they are used in combination with other test candidates to supplement or enhance the mode(s) of action they provide. Therefore pH-buffer additives are not regarded as technically feasible used in isolation for the purposes of the use primer products other than wash or bonding primers.

With respect to the criteria of economic feasibility and reduction in hazard profile, pH-buffering additives demonstrate a favourable outcome.

Due to not being a technically feasible option to replicate the key functions and performance requirements of the chromated primer, pH-buffering additives are not considered 'generally available' to be used in isolation. As a consequence, pH-buffering additives used in isolation are not deemed to be suitable alternative for this primer use.

3.5.8 Test Candidate 7: Phosphate-based corrosion inhibitors

3.5.8.1 Introduction – summary of status reported in parent applications

Parent AoAs report the evaluation of phosphate-based test candidates. Examples include orthophosphates and polyphosphates, zinc phosphate, aluminium triphosphate, barium phosphate and aluminium zinc phosphate. Magnesium/calcium aminophosphate with modified orthophosphate or polyphosphate corrosion inhibitors have also been reported.

In general, corrosion resistance and active corrosion resistance were reported as insufficient.

Testing of Mg/Ca-aminophosphate salts in solvent or water-based epoxy primers failed to meet the corrosion resistance requirements in the salt spray test (ISO 9227). Corrosion performance of these products is also not sufficient on steel. Significant corrosion is observed after 288-430 hours in the salt spray test (CCST, 2017).

Requirements for active corrosion inhibition were not met. Amine or epoxy matrices in combination with zinc phosphate and cerium salt which failed to meet minimum requirements. After 3000 hours on Aluminium substrates, pitting corrosion appeared. Creepage from a scratch was >1.25 mm (on Cr(VI)-free conversion coating pre-treated aluminium) and around 1.5 mm or higher (TSA[39] pre-treated aluminium)(CCST, 2017).

Adhesion, layer thickness, and chemical resistance were reported to meet the requirements. On AA2024-T3 aluminium alloy pre-treated with TSA or conversion coatings, GT0 was achieved for dry adhesion, and GT0-1 was achieved after water immersion for 14 days. Chemical resistance also met the requirements. Layer thickness was reportedly sufficient (7-20 µm for Fuel tank Primer and 20 – 50 µm for Aluminised Primer)(CCST, 2017).

3.5.8.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of Phosphate-based corrosion inhibitors

Section 3.5.1 introduces how innovation has resulted in mixtures of individual corrosion inhibitors in proprietary formulations. An example of this is a proprietary formulation combining zinc based and phosphate-based inhibitors. Inferior corrosion resistance compared to the legacy Cr(VI) based primer is reported. **Figure 3-17** illustrates the outcome of a screening test to assess the corrosion resistance of scribed test coupons. These are treated with the formulation containing phosphate based corrosion inhibitor, top images, and the benchmark Cr(VI) based basic primer, bottom images, with the characteristic pale yellow colouration. Both tests were performed in duplicate. The pass criteria required equal to or better than performance compared to the benchmark over the same duration. As shown, the test candidate coupons exhibit significantly more blistering around the border region together with corrosion products at the scribe site in the centre of the coupons. As a consequence, these results were considered a fail.

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[39] Tartaric-sulphuric acid anodising

Figure 3-17: Corrosion resistance: Test candidate basic primer containing phosphate-based corrosion inhibitors

Top images: Corrosion of scribe on test candidate treated coupon

Bottom images: Scribed benchmark coupon treated with Cr(VI) basic primer

Source: ADCR member

Chemical resistance performance is reported to be inadequate for some scenarios of use. **Figure 3-18** shows a chemical resistance test according to ASTM D 3359. After exposure to the chemical the coated test panel is scribed to assess any loss of adhesion of the coating to the substrate. The image on the left clearly shows areas of substrate exposed along the scribe lines indicating removal of the coating. In contrast, the benchmark test panel on the right demonstrates no loss of adhesion. This is indicative of no deterioration of the Cr(VI) based primer after chemical exposure.

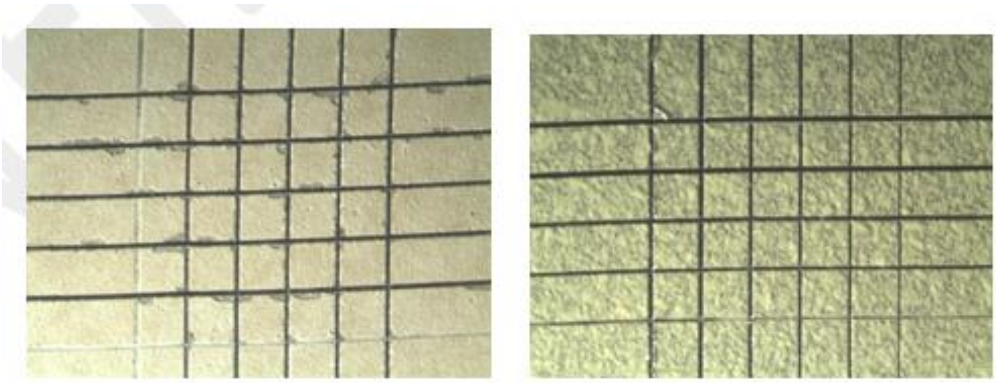

Figure 3-18: Chemical resistance: Test candidate phosphate-based corrosion inhibitors
Left: Test Candidate: Areas of failed adhesion following chemical exposure
Right: Chromated primer benchmark. No loss of adhesion following chemical exposure
Source: ADCR member

Another member reported testing phosphate-based test candidates for basic primers. Tests are still being carried out for corrosion resistance, adhesion promotion and layer thickness. Other tests have acceptable performance or are not applicable in this case. The phosphate-based candidate does not work on all design configurations and for all performance requirements. Progression of phosphate-based test candidates is at the screening stage and has been found not to offer sufficient performance for all configurations. Referring to the timeline presented in **Figure 3-10**, substitution process, phosphate-based corrosion inhibitors have attained TRL 3 working towards TRL 4 in most cases.

Economic feasibility of Phosphate-based corrosion inhibitors

One member observed that while in general Cr(VI)-free products are more expensive, implementation of this test candidate is at present thought to be in line to Cr(VI)-based primers, or with a limited increase in cost. They noted that implementation costs are difficult to assess at this stage due to e.g., the uncertainty relating to the final number of design configurations.

Health and safety considerations of Phosphate-based corrosion inhibitors

Table 3-14: Hazard profiles of selected phosphate based corrosion inhibitors

Phosphate-based corrosion inhibitor	CAS Number	Hazard Classification and Labelling
Aluminium dihydrogen triphosphate	13939-25-8	Eye Irrit. 2; H319
Source: ADCR member		

Availability of Phosphate-based corrosion inhibitors

One member noted that their strategic procurement department is an integral part of the qualification process and that no major issues have been identified with phosphate-based blends from a supply chain point of view. However, they expect a phased transition from Cr(VI) primers to Cr(VI)-free primers due to e.g. type of substate, or military versus civil applications. Proprietary formulations containing phosphate-based primers are freely available on the marketplace. However as described above, this test candidate has not achieved required performance versus the incumbent chromate primer, and therefore is not considered 'generally available' to all users.

Suitability of Phosphate-based corrosion inhibitors

To be considered as suitable to substitute Cr(VI) based primers, the test candidate must fulfil the requirements discussed in Section 3.5.1. This section outlines each element that together constitute suitability of the test candidate to be an alternative to the incumbent chromate. From a point of view of technical feasibility, the test candidate demonstrates clear weaknesses with respect to corrosion resistance and chemical resistance despite being used in a proprietary formulation. Further development work is required before the test candidate can be progressed further in the substitution process for the affected design/substrate combinations. Impact on economic feasibility is low or neutral, and the test candidate represents a reduction in hazard profile compared to the incumbent chromate substances.

However, due to the performance deficiencies outlined above, and the relatively immature development stage, this test candidate is not considered generally available to many users of protective primers. As a consequence this test candidate is not currently considered suitable for this use.

3.5.9 Test Candidate 8: Rare-earth based corrosion inhibitors

3.5.9.1 Introduction – summary of status reported in parent applications

Parent AoAs report the evaluation of rare-earth based test candidates. Formulations typically comprise praseodymium or cerium compounds (such as praseodymium hydroxide or cerium nitrate) in combination with other additives.

Generally, it was reported that praseodymium compounds in combination with other additives are effective corrosion inhibitors in epoxy polyamide primers when the primer is deposited onto high strength aluminium alloys with chromate loaded conversion coating. The primers do not perform as well when they are applied on non-chromate conversion coatings or bare Al alloys.

AA2024-T3 aluminium alloy test panels showed that primer systems based on Praseodymium oxides, Pr_2O_3 or Pr_6O_{11} provided corrosion protection for up to 3000 hours (ASTM B117) when applied after pre-treatment with chromate conversion coating but not when they were applied after pre-treatment with Cr(VI)-free conversion coatings. When cerium salts were tested in similar conditions (including substrates pre-treated with TSA), creepage from scratch was > 1.25 mm and pitting appeared after 3000 hours, meaning corrosion requirements were not met (CCST, 2017). Minimum requirements for filiform corrosion were achieved (EN 3665), but when corrosion protection up to 3000 hours is required, the test candidates do not meet the requirements (CCST, 2015b).

It was reported that addition of 0.5% by weight cerium oxide to a magnesium-rich primer was shown to significantly improve the protection performance on AZ91D magnesium alloy, however no detailed results were provided (CCST, 2017).

It was reported in one of the parent Applications that results for chemical resistance and compatibility with sealants were not reproducible (i.e. not acceptable).

3.5.9.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of Rare-earth based corrosion inhibitors

A commercially available proprietary formulation containing rare-earth based corrosion inhibitor test candidates is reported by one member to have been in use as a basic primer for a period of years. However, it is also reported that implementation is limited across their suite of applications as performance is insufficient for use with most production programmes.

Another member reported progression to TRL 6 maturity in basic primer type application. This was with specific technically challenging components with progression including the revision of design drawings. Post TRL 6 actions will expand to evaluation of the test candidate with other less technically demanding components. Priority is given to those substrates made from the most sensitive and challenging substrates. Additional time is forecast for activities leading to the industrialisation of the test candidate with other component designs. For example, revisions to design drawings and Maintenance Manuals is reported to take up to five years, required for progression to TRL 9. An additional five years minimum is estimated for field testing after reaching TRL 9. This is to ensure components treated with the test candidate perform reliably in all related service environments.

Separately from above, a basic primer application of rare-earth based corrosion inhibitors used in a proprietary formulation exhibited mixed results dependent upon the substrate. Testing on less corrosion resistant aluminium alloy series, 2XXX and 7XXX, ceased at an immature TRL 3. However, in conjunction with 6XXX series aluminium alloy substrate results have been far more positive. Performance indicators for attributes including corrosion resistance, bonding to other materials in the assembly, and dynamic performance are acceptable contributing to progression forecast to reach MRL 10 by 2026. This disparity in compatibility and performance attributes between the above examples of aluminium alloy series serves to illustrate the importance of substrate to the likelihood of successful substitution for individual designs.

Economic feasibility of Rare-earth based corrosion inhibitors

The cost of the test candidate is reported to be higher than the Cr(VI)-based primer. Additional costs from utilisation of the test candidate; for example, operator training, and energy consumption are reported to be neutral compared to legacy chromated primer systems by one member. This is in part attributed to the common application method. It is reported by one member that costs attributed to post TRL 6 activities could be in the order of €100,000, including further testing and certification requirements.

Health and safety considerations related to the use of Rare-earth based corrosion inhibitors

For the purposes of understanding the risks associated with the test candidate, by way of example dipraseodymium trioxide is reported as present in at least one proprietary blend containing rare-earth based corrosion inhibitors. Based on publicly available data, this substance has a notified classification and labelling designation of Not Classified[40]. This represents a reduction in hazard profile compared to legacy Cr(VI) based primer systems.

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[40] https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/52314, accessed 12 January 2024

Availability of Rare-earth based corrosion inhibitors

As stated above proprietary formulations have been commercially available on the market and used for primer applications, including basic primers, for a period of years, in limited applications.

Limitations in technical feasibility and regulatory constraints; certification, limit adoption of this test candidate across all applications of Cr(VI)-based primers for the use primer products other than wash or bonding primers.

Although reported progression has reached MRL 10 by some members for limited programmes; status for other applications is less mature ranging from TRL3 to TRL 6. As a consequence of not meeting all performance requirements, including corrosion resistance for some substrates, further testing is required before the implementation of the test candidate can be initiated. Therefore, the test candidate rare-earth based corrosion inhibitors is not considered as 'generally available' for the above primer applications.

Suitability of Rare-earth based corrosion inhibitors

To be considered as suitable to substitute Cr(VI) based primers, the test candidate must fulfil the requirements discussed in Section 3.5.1. This section outlines each element that together constitute suitability of the test candidate to be an alternative to the incumbent chromate.

In the case of rare-earth corrosion inhibitors, they are commercially available, within proprietary formulations, and their role as an alternative is already well established with evidence of adoption in some designs within the industry. Examples of rare-earth elements used in proprietary formulations include dipraseodymium trioxide which is noted as providing a clear reduction in hazard profile compared to Cr(VI) based primer systems. However, a variety of technical challenges remain to be resolved for certain substrates. These substrates are reported to not meet performance thresholds for corrosion resistance for example, failing to progress beyond TRL 3, and require further testing and evaluation. For those designs that have progressed to TRL 6 and beyond, additional testing including field trials are required before the test candidate is approved for industrialisation. At present, for the above reasons, rare-earth based corrosion inhibitors cannot be considered 'generally available' to the sector and therefore not suitable for all component designs for the 'use' of primer products other than wash or bonding primers.

3.5.10 Test Candidate 9: Sacrificial metal-based corrosion inhibitors

3.5.10.1 Introduction – summary of status reported in parent applications

Evaluation of sacrificial metal-based test candidates was briefly discussed in one of the parent Applications, but with limited technical details.

Sacrificial metal-based test candidates contain magnesium, aluminium, or zinc alloy particles of specific shapes, sizes, surface conditions, and alloy compositions, and can also be modified to control their reactivity. The exact identify of these materials and the composition of proprietary formulations containing them was undisclosed as they were reported to be confidential business information.

It was reported these materials perform insufficiently with regard to the corrosion requirements for the majority of aerospace applications (GCCA, 2017b).

Magnesium based test candidates are identified as delivering a sacrificial mode of action for primer applications, namely structural primers (CCST, 2015b). This test candidate is discussed in Section 3.5.2

3.5.10.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of Sacrificial metal based corrosion inhibitors

The term 'sacrificial metal based corrosion inhibitors' overlaps with the test candidates, magnesium based corrosion inhibitors and zinc based corrosion inhibitors. Magnesium particles are added to the primer matrix to corrode sacrificially producing corrosion products with associated impacts, see Section 3.5.2.2. The white corrosion products produced were reported to be counterproductive interfering with the surface appearance of the substrate. This reportedly makes it difficult to distinguish between substrate corrosion and the products of the sacrificial corrosion inhibitor for some applications and therefore this test candidate was deemed unacceptable in this scenario.

Economic feasibility of Sacrificial metal based corrosion inhibitors

As reported, magnesium based corrosion inhibitors are examples of sacrificial mode of action. Referring to Section 3.5.2.2 costs attributable to implementation of magnesium based corrosion inhibitors delivering sacrificial corrosion resistance mode of action can exceed €70 million over an extended development cycle; up to 12 years.

Health and safety considerations related to the use of sacrificial metal based corrosion inhibitors

Table 3-15: Hazard profiles of sacrificial metal based corrosion inhibitors

Sacrificial metal-based corrosion inhibitor	CAS Number	Hazard Classification and Labelling
Magnesium	7439-95-4	Flam. Sol. 1;H228, Pyr.Sol.1; H250, Water react.1; H260, Water-react.2; H261, Self-heat.1; H252
Source https://echa.europa.eu/fi/brief-profile/-/briefprofile/100.028.276		

Availability of sacrificial metal based corrosion inhibitors

As stated, magnesium is reported to have a sacrificial mode of action providing an overlap with this test candidate category. Magnesium rich proprietary formulations are commercially available. However, there are significant limitations to availability from a regulatory perspective, i.e. **"*legal*" and factual requirements of placing them on the market[41],** as a consequence of limited technical feasibility. This governs the scope of use for aerospace applications. An example described in Section 3.5.2.2 is the impact on weight, surface appearance, or repairability which are all performance requirements and required for some designs subject to primer treatment. Therefore this test candidate cannot be considered as 'generally available' to the sector for this protective primer use.

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[41] European Commission note 27 May 2020

Suitability of sacrificial metal based corrosion inhibitors

Gauging the suitability of sacrificial metal based corrosion inhibitors draws upon how the example of magnesium rich primers perform in relation to the suitability criteria described in Section 3.5.1.

As reported above, this test candidate fails to meet all required aspects under each criteria, excepting economic feasibility where costs are incurred although these are reported to be sustainable over the lifetime of development programmes. As a consequence, sacrificial metal based corrosion inhibitors cannot be considered as a suitable alternative for the use of protective primers.

3.5.11 Test Candidate 10: Zinc-based inhibitors (including zinc molybdates)

3.5.11.1 Introduction - summary of status reported in parent applications

Parent AoAs report the evaluation of zinc-based test candidates. Zinc-based primers include:

- "Zinc-rich primers" (zinc particles present in concentrations > 80 % (w/w) in dry paint films) and "zinc primers" with zinc concentrations 25-70 % (w/w);
- Confidential formulations reportedly containing zinc cyanide and zinc oxide. These systems contain a zinc–organic complex combined with a hydrotalcite which slowly releases the corrosion inhibitor; and
- Zinc molybdates.

In general, corrosion requirements were reported as not being met by the zinc-based test candidates.

It was reported (CCST, 2015b)that zinc-rich test candidates provided good galvanic corrosion protection on steel substrates. It was reported salt spray test performance (3000 hours, <1.25 mm) on clad and unclad aluminium alloys was acceptable, but filiform testing exceeded the acceptable maximum (>3 mm after 960 hours, compared to the acceptable maximum of 2 mm). Active corrosion inhibition failed (pitting observed after 1,000 hours). The crevice corrosion test also failed (CCST, 2017) (CCST, 2015b). Adhesion, chemical resistance and layer thickness for zinc-based test candidates on AA2024-T3 pre-treated with TSA were reported as sufficient (CCST, 2017).

Zinc cyanamide[42] and zinc oxide-containing test candidates were tested in "self-priming topcoats" for repair activities. Corrosion inhibition was reportedly inferior to strontium chromate basic primer plus topcoat systems, and self-priming topcoats are not basic primers as they are not formulated to enable additional coating layers. They did however provide superior adhesion and were reported to have been qualified for less demanding niche aircraft field repair applications (GCCA, 2017b). Zinc molybdates were reported to be used in niche fastener protection uses, but do not provide the broad corrosion requirements provided by strontium chromate-containing basic primers (GCCA, 2017b). It was reported they passed requirements for hardness, adhesion, layer thickness, and impact resistance, but corrosion performance and chemical resistance was not sufficient (CCST, 2015b).

It was also reported that zinc pigments do not provide active corrosion inhibition (CCST, 2015b).

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[42] US5378446A available at https://worldwide.espacenet.com/patent/search/family/027122498/publication/US5378446A?q=US5378446A accessed 15 April 2024

3.5.11.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of Zinc-based (including zinc molybdates)

Zinc based test candidates are reported to be used in a range of proprietary formulations. Where identified the following performance requirements have been reported to have been comparable to chromate based primer for at least one substrate/design combination.

- Temperature resistance including thermal cycle resistance;
- Mechanical properties;
- Layer thickness
- Surface appearance; and
- Compatible with difference application methods.

With regard to key functions and other performance requirements, in one example adhesion promotion to subsequent top-coats was sufficient. However, adhesion failure was observed on aluminium surfaces. Due to this reported failure of zinc based primers on aluminium substrates, further testing of sealant compatibility was not conducted by the relevant member. To help resolve these deficiencies zinc based corrosion inhibitors were not developed further in isolation. As a consequence, zinc-based corrosion inhibitors used in Cr(VI)-free primers may be combined with other corrosion inhibitors working in synergy with one another. Examples of zinc based corrosion inhibitors reported as used in proprietary formulations include, zinc powder, trizinc bis(orthophosphate), and zinc oxide

With regard to the key function of corrosion resistance, an example of a proprietary formulation containing zinc based corrosion inhibitor is reported to be reserved for touch-up applications and not offer longer-term corrosion protection. Recognising this deficiency, this proprietary formulation is reported to be implemented under these restricted circumstances. Implementation of this test candidate for other designs is subject to successful completion of specific testing regimes dictated by the relevant design owner(s). Therefore, this application of a proprietary formulation utilising zinc based corrosion inhibitors is not considered a universal option across all designs requiring Cr(VI)-based touch-up. Progression reported by one member to expand the scope of this touch-up application has reached a mature TRL 8.

Economic feasibility of Zinc-based (including zinc molybdates)

Economic feasibility of this candidate is dependent on the cost of proprietary formulations that it used in. Additional costs of up to 50 percent are reported although this can be partly mitigated as the quantity required of the proprietary formulation can be lower.

Other costs are dictated by the nature of the testing programme specified by the design owner and associated certification process. For example, as reported for other test candidates, estimated costs to develop a test candidate through the various phases of the development plan leading to implementation and MRL 10 status can be up to several tens of millions of euros. These are one-off investment costs; however, ongoing production costs can result. For example, increased operational costs due to a longer curing time compared to chromated primers. Such costs are likely to vary depending on upon the precise composition of the carrier formulation and operational conditions at a given site.

Health and safety considerations related to the use of Zinc-based inhibitors (including zinc molybdates)

A number of examples of substances within the group captured by zinc based inhibitors are reported in the parent applications and in turn in the above technical feasibility review. **Table 3-16** summaries the hazard profile of examples of this test candidate. All examples proved demonstrate a reduction in hazard profile compared to CR(VI) based primer.

Table 3-16: Hazard profiles of selected zinc based corrosion inhibitors

Zinc-based corrosion inhibitor	CAS Number	Hazard Classification and Labelling
Zinc powder (a)	7440-66-6	Aquatic Acute 1; H400, Aquatic Chronic 1; H410, Not classified
Trizinc bis(orthophosphate) (b)	7779-90-0	Aquatic Acute 1; H400, Aquatic Chronic 1; H410
Zinc oxide(c)	1314-13-2	Aquatic Acute 1; H400, Aquatic Chronic 1; H410

Source
(a) https://echa.europa.eu/brief-profile/-/briefprofile/100.028.341
(b) https://echa.europa.eu/brief-profile/-/briefprofile/100.029.040
(c) https://echa.europa.eu/brief-profile/-/briefprofile/100.013.839

Availability of Zinc based inhibitors (including zinc molybdates)

Proprietary formulations that contain zinc based corrosion inhibitors are commercially available. It is reported that supply chains may need to be managed carefully to maintain consistent supply as demand increases, subject to design owner approval.

As reported above, technical feasibility of zinc based corrosion inhibitors is inferior to Cr(VI) based primers. Both corrosion resistance and adhesion to substrate are reported to be insufficient, although adhesion promotion to subsequent top-coat is reported as acceptable. Progression of the test candidate for touch-up applications is at an advanced state. However, it is reported to only fulfil niche requirements at present such as touch-up.

Therefore, , due to lack of certification for a broad range of primer uses zinc based corrosion inhibitors is not considered as 'generally available' for protective primer applications. .

Suitability of Zinc based inhibitors (including zinc molybdates)

To be considered as suitable to substitute Cr(VI) based primers, the test candidate must fulfil the requirements discussed in Section 3.5.1. The major drawback reported for this test candidate is the limited scope of technical feasibility where implementation is reported to be limited to touch-up processes only which do not deliver longer-term corrosion protection.

Current development status is relatively mature; TRL 8 in one reported case. Test programmes are ongoing to increase the scope of use for different designs albeit limited to touch-up applications. Although it is noted to meet selected performance requirements, these are insufficient in light of the above deficiencies.

Proprietary mixtures containing zinc-based corrosion inhibitors are commercially available. However, as stated, approval and certification of the test candidate is by no means universal versus the scope of use required. Therefore, zinc-based corrosion inhibitors cannot be considered ‘generally available’. In conclusion, zinc-based corrosion inhibitors are not considered a suitable alternative for this use.

3.5.12 Test Candidate 11: Lithium based corrosion inhibitors

3.5.12.1 Introduction - summary of status reported in parent applications

Minimal information was reported on lithium-based test candidates in the parent applications. The only reference reported that it was a new technology, and insufficient data was available (GCCA, 2017b).

3.5.12.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of Lithium based corrosion inhibitors

Lithium based corrosion inhibitors are available in proprietary mixtures. These mixtures are reported to be supplemented with other short-listed test candidates including zinc based and organic corrosion inhibitors. Performance evaluation of examples of these proprietary mixtures containing lithium-based corrosion inhibitors is ongoing in basic, structural and fuel tank primer applications. As reported, the parent applications failed to provide any significant information on the performance of this test candidate either used in isolation, or present in a proprietary mixture. Consequently, it was considered to be at very early stages of investigation. Since then, progression is reported to have reached a wide range of maturity ranging from TRL 1-2 to TRL 4-5, with an expectation for lower maturity TRL 1-2 to have also progressed to TRL 4 in 2024. In contrast one member reports progression to MRL 10 for some structural primer applications. This proprietary mixture containing a lithium-based corrosion inhibitor is limited to exterior decorative applications that can be easily inspected.

Corrosion resistance is variable. Not all scenarios of use deliver acceptable performance. A degree of interdependency with the pre-treatment process used prior to application of basic primer type is reported. For example, the use of Cr(VI)-free chemical conversion coating appears to reduce corrosion resistance in some cases when used in combination with primer mixtures containing lithium based corrosion inhibitors. More work is required to determine the source of the deficiency and whether it can be resolved via reformulation. Compatibility testing with Cr(VI)-free pre-treatments is an integral part of the assessment of the primer. This can add time to the substitution process; up to 12 months or more, although this is not compounded by the need for additional or new equipment.

Incompatibility with sealants applied on the primer surface; fuel tank and basic primer applications, has been observed. This is associated with exposure to warm and humid conditions (40°C/95% relative humidity) for as little as less than a day or exposure, of up to six weeks, depending on the primer/sealant combination.

Favourable results are reported for adhesion promotion in limited situations where sealant compatibility is not a requirement. Chemical resistance, layer thickness, mechanical properties and surface appearance used for basic primer and fuel tank primer applications are reported to be acceptable.

As reported lithium-based inhibitors are available in proprietary mixtures. Therefore, there is the possibility that positive and negative performance aspects may in part be attributed to other components in the mixture, or as a result of synergies. The formulator and design owner may need to share data in order to develop new iterations of a proprietary mixture to address any weaknesses.

Where this is the case, non-disclosure agreements may be in place preventing disclosure of all components within the mixture.

Economic feasibility of Lithium based corrosion inhibitors

Costs attributed to the use of lithium based corrosion inhibitors is reported to be represent an increase compared to Cr(VI)-based primers. Costs associated with screening and developing test candidates over a period of a decade or more can be tens of millions of Euros. Significant costs are from the development to certification process. Costs from the progression of the test candidate from development to mature TRL 7 to 8 varies depending on the test regime demanded by the design. Examples of reported costs are in the range of €200,000 - €300,000. Other associated costs may also be incurred from work to ensure that the adjacent processes in the treatment system, for example conversion coating, are compatible with the Cr(VI)-free primer type.

Health and safety considerations related to the use of Lithium based corrosion inhibitors

The hazard profile of lithium-based corrosion inhibitors is illustrated by the lithium containing substance trilithium orthophosphate (CAS 10377-52-3). This is representative of lithium substances that can be found in proprietary mixtures. The substance's notified classification and labelling entry[43] confirms that it represents a reduction in hazard profile compared to the incumbent Cr(VI)-based primers.

Availability of Lithium based corrosion inhibitors

As stated above proprietary mixtures are commercially available on the market. Although significant progression has been made since the parent applications were published, this is still at a relatively immature stage in the substitution process as outlined in Section 3.1.2.

Lithium based corrosion inhibitors have not achieved sector wide certification. Where industrialisation has been achieved this is restricted to specific scenarios such as were easy inspection is possible. Consequently, they are not considered 'generally available for industrialisation for the use 'primer products other than wash or bonding primers'.

Suitability of Lithium based corrosion inhibitors

To be considered as suitable to substitute Cr(VI) based primers, the test candidate must fulfil the requirements discussed in Section 3.5.1. This section outlines each element that together constitute suitability of the test candidate to be an alternative to the incumbent chromate.

Technical feasibility is reported to be variable depending on the performance requirements expected from the treated design. A decrease in corrosion resistance is reported overall compared to threshold requirements delivered by chromated primer systems. This has resulted in further development of proprietary mixtures.

An additional complication is incompatibility with certain Cr(VI)-free pre-treatments and also some sealants used in combination with certain primers types, for example fuel tank primers. Sealant incompatibility has reportedly led to adhesion failure. In contrast, good performance characteristics

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[43] CLH Inventory available at: https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/46533https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/46533

are reported for designs not subject to the above environment. These include adhesion promotion, chemical resistance, layer thickness and mechanical properties. In summary more work is required to improve the technical feasibility of this test candidate across all design and operational environments.

Although significant economic impacts are forecast, these are in line with development and industrialisation costs attributed to the substitution of chromated primer systems. Compared to the incumbent chromated primer a reduction in hazard profile is reported. However, due to current technical feasibility deficiencies, immature progression, and not being 'generally available' lithium-based corrosion inhibitors cannot be considered as a suitable alternative for this use.

3.5.13 Test Candidate 12: Proprietary mixtures of Cr(VI)-free test candidate corrosion inhibitors

3.5.13.1 Introduction

This category of test candidates comprises potential alternatives where a proprietary mixture 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 mixtures 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 mixtures are comprised of corrosion inhibitors/technologies described in test candidates 1 to 11.

In the parent AfAs, the test candidate "Cr(VI)-free (confidential)" was used to describe proprietary formulations comprised of mixtures of corrosion inhibitors (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.

As stated, the composition of the proprietary mixtures was reported as confidential business information and the specific corrosion inhibiting substance(s) were not disclosed in the parent AfA. However, technical feasibility was reported which is summarised below. (CCST, 2015b)report corrosion resistance for basic primer applications with this category of alternative being promising when tested in epoxy and polyurethane matrices; no corrosion pits on AA2024-T3 alloy pre-treated with tartaric-sulphuric acid anodising after 3000 hours (ISO 9227 and ISO 7253). Maximum filament length from filiform corrosion testing (EN3665) was 2 mm after 960 hours. However, further testing was required to comply with test requirements; 3000-9000 hours (ISO 9227), and 3000- 6000 h (ISO7253).

In contrast there was a marked decline in performance when tested with non-chromated conversion coating pre-treatment. Salt spray corrosion test (ISO 9227 and ISO 7523) after 3000 hours exhibited greater than 1.25 mm creepage visible on the substrate with a filament length of greater than 2mm, failing minimum corrosion requirements. In addition to the above deficiency for long-term corrosion resistance, active corrosion inhibition was reported to be absent.

Other technical feasibility criteria, adhesion, chemical resistance and compatibility with substrate were reported as sufficient for basic primer applications. Performance of this category of corrosion inhibitor was not reported for other applications of this use; structural, fuel tank and aluminised primer applications.

In conclusion, implementation of this category of test candidate in basic primer application on aluminium alloys was not expected for at least 15 years as a consequence of the reported absence of long-term corrosion resistance.

3.5.13.2 Progression reported by ADCR members

Technical feasibility/Technical Readiness Level of Proprietary mixtures of Cr(VI)-free test candidates

Basic primer and fuel tank primer applications: Members reported deficiencies for corrosion resistance, compatibility with substrates sealants and other coatings, and mechanical properties; flexibility failure (ISO1518-02) for fuel tank primer application. Other members reported more positive results with other proprietary mixtures with satisfactory performance against the aforementioned criteria, although in some cases testing is ongoing with results to be confirmed. This variability of requirements across the consortium demonstrates the scope of service environments that chromated primers need to perform within, and that Cr(VI)-free alternatives must replicate.

Where failures are reported, members working in collaboration with partners have restarted development programmes re-formulating mixtures to focus on resolving these deficiencies. Where this is the case progression is reported to be no more than TRL 3 with more mature earlier iterations at TRL 4, with some expectations to reach TRL 6 in December 2026, and if successful MRL 10 by December 2031. An additional consideration contributing to the rate of adoption for this test candidate is that progression is variable for different substrates. For example non-aluminium substrates are reported to be at a more advanced maturity, in some cases up to TRL 6. The extensive and varied array of aluminium alloys prevalent within the A&D sector, can by its nature add complexity, and therefore time, to the development of a Cr(VI)-free primer test candidate with this category of substrates.

Proprietary mixtures of Cr(VI)-free test candidates for fuel tank primer application are reported to meet all required technical feasibility criteria for some limited programmes. Scope of use is constrained by the test candidate's physical appearance as it is not translucent, and consequently not suitable for all applications. Another variable impacting its wider scope of use is additional cure time. This is an additional barrier to use for some fuel tank primer applications.

Reported progression of this category of test candidate for structural primer applications ranges from TRL 3 to TRL 6 anticipated by 2026 and up to MRL 10 by expected by 2030. This assumes that all outstanding performance testing meet pass threshold requirements, and this is achieved within projected timescales. Currently all testing is ongoing and not finalised.

Progression of Proprietary mixtures of Cr(VI)-free test candidates for aluminised primer applications is reported to be less advanced. Resources are typically prioritised towards high volume applications of the use in terms of affected designs, these being; basic, fuel tank and structural primer applications which are typically used far more extensively within the industry. Members have reported that planning of development and testing work for this category of test candidate for the purposes of aluminised primer is scheduled for 2024 with expectation to reach TRL 3 in 2026, and qualification in 2033 assuming progression proceeds at the expected rate.

Economic feasibility of Proprietary mixtures of Cr(VI)-free test candidates

Costs attributed to increased operational costs incurred from longer curing time is one factor associated with the migration from chromated primers to Cr(VI)-free for fuel tank primer application.

Research and Development, and performance testing costs for each non-chromated primer can vary significantly depending upon the nature of the primer application, the number of tests required for qualification and implementation in the supply chain, the duration of testing, and the number of designs affected by the change. Associated estimated costs are reported to range up to €70 - 90M over a 12 year programme.

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

Due to the confidential nature of this category of test candidate, it is not possible to assess the specific health and safety considerations for these test candidates. When considering the hazard profile of each proprietary mixture captured within this test candidate family versus chromated primers, additional consideration may be required, depending on the composition of the proprietary mixture, to avoid the potential for regrettable substitution.

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, and therefore should constitute a reduction in overall risk compared to the incumbent Cr(VI)-based primers. This will need to be assessed on a case-by case basis.

Availability of Proprietary mixtures of Cr(VI)-free test candidates

As described these test candidates are on the whole either commercially available or subject to commercial availability upon approval of all required performance testing. As reported some have been implemented for limited applications where requirements allow, for example for fuel tank primer applications. However, this test candidate cannot be considered ‘generally available’ to the A&D industry as a whole.

Suitability of Proprietary mixtures of Cr(VI)-free test candidates

This category of test candidate is at a mature state of progression for some applications of protective primers. Significant range of testing is still required to advance the development of newer formulation iterations and to progress those that are more mature. The expectation is that all will benefit from a reduction in hazard profile compared to the incumbent chromated primers.

As described above, the test candidate is available on the market as proprietary mixtures. However, in the majority of reported cases they are not certified across all existing applications or designs reliant upon the use. Therefore, they cannot be considered as ‘generally available’. Noting the above current limitations, it is concluded that this is not a suitable test candidate for all component designs for this primer use.

3.6 Conclusions on shortlisted alternatives

Table 3-17 summarises the current development status of the test candidates to replace strontium chromate, potassium hydroxyoctaoxodizincate dichromate and pentazinc chromate octahydroxide in protective 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 3-17: Conclusions on suitability of short-listed test candidates for 'protective' primers

Test Candidate	Technical feasibility	Economic feasibility	Hazard reduction	Availability	Suitability
Magnesium based corrosion inhibitors	Low	Moderate	High	Moderate	Low
Silane-based processes including sol-gel coatings	Low	Moderate	High	Low	Low
Electrocoat	Low-Moderate	Low	High	Low	Low
Calcium-based corrosion inhibitors	Low	High	High	Low	Low
Organic and organometallic corrosion inhibitors	Low	Moderate	High	Low	Low-Moderate
pH-buffering additives	Low	Not reported	High	Low	Low
Phosphate-based corrosion inhibitors	Low	Moderate	High	Low	Low
Rare-earth based corrosion inhibitors	Moderate	Moderate	High	Low-Moderate	Moderate
Sacrificial metal-based corrosion inhibitors	Low	Moderate	High	Moderate	Low
Zinc-based (including zinc molybdates)	Low	Moderate	High	Low	Low - Moderate
Lithium based corrosion inhibitors	Low -Moderate	Moderate	High	Low	Low-Moderate
Proprietary mixtures of Cr(VI)-free test candidates	Low - Moderate	Moderate	High	Moderate	Moderate

The Economic feasibility criteria assessment is based on estimated ongoing supply and production costs associated with using the test candidate in place of the chromated primer application. However, the significant costs ascribed to the screening, development, staff training, certification and industrialisation of a test candidate primer system range widely. Multiple designs, suppliers and manufacturing lines are often affected by the qualification and certification of an alternative. Anticipated estimates of in excess of €70 million are reported over a 12 year timeframe covering the development, substitution, and industrialisation of a Cr(VI)-free alternative. These on-off costs are considerable and must be considered in the overall assessment of economic feasibility for different actors in the supply chain. It may not be economically feasible to qualify new pre-treatment, primer and subsequent coating systems for legacy aircraft i.e. no longer in production. Resource may need to be prioritised for those models still in production.

It should also be noted that it is not possible to provide an exact assessment of the health and safety considerations for Test Candidate 12, Proprietary mixtures of Cr(VI)-free test candidates. Additional consideration of the proprietary mixture hazard profile, which is not possible in this review report, due to confidential business information constraints, may be required before adoption to minimise the potential for regrettable substitution.

Those test candidates indicated to be at a moderate to high suitability status are still limited to specific applications of the primer use on certain designs and substrate materials. More work is required to assess their suitability across all applications of the use, 'Primer products other and wash and bonding primers' before they could be considered as suitable and sustainable in the long-term.

3.7 The test candidate development plan

3.7.1 Introduction

As outlined in Section 3.1.2, the A&D sector is subject to regulatory controls governing the certification of processes and design used in the manufacture of products. These are in place to ensure continued airworthiness and reliability of products in both civil and military applications. As described in Section 1.7, until this process is completed test candidates are not considered 'generally available' following the European Commission's definition[44], to be implemented and adopted in the supply chain, including MRO service providers.

The Analysis of Alternatives has determined that an alternative is not generally available to all actors in the supply chain for all purposes for the single use of primer products other than wash or bonding primers. ECHA guidance states that where an AoA concludes there are no suitable alternatives available in general, a plan should be provided detailing the activities undertaken to implement a suitable alternative in the future. The following sections present progression made by the ADCR consortium members to substitute chromated primers with test candidates since the parent authorisations were granted.

3.7.1.1 Factors affecting the test candidate 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.

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[44] 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

Each factor will contribute to the achievement of milestones that must be met to realise delivery of the substitute(s) to Cr(VI) for protective 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 protective primers containing Cr(VI) that is uniquely reflective of their individual situation. Additionally, an individual member often has multiple development plans for substitution of Cr(VI) based primers from the use 'Primer products other than wash and bonding primers', running in parallel work streams. The reason for different development plans within one member is that they are segmented by factors such as type of substrate, component design, test candidate, and type of coating system. These different plans are progressed simultaneously although they typically have differences in timing of milestones and anticipated achievement of each TRL/MRL level. This is 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 specialist test facilities, and prioritisation of certain types of component.

The scope of these development plans may also change over time. One member reported that when their development plans were first initiated, they targeted a replacement for the incumbent Cr(VI)-primer which could be used across all aluminium alloys (such was their experience with the broad compatibility provided by protective primers containing strontium chromate). However as no proposed candidate met the performance requirements for all current applications, despite several years of testing and process optimisation efforts, the decision was made to only pursue industrialisation for a subset of the components impacted. A new development plan was then initiated for components made of other aluminium alloys. Where it is feasible to substitute the use of chromates by a substrate which is less prone to corrosion, this has been done, and the remaining development plans are those for which it is not feasible to substitute with a different substrate.

3.7.1.3 Interplay with other test candidate development plans

As noted in Section 2.3.1.3, in almost all cases there is a surface treatment undertaken prior to application of the protective primer, and most commonly this is a chemical process (anodising, chemical conversion coating, or electroplating) or application of another primer product (wash or bonding primer). All of these surface treatments have historically used Cr(VI), and whilst in many cases members have already implemented Cr(VI)-free anodic processes, for example, for use prior to primer application, there are still a number of ongoing development and/or substitution plans particularly for the replacement of Cr(VI)-based chemical conversion coating and functional chrome plating. In addition, development plans aimed at the replacement of wash primers containing chromates are also ongoing.

The progression and success of these plans for the replacement of protective primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate and/or pentazinc chromate octahydroxide are dependent on the development and implementation of Cr(VI)-free alternatives for use in these associated treatments. Any unexpected obstacles affecting the progression of these plans will impact the planned timing of the substitution of incumbent chromated primers for protective primer replacement.

In many cases, a member will target substitution of Cr(VI) from both the surface treatment and primer product other than wash or bonding primers at the same time.

3.7.2 Test candidate development plans for ADCR members using primer products other than wash or bonding primers

3.7.2.1 Test candidate development plans

The expected progression of ADCR members' development plans to replace protective primer containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate and/or pentazinc chromate octahydroxide is shown in **Figure 3-19** below. The progressive stages of the substitution process (development, qualification, validation etc.) are shown in the diagram and described in detail in Section 3.1.2. Implementation and progression of development and substitution plans ultimately leads to reduced Cr(VI) usage. MRL 10 is the stage at which manufacturing is in full rate production and is therefore where Cr(VI) use is expected to be eliminated due to replacement with an alternative within the use covered by the relevant test candidate development plans leading to substitution.

Recognising the SEAC's need for information which reflects the position of individual companies and their value chains, the test candidate development plans represent a granular analysis of the progression made by each OEM and DtB company supporting the use of primer products other than wash or bonding primers in the process leading to substitution. As design owners, the test candidate development and substitution 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 TRL 9 and MRL 10).

The data in **Figure 3-19** show the expected progress of 44 distinct development plans for primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate and/or pentazinc chromate octahydroxide, covering different plans across different members, and multiple plans within individual members. The data has been aggregated to present the expected progression leading to substitution of primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate and/or pentazinc chromate octahydroxide for the ADCR consortium as a whole.

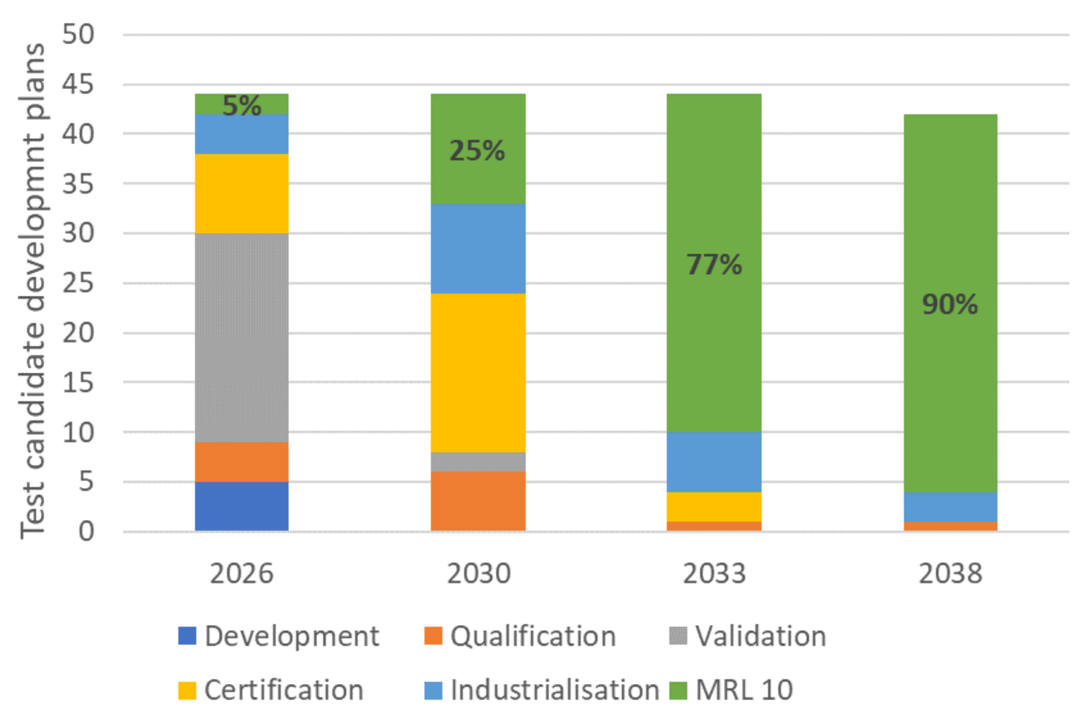


Figure 3-19: Expected progression of test candidate development plans for the use of protective primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate and/or pentazinc chromate octahydroxide, by year.
The vertical axis refers to number of test candidate development plans (some members have multiple plans for protective primers). The percentage value shown on each of the green bars indicates the proportion of 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 development plans in each of the years (this variation is due to issues such as technical difficulty, types of surface treatment and subsequent coating, types of substrates, types of components); and
- Expected progression in future years as an increasing proportion of the plans reaching MRL 10.

The dates at which each 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 the 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 3-19**. The actual status of the development plans 12 years from now could be different to our expectations today.

Because many members have multiple development plans for the use of protective primer, it is the case that for those plans that are not expected to have achieved MRL 10 by a given date, other development and substitution plans from the same member will have progressed to this level. This highlights the complexity of multiple development and substitution plans within members. The timeline associated with any individual development or substitution activity will be dependent on a multitude of factors including: the number and nature of technical criteria associated with the formulation or substance to be substituted; the maturity of research into proposed candidates which has already been undertaken by formulators and design owners; the number of components onto which the existing primer is applied; the availability of expert resource and specialist test facilities; interrelationships with other processes which are also being substituted; the availability and robustness 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 potential need for more than 12 years has been identified by some OEMs due to their inability to identify any technically feasible alternatives to date. This is illustrated by the near equivalence between the number of test candidate development plans at the development phase in 2026, and the number where it is anticipated MRL 10 will not be reached by 2038. For proposed candidates which have not yet progressed beyond TRL 3, predicting the length of time until industrialisation will be completed can be a particularly difficult task because iterative re-formulations of a proposed candidate are not uncommon. Each of these re-formulations results in the timeline for this development plan being reset. A proportion of those plans which are not anticipated to progress to MRL 10 until 2038 or beyond are also impacted by the needs of MROs and MoDs for continued use in the maintenance and repair of in-service (legacy) final A&D products.

The timeframes associated with the activities presented in **Figure 3-19** 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 5% 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 test candidate development plans within this 5% for which certification is currently ongoing, additional actions may arise as an outcome of the certification process, which could delay implementation to beyond 2026.

3.7.2.2 Requested Review Period

It can be seen in **Figure 3-19** that despite ongoing and concerted efforts of the members to develop and implement alternatives to protective primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate 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 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 stages. 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. For any remaining in progress 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 requests a review period of **12 years** for the use of primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate 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) and adhesion promotion in primer products other than wash or bonding 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.

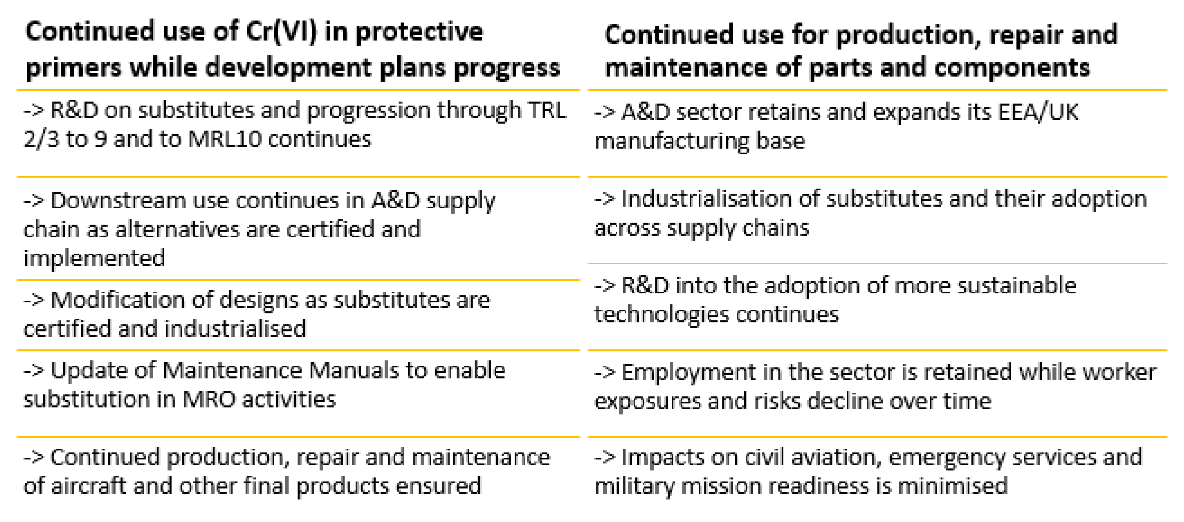
Until suitable alternatives which are compatible with all the relevant primer processes, and which deliver an equivalent level of functionality are, qualified, validated and certified for the production of individual components and products, use of strontium chromate, potassium hydroxyoctaoxodizincate dichromate, and pentazinc chromate octahydroxide in primer products other than wash or bonding 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, 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 primer products other than wash or bonding 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 plans, 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** as follows:



Continued use of Cr(VI) in protective 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 strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and pentazinc chromate octahydroxide used in primer products other than wash or bonding primers, including projected tonnages over the requested review period; and
- The risks associated with the continued use of strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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 as 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 primer products other than wash or bonding 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[45]). As noted by the European Commission, the industry is "characterised by an extended supply chain and a fabric of dynamic small- and medium- sized enterprises throughout the EU, some of them world leaders in their domain"[46]. **Figure 4-2** 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".[47]

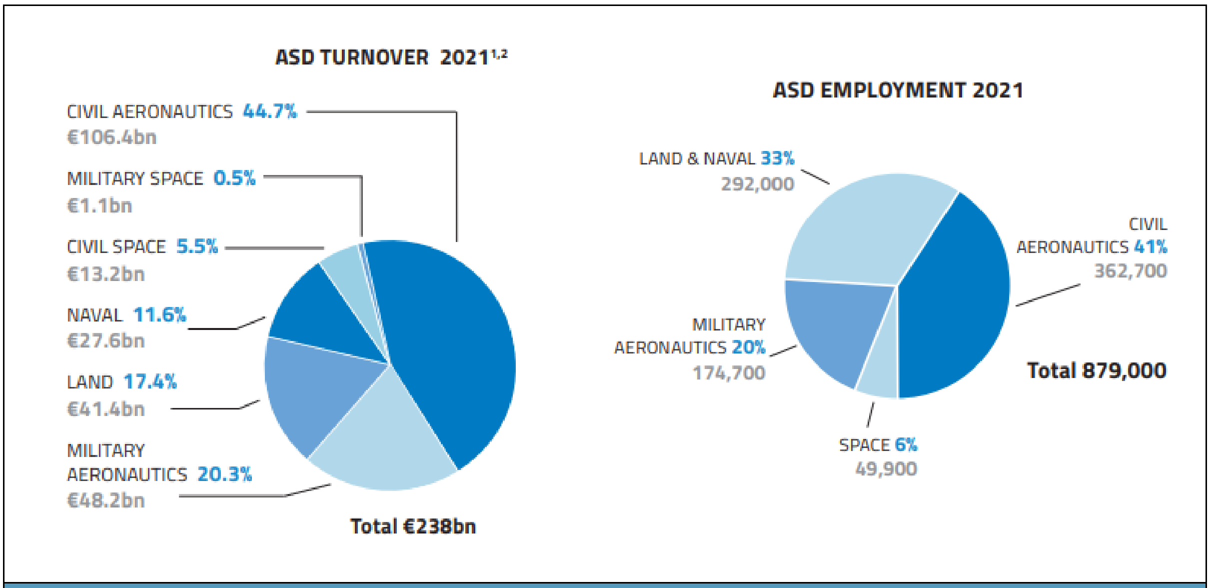


Figure 4-2: Turnover and Employment for the European A&D Industry in 2021 (snip taken from ASD, 2022), available at https://asd-europe.paddlecms.net/sites/default/files/2022-11/ASD_Facts%20%26%20Figures%202022.pdf

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 €106.4bn for the year 2021, which compares to €81.6bn 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 it will now go out of production but remain in service). Given the need to ensure on-going

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

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

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

airworthiness and due to certification requirements, there will continue to be a "legacy" demand for the use of primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate 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.[48]

- 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 strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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 strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and pentazinc chromate octahydroxide in primer products other than wash or bonding 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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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 primer products other than wash or bonding primers

4.2.3.1 Profile of downstream users

As noted in Section 2, use of primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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:

- Fittings, hinges, shear ties, webs, frames.

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

- Leading Edge Slat mechanisms, Trailing edge flap supports in wings.
- Landing gear systems.
- Aircraft flight control and actuation system.
- Gears and gearboxes.
- Parts of shells/missiles/mortar bodies.

Table 4-1 provides an indication of numbers of respondents by role in the supply chain and by size of company.

Table 4-1: Numbers of SEA respondents using strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide in primer products other than wash or bonding primers

Role	Number of companies/sites	Company Size[49]
Build-to-Print	11/12	6 small 3 medium 1 large
Design-to-Build	7/12	1 small 3 medium 3 large
MRO only	2/3	2 large
OEM	5/11	1 small 3 large
Total	**25/38**	-

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 strontium chromate, potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide in primer products other than wash or bonding 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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[49] 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 strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide in primer products other than wash or bonding 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
C2540 - Manufacture of weapons and ammunition	1	650.35	97,239	73,284	9%
C2561 - Treatment and coating of metals	19	13.75	51,122	30,408	22%
C2594 - Manufacture of fasteners and screw machine products	1	3.11	67,358	35,283	23%
C2599 - Manufacture of other fabricated metal products not elsewhere classified	3	155.09	56,993	30,784	19%
C263 - Manufacture of communication equipment	0	342.22	133,333	54,530	30%
C265 - Manufacture of instruments and appliances for measuring, testing and navigation; watches and clocks	0	253.08	104,777	67,612	16%
C2815 - Manufacture of bearings, gears, gearing and driving elements	2	209.76	69,726	39,863	18%
C3030 - Manufacture of air and spacecraft and related machinery	10	648.17	116,492	67,263	16%
C3040 - Manufacture of military fighting vehicles	1	648.17	116,492	67,263	16%
C3316 - Repair and maintenance of aircraft and spacecraft	11	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 25companies 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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide and taking into account the size distribution of the companies that are involved in such activities[50]. 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[51] (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 15% 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 strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide in primer products other than wash or bonding primers (based on 2022 ONS data)

Sites covered by SEA responses/Extrapolated number of sites	Estimated turnover based on weighted average £ million	Gross operating surplus (estimate based on 15%) £ million
38 GB sites	9,134	1,655
Extrapolation to all sites involved in use of strontium chromate, potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide in primer products other than wash or bonding primers in GB		
130 GB sites	29,711	5,385
Source: Based on SEA questionnaire responses, combined with ONS data		

4.2.3.3 Economic importance of use of primer products other than wash or bonding primers to revenues

Use of primer products other than wash or bonding 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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide.

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[50] 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.

[51] ONS defines the GOS rate 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.

As the supply chains covered by this SEA vary from manufacturers of small components to producers of much larger components (e.g., components for landing gear versus doors and/or skirts), the responses vary significantly across companies. Of key importance is that for the design owners use of Primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide continues to be critical. The loss of these primers would result in the loss of a significant level of turnover due to the inability to meet airworthiness requirements, even though as a process it accounts for only a very small percentage of production costs.

Table 4-4 shows the revenue linked to using chromate-containing primers for companies in GB. Responses vary, with some companies stating that less than 10% 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 priming, often perform other machining work within the aerospace and defence industry. This includes manufacture of electrical and hydraulic components, as well as assembly and maintenance.

As would be expected, although use of primer products other than wash or bonding primers in of itself does not account for a significant percentage of turnover, all of the OEMs highlighted the critical importance of primer products other than wash or bonding 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 primers other than wash and bonding 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%
Build-to-Print	1	1	3	2	4
Design-to-Build	1	0	1	0	6
MROs	1	0	0	1	0
OEMs	4	0	0	1	1

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 three chromates in primer products other than wash or bonding 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 components.

Some examples of investments made across all supplier types include:

- Air fed masks, air supply and pre filtration system, at £18,000 in 2018
- Environmental qualification of product at £10,000
- Paint Booths and equipment at £1.5 million between 2012 and 2022, with an estimated lifetime of 20 years.

- Small scale process trials for customer approval leading to implementation of chrome free processes at a cost of £10,000 in 2018 and 2022.

Further information on the R&D carried out by the OEMs (and DtB companies) is provided in Section 3.4.

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 strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide in primer products other than wash or bonding primers provides corrosion resistance (including active corrosion inhibition), adhesion promotion, and compatibility with substrates 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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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 primer products other than wash or bonding primers containing strontium chromate, 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 kilometres 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.

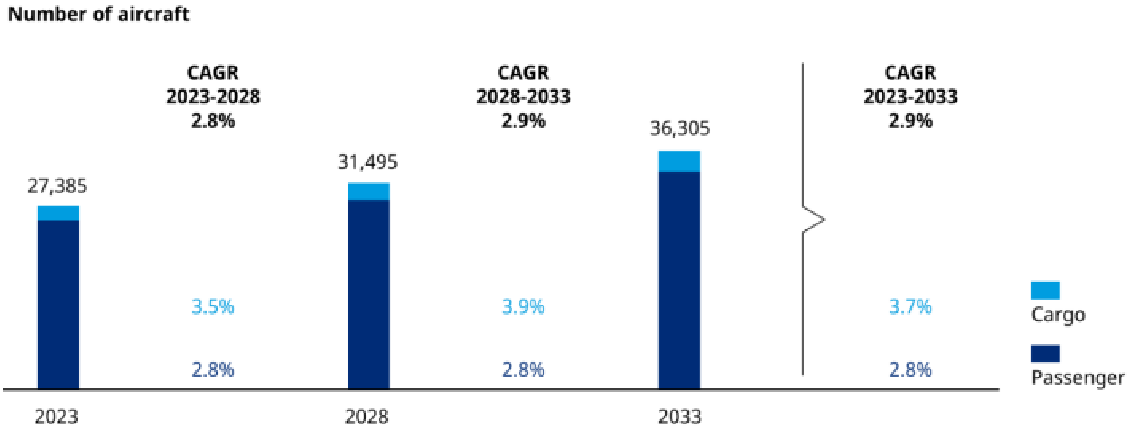
The economic importance of ensuring that aircraft retain their airworthiness is illustrated by the figures quoted in Section 2 above for the number of air passengers transported in the European Union in 2019 (over 1 billion), as well as the net profits of the airlines in 2019 at US$ 6.5 billion (€5.8 billion, £5.1 billion).

The military importance 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 chromates 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**[52], with this suggesting CAGR from 2023 to 2033 of around 2.9%.



Note: Fleet sizes as of beginning of year; CAGR stands for compound annual growth rate
Source: Oliver Wyman analysis

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.[53]

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

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

Boeing's 2023 Commercial Market Outlook[54] 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.

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.[55]

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 GB with a consequent loss in Gross Value Added (GVA) to the GB economy, with enormous impacts on employment.

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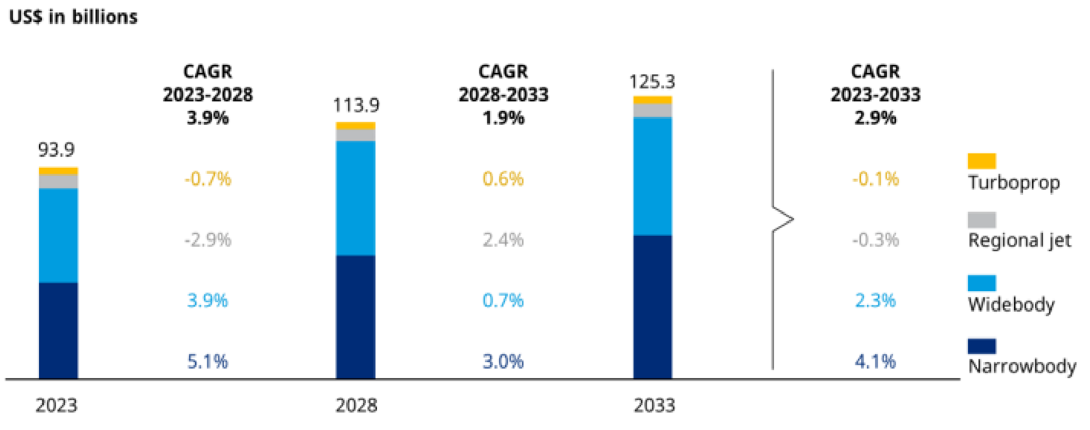
[54] https://www.boeing.com/commercial/market/commercial-market-outlook/index.page

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

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 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**.[56, 57]



Note: CAGR stands for compound annual growth rate
Source: Oliver Wyman analysis

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.

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

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

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[58]. 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 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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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%[59].

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

The CSR reported tonnage of:

- 0 to 3100 kg StC used per year per site, therefore up to 791 kg Cr(VI) per year per site
- 0 to 30 kg PCO used per year per site, therefore up to 2.69 kg Cr(VI) per year per site
- 0 to 2200 kg PHD used per year per site, therefore up to 546 kg Cr(VI) per year per site

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

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

At most sites StC is used in primer products.

4.3.2 Consultation for the SEA

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

Based on consultation for the SEA, it is estimated that 51.22 tonnes of StC, 4.01 tonnes of PCO and 2.38 tonnes of PHD are used in protective 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 significant proportion of members development plans (48%) are anticipated to be at the validation phase, with most of the remaining plans expected to be spread across development (11%), qualification (9%), certification (18%) and industrialisation (9%). If alternative development plans progress as anticipated the remaining 5% will be at MRL 10 by 2026, with use of Cr(VI) covered under this plan fully eliminated.

Where possible, requirements for use of protective primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide in new designs are being phased out, however aircraft and defence equipment that require their use remain in production and operation, for example aluminium fan module engine components.

With every relevant A&D scenario the sector has been taking chromates out wherever possible. However, for primers, the only opportunity to reduce Cr(VI) is exterior primers as described earlier. There are limited situations where engineers may specify non-chromate primer in low corrosion zones (e.g. some decorative parts in the main cabin). However, this is extremely limited in scope.

Use of strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide in primer products other than wash or bonding 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

Strontium chromate (StC; Entry No. 29), potassium hydroxyoctaoxodizincatedichromate (PHD; Entry No. 30) and pentazinc chromate octahydroxide (PCO; Entry No. 31) have been included into Annex XIV of Regulation (EC) No 1907/2006 due to their intrinsic property to be carcinogenic. StC is classified as carcinogenic Cat. 1B while PHD and PCO are classified as carcinogenic Cat. 1A.

- 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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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 (HSE) organisational plans. A mix of technical, organisational and personal-protection-based measures are in place to reduce workplace exposures. The sites adhere to best practices to reduce workplace exposures and environmental emissions to as low as technically and 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 primer products other than wash or bonding 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 protective primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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.

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 primer products other than wash or bonding primers containing strontium chromate and/or pentazinc chromate octahydroxide and/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 primer products other than wash or bonding primers containing strontium chromate and/or pentazinc chromate octahydroxide and/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 a 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

Table 4-6: Overview of exposure scenarios and their contributing scenarios

ES number	ES Title	Environmental release category (ERC)/ Process category (PROC)
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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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 primer products other than wash or bonding primers containing strontium chromate, 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	Workers not also spraying outside of spray booth/room/hangar	10 workers per day per site	7.80E-04
WCS1 - part 2	Workers also spraying outside of spray booth/room/hangar	1 worker per day at 20% of sites	2.66E-03
WCS2 - part 1	Workers performing short-term spraying	8 workers per day at 20% of sites	3.92E-03
WCS2 - part 2	Workers performing long-term spraying	18 workers per day at 20% of sites	2.51E-03
WCS3	Operators performing brushing/rolling	18 workers per day per site	9.60E-04
WCS4	Machinists	18 workers per day at 30% of sites	2.85E-04
WCS5	Sanders in a dedicated hangar	16 workers per day at 30% of sites	4.60E-04
WCS6	Workers performing media blasting in closed system	6 workers per day at 30% of sites	5.74E-04
WCS7	Workers performing media blasting in a room/hall	6 workers per day at 10% of sites	2.89E-03
WCS8	Maintenance and/or cleaning workers for spray area(s)	3 workers per day per site	7.10E-05
WCS9	Maintenance and/or cleaning workers (excluding spray areas)	9 workers per day per site	1.98E-04
WCS10	Incidentally exposed workers	14 workers per day per site	2.34E-04
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
2.61E-03	7.56E-05	1.83E-05	1.46E-08	7.56E-05
a) RAC dose-response relationship based on excess lifetime lung cancer risk (ECHA, 2013): Exposure to 1 µg/m3 Cr(VI) relates to an excess risk of 2.9x10-2 for the general population, based on 70 years of exposure; 24h/day. b) RAC dose-response relationship based on excess cancer risk for tumours of the small intestine (ECHA, 2013): Exposure to 1 µg/kg bw/day Cr(VI) relates to an excess risk of 8x10-4 for the general population, based on 70 years of exposure; daily exposure.				

4.4.3 Populations at risk

4.4.3.1 Worker assessment

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 130 sites
WCS1 - part 1	Workers not also spraying outside of spray booth/room/hangar	10 workers per day per site	1300
WCS1 - part 2	Workers also spraying outside of spray booth/room/hangar	1 worker per day at 20% of sites	26
WCS2 - part 1	Workers performing short-term spraying	8 workers per day at 20% of sites	208
WCS2 - part 2	Workers performing long-term spraying	18 workers per day at 20% of sites	468
WCS3	Operators performing brushing/rolling	18 workers per day per site	2340
WCS4	Machinists	18 workers per day at 30% of sites	702
WCS5	Sanders in a dedicated hangar	16 workers per day at 30% of sites	624
WCS6	Workers performing media blasting in closed system	6 workers per day at 30% of sites	234
WCS7	Workers performing media blasting in a room/hall	6 workers per day at 10% of sites	78
WCS8	Maintenance and/or cleaning workers for spray area(s)	3 workers per day per site	390
WCS9	Maintenance and/or cleaning workers (excluding spray areas)	9 workers per day per site	1170
WCS10	Incidentally exposed workers	14 workers per day per site	1820
Total			**9360**

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

Location of sites	No Sites	Population Density per km2	Exposed population
GB	130	2708.66	1,106,235

4.4.4 Residual health risks

4.4.4.1 Introduction

Under the Applied-for-Use Scenario, use of strontium chromate, potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide in primer products other than wash or bonding 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[60]. 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[61] cancer cases were derived from the Cancer Today database, see **Table 4-11** below.

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[60] 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).

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

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:

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

where π is the number of additional fatal lung cancer cases and σ is the number of additional non-fatal lung 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 strontium chromate, potassium hydroxyoctaoxodizincate dichromate, and/or pentazinc chromate octahydroxide in primer products other than wash or bonding 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	1300	7.80E-04	**1.01**	**0.27**
WCS1 - part 2	26	2.66E-03	**0.07**	**0.02**
WCS2 - part 1	208	3.92E-03	**0.82**	**0.22**
WCS2 - part 2	468	2.51E-03	**1.17**	**0.31**
WCS3	2340	9.60E-04	**2.25**	**0.60**
WCS4	702	2.85E-04	**0.20**	**0.05**
WCS5	624	4.60E-04	**0.29**	**0.08**
WCS6	234	5.74E-04	**0.13**	**0.04**
WCS7	78	2.89E-03	**0.23**	**0.06**
WCS8	390	7.10E-05	**0.03**	**0.01**
WCS9	1170	1.98E-04	**0.23**	**0.06**
WCS10	1820	2.34E-04	**0.43**	**0.11**
	Years - Lifetime	**40.00**	**6.85**	**1.82**
	Years - Review period	**12.00**	**2.06**	**0.55**
	Years - Annual	**1.00**	**0.17**	**0.05**

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	130	1,106,235	7.56E-05	83.63	51.26
Years - Lifetime cases			**70.00**	**83.63**	**51.26**
Years - Review period			**12.00**	**14.34**	**8.79**
Years - Annual			**1.00**	**1.19**	**0.73**

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[62]. 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[63] 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[64]. 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[65]. 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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[62] EC Better Regulation Toolbox – Tool #61: https://ec.europa.eu/info/sites/default/files/file_import/better-regulation-toolbox-61_en_0.pdf

[63] 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.

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

[65] 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[66]			
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)[67]			
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[68]. 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 3.5% 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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[66] 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.

[67] 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.

[68] 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[69]. Taking into account the latency period of cancer after exposure, a 10-year lag is applied[70]. 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 **£4.2 to 5.9 million** for GB, based on the assumption that chromate-based protective priming 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	2.06E+00	5.46E-01	2.06E+00	5.46E-01
Annual number of cases	1.71E-01	4.55E-02	1.71E-01	4.55E-02
Present Value (PV, in 2021 prices)	£4,057,055	£134,466	£5,795,793	£134,466
Total PV costs	**£4,191,521**		**£5,930,258**	
Total annualised cost	**£433,755**		**£613,687**	

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

[70] 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 **£30.6 million - £42.7 million** for GB, based on the assumption that use of primer products other than wash or bonding 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	14.34	8.79	14.34	8.79
Annual number of cases	1.19	0.73	1.19	0.73
Present Value (PV, in 2021 prices)	£28,297,309	£2,296,208	£40,424,727	£2,296,208
Total PV costs	**£30,593,517**		**£42,720,935**	
Total annualised cost	**£4,465,868**		**£6,236,160**	

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 the chromates in use of primer products other than wash or bonding primers across the sector at an estimated 130 GB sites covered by this combined AoA/SEA. It should also be recognised that workers using chromate-based primer products other than wash or bonding primers may also be using the chromates for other processes. As a result, their monitoring data may reflect aggregate exposures rather than just protective 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	16.39	9.33	16.39	9.33
Annual number of cases	1.37	0.78	1.37	0.78
Present Value (PV, in 2021 prices)	**£28,148,296**	**£2,114,686**	**£40,211,852**	**£2,114,686**
Total PV costs	**£30,262,983**		**£42,326,538**	
Total annualised cost	**£4,417,619**		**£6,178,588**	

5 Socio-Economic Analysis of Non-Use

5.1 The Non-Use Scenario

5.1.1 Summary of consequences of non-use

The inability of companies to undertake chromate based protective priming across GB would be severe. This use is critical to the key functions provided by the chromates: corrosion resistance (including active corrosion inhibition); adhesion promotion; and compatibility with substrate. 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 primer products other than wash or bonding primers was no longer authorised and where qualified and certified alternatives are not available according to the definition of "generally available"[71], design owners (i.e. OEMs and DtB companies) would be forced to re-locate some or all of their parts production, manufacturing and maintenance activities outside 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 primer products other than wash or bonding 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 protective priming outside GB or shift to suppliers outside of GB

⇩

OEMs would shift manufacturing outside GB due to the need for protective priming to be carried out in sequence with other treatments. It would be inefficient and costly to transport components and products outside GB for protective 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 protective 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 protective 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

⇩

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[71] 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)

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 primer products other than wash or bonding 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 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 strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide in primer products other than wash or bonding primers. The subject of these discussions included:

- The effects from the loss of primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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 was summarised in Section 4 as part of the description of the continued use scenario.

Moving to a poorer performing alternative was ruled out based on the unacceptability of such an option to the OEMs due to safety and airworthiness requirements, as detailed further below. Follow-up questions were asked to establish why producing components overseas and shipping them back to GB was not feasible, 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 above list. These comments are presented below and demonstrate the differences that exist within the aerospace supply chain and hence how the most plausible scenarios will vary by role.

Further details on the non-use scenario for the different types of companies are provided below, starting with OEMs as the main design owners, followed by DtBs, BtPs, and MROs. 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/Tier 1	MROs- only	Design-to-Build only	Build-to-Print only
It is unclear at this time/The decision is up to our customer	1	0	1	4
We may have to cease all operations as the company will no longer be viable	0	1	0	1
We will focus on other aerospace uses or on non-aerospace and defence uses	0	0	0	1
We will shift our work outside GB	1	1	1	0
We will stop undertaking use of the chromate(s) until we have certified alternative	0	1	4	3
Number of responses (companies)	2	3	6	9

5.1.2.1 OEMs

In discussions, the OEMs all stressed that the aim is the replacement of the use of primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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 GB. This is the most plausible scenario for the majority of OEMs directly involved in the use of primer products other than wash or bonding primers** containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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 GB while transferring use of primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide outside GB. This would result in huge numbers of components being transferred outside GB for repairs or touch-up, which would not be economically feasible. Furthermore, given the reliance on the use of primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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 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 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 GB depends on the integrated “system” of activities undertaken at individual sites. Primer products other than wash or bonding 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 primer products other than wash or bonding primers; all activities related to the manufacture of the relevant components, aircraft and other products may need to be moved outside GB. Note that this shifting of activity outside 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 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 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 GB.

5.1.2.2 Design-to-Build

Six responses were received from DtB companies, the majority stated that they would stop undertaking use of the chromates until they have a certified alternative. One company stated that the impacts of non-use were: “Requalification of products will, when possible, be an extensive task (for each single part number) and possibly cost prohibitive. If prohibitive, our business in that area may be curtailed drastically”. Another stated that the manufacture of components would be halted which would stop the building of planes in GB. Companies stated that they had sites outside GB, in the USA and India, where they were able to relocate operations.

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. Most confirmed that the choice of whether to use primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide is not theirs but their customers’. Several noted that they could not shift to alternative primer products other than wash or bonding 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. GB

One company stated: “As a sub contract finisher we can only be guided by our customer / design authority.”

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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide were 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 may be required, it would be difficult to 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 primer products other than wash or bonding primers. Where these requirements mandate the use of primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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 these 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 primer products other than wash or bonding primers 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[72], 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 including:

- 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 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 primer products other than wash or bonding 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

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[72] 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.

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.
- 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 protective 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 primer product other than wash or bonding primers 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 primer products other than wash or bonding primers containing Cr(VI) are crucial to the manufacture of the relevant aircraft components in 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 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[73]. 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 outside GB 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.

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

- 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 GB anymore (if use of primer products other than wash or bonding 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.

- 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) and there is no precedent to rely on, as this NUS is entirely contrary to current industry practice.

The result would be that the cost of operating in 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 other locations. As production moves outside 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 used in the primer formulations/formulations themselves would be impacted by the loss of sales, with the market for primer products other than wash or bonding primers for A&D relocating outside GB.

2. OEMs directly involved in use of primer products other than wash or bonding primers would move a significant proportion of their manufacturing (if not all) outside 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 primer products other than wash or bonding 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 GB are estimated at 50% of manufacturing turnover.** There would be a significant loss of jobs directly related to use of primer products other than wash or bonding primers, as well as across other manufacturing activities.

3. OEMs who do not carry out protective priming themselves would still move some of their manufacturing operations outside 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 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 GB to third countries in order to continue supplying the OEMs. However, a significant proportion of the existing BtP companies involved in use of primer products other than wash or bonding primers will cease this use in GB. Those that do not know what will happen as the decision is up to their customer, will either relocate outside of 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, 45% turnover losses are estimated, whereas 50% is estimated for DtBs.**

6. MROs will also be severely affected, and the majority of operators indicated that they will 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 50% 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 becoming obsolete and unavailable due to the inability to carry out repairs and/or maintenance activities according to manufacturers' requirements.

9. Taken together there would be significant economic impacts from the loss of manufacturing and maintenance to 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 the 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"[74].

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 primer products other than wash or bonding 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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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.

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

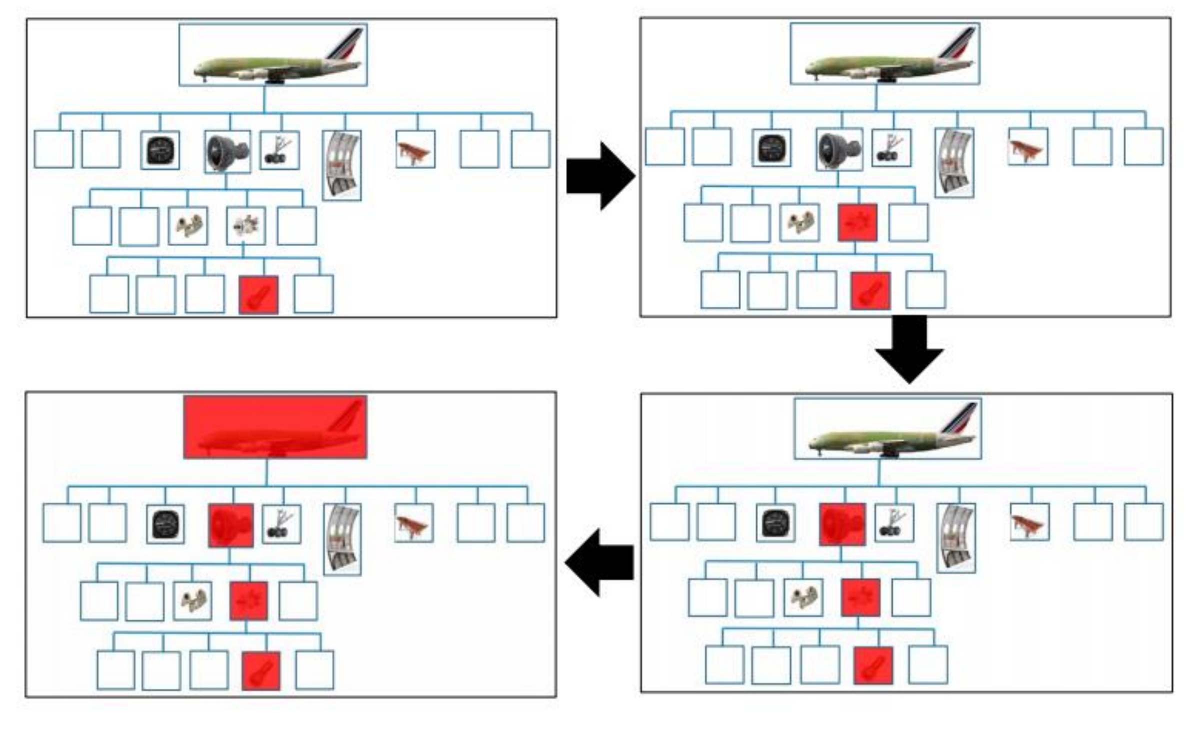

Figure 5-1: Interdependency of component availability in the manufacture of a final product
Source: GCCA (AfA 0116-01)

MROs will be similarly affected. It is technically not possible (or economically feasible) to carry out repairs to large components outside GB, and then ship them back for reassembly in a final product in 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 GB, leading to OEMs having to create entirely new supply chains outside 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 GB until the new industrial facilities were in place and ready to operate outside 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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide. At the specific supplier level, these impacts may vary in their significance, as the importance of primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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 tens of millions per annum Euro/Pound sterling to the applicants. Over time, as consumption of the primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide reduces in line with companies' substitution 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 primer products other than wash or bonding primers outside GB due to already existing supply chain sites in other countries, for example, the USA, Canada, China, Mexico, Morocco, etc. and to outsource manufacturing as the supply chain is spread around the world. 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 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, however, 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 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 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 strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and 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.

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 strontium chromate, potassium hydroxyoctaoxodizincatedichromate, or pentazinc chromate octahydroxide and those whose jobs would be affected due to a cessation of production activities or due to companies moving outside 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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide would cease to all employees in the event of closure are significant:

- Over 1,700 jobs involving workers directly involved in use of the chromates, 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 3,500 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 GB.

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

	No. Site Responses	Direct job losses	Additional direct job losses – due to a cessation of manufacturing/MRO activities
Build-to-Print	12	294	130
Design-to-Build	12	101	610
MROs	3	79	251
OEMs	11	2	61
Total	**38**	**476**	**1052**
Job losses - Extrapolation of job losses under the Non-Use Scenario			
Build-to-Print	45	1,103	488
Design-to-Build	40	337	2,033
MROs	10	263	837
OEMs	35	6	194
Total	**130**	**1,709**	**3,552**
Total GB direct and additional		**5,260**	

It is important to note that these losses do not equate to 100% of the jobs at these sites, as there would not be a full cessation of activities at all sites.

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	55,629.09	16.35 million	7.23 million
Design-to-Build	55,629.09	5.62 million	33.93 million
MROs	80,555.56	6.36 million	20.22 million
OEMs	116,492.43	0.23 million	7.11 million
Total		**28.57 million**	**68.49 million**
		Total GB	**97.06 million**
Extrapolation of job losses under the Non-Use Scenario			
Build-to-Print	55,629.09	61.33 million	27.12 million

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 - £
Design-to-Build	55,629.09	18.73 million	113.11 million
MROs	80,555.56	21.21 million	67.40 million
OEMs	116,492.43	0.74 million	22.61 million
Total		**102.01 million**	**230.24 million**
		Total GB	**332.25 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 SIC responses. MRO and OEM GVA figures from ONS (2022).**			

The magnitude of these GVA losses reflects the fact that use of chromate-based primer products other than wash or bonding primers takes place across a large number of sites in GB, including large numbers of BtP suppliers and MROs (civil and defence).

For comparison, turnover for the UK A&D sector (including NI) is around €57 billion (£50 billion) in 2020[75]. 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 GB should use of chromate-based primer products other than wash or bonding 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 £159 million extrapolated out the 130 GB sites using primer products other than wash or bonding primers.

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

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	23.59 million	14.00 million	9.59 million
Design-to-Build	39.55 million	23.47 million	16.08 million
MROs	26.58 million	10.90 million	15.69 million
OEMs	7.34 million	2.08 million	5.26 million
Total	**97.06 million**	**50.45 million**	**46.61 million**
Operating surplus losses - Extrapolation to the estimated 130 GB sites			
Build-to-Print	88.45 million	52.49 million	35.96 million
Design-to-Build	131.84 million	78.25 million	53.59 million
MROs	88.61 million	36.32 million	52.29 million
OEMs	23.35 million	6.62 million	16.73 million
Total	**332.25 million**	**173.68 million**	**158.58 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) 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 primer products other than wash or bonding 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. 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. 15% GOS losses across all roles)			
	Turnover loss %	**Turnover lost per annum - £**	**GOS losses per annum - £**
Build-to-Print	44%	368 million	77 million
Design-to-Build	48%	400 million	84 million
MROs	50%	171 million	31 million
OEMs	46%	3,298 million	511 million
Total		**4,236 million**	**704 million**
Extrapolation to the estimated 130 GB sites			
Build-to-Print	44%	1,379 million	290 million
Design-to-Build	48%	1,332 million	280 million
MROs	50%	571 million	102 million
OEMs	46%	10,492 million	1,627 million
Total		**13,775 million**	**2,300 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 £159 million per annum for GB

- Turnover based approach estimates of lost operating surplus across all sites:
    - Losses of £2,300 million per annum for 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 primer products other than wash or bonding 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 three 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 profits estimated from turnover - £	GVA-based Operating Surplus Losses - £
1 year profit losses (2025)	2,299.86 million	158.58 million
2 year profit losses (2026)	4,369.03 million	301.25 million
4 year profit losses (2028)	8,447.57 million	582.47 million
7 year profit losses (2031)	14,062.59 million	969.63 million
12 year profit losses (2036)	22,224.32 million	1,532.39 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 GB, leading to a second wave of negative impacts on GB markets. 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 GB

This combined AoA/SEA has been prepared so as to enable the continued use of primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide across the entirety of 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 GB

Under the non-use scenario, it is likely that some of the major OEMs and DtB suppliers would move outside 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 GB. These competitors would gain a competitive advantage due to their ability to continue to use primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide and due to their proximity to the OEMs and DtB, thus minimising logistic and transport issues.

5.2.4 Wider socio-economic impacts

5.2.4.1 Impacts on air transport

Under the Non-Use Scenario there would be significant impacts on the ability of MROs in 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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide, they would have to be performed outside GB 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 GB for repairs, with dramatic financial and environmental impacts.

Should MRO facilities be relocated outside GB, airlines will also experience additional delays to routine aircraft maintenance due to transport requirements and capacity constraints at MRO facilities outside the EU. Indeed, it may take some time to build up capacity to accommodate additional demand from EU-based operators, potentially resulting in a large number of aircraft being grounded until maintenance checks can be completed.

As a result, airlines would need to have additional spare components/engines/planes to account for the added time that aircraft would be out of commission due to extended MRO times. Airports may also have to build up large inventories of spare components to replace products that currently can be repaired, with this going against the desire to ensure sustainability within the sector.

The need to have maintenance performed outside 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 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 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)[76], 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[77] 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

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

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

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 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.

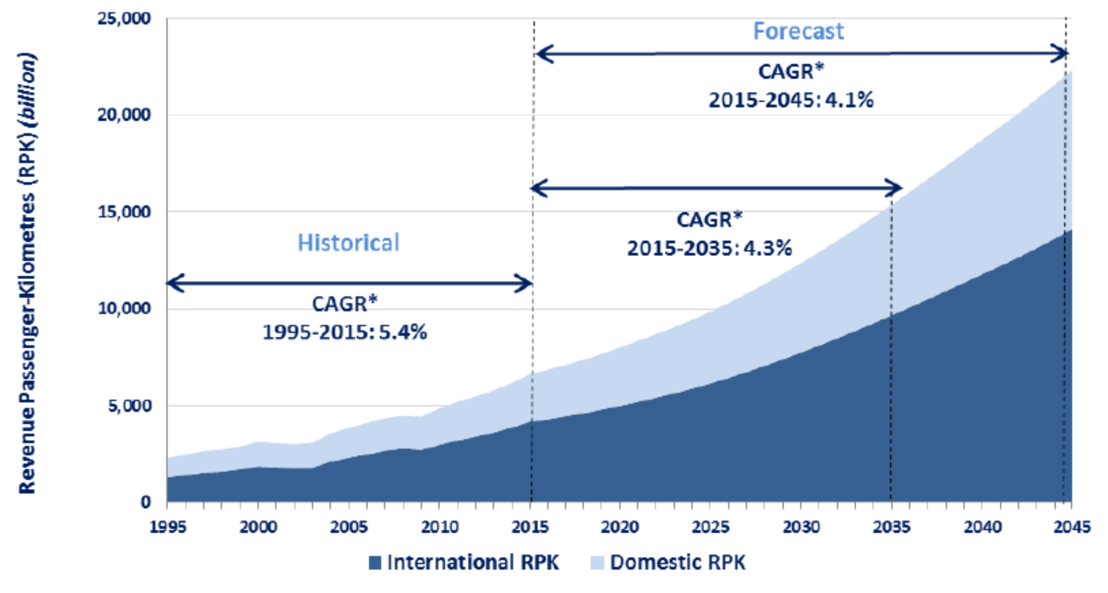

Figure 5-2: Forecast compound annual growth rates – Revenue Passenger-kilometres

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[78]. 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[79] (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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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

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

[79] https://www.statista.com/statistics/1094689/annual-growth-rate-air-passenger-traffic-europe/

buying more planes or stockpiling of components, which would inevitably give rise to increases due to the costs of holding spares and/or bringing spare planes on-line).

5.2.4.2 Defence-related impacts

Defence related impacts under the NUS would have two dimensions: impacts on military forces; and impacts on companies acting as suppliers to military forces.

Two national Ministries of Defence have provided information regarding their use of primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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 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 billion of estimated direct and indirect economic effects through innovations, new technologies, and products.[80]

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)[81]. The aim will be to support high-end defence capability projects such as the next generation of fighter aircrafts, tanks,

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[80] https://www.evropskyvyzkum.cz/cs/storage/bf5134fec407f6e005288c0e2631ad232c38c013?uid=bf5134fec407f6e005288c0e2631ad232c38c013

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

and ships, as well as critical defence technologies such as military cloud, Artificial Intelligence, semiconductors, space, cyber or medical countermeasures. It will also spearhead disruptive technologies, notably in quantum technologies and new materials, and tap into promising SMEs and start-ups. Some of these gains may not be realised if the main GB defence OEMs have to divert resources into shifting part of their manufacturing base outside of 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 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 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 GB under the NUS, then some proportion of such multiplier effects would be lost to GB economy. In addition, the ability of 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	• £1.53 to 22.22 billion over 12 years (£0.16 to 2.30 billion 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, 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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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 strontium chromate, potassium hydroxyoctaoxodizincate dichromate, and pentazinc chromate octahydroxide and not using strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and pentazinc chromate octahydroxide are separated on both sides of the GB 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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide, it would force the manufacturer to go to a non-European site. In the case of a major repair, aircraft that could not fly would become stranded or, less likely, would have to be dis-assembled for transport to a non-European site. Some stranded final products would become obsolete prematurely, due to the 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 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 aircrafts.

5.4 Social impacts under non-use

5.4.1 Direct and additional 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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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.

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 below. The magnitude of these figures reflects the importance of primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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.

The figures in **Table 5-8** indicate that approximately 5,000 A&D jobs would be in jeopardy under the NUS extrapolated out to the estimated 130 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	1,590
Design-to-Build	2,370
MROs	1,100
OEMs	200
Total	5,260

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[82]).

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[83] as a whole that varies according to the mean duration of unemployment. These vary by country, with the mean duration of unemployment weighted by the number of employees for each country relevant to A&D sector 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 £50k 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 estimate of the social costs of unemployment is £549 million, for the 5,260 estimated job losses.

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

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[82] 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

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

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[84] 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 Aerospace Cluster Partnership (EACP)[85] 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).

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[84] 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

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

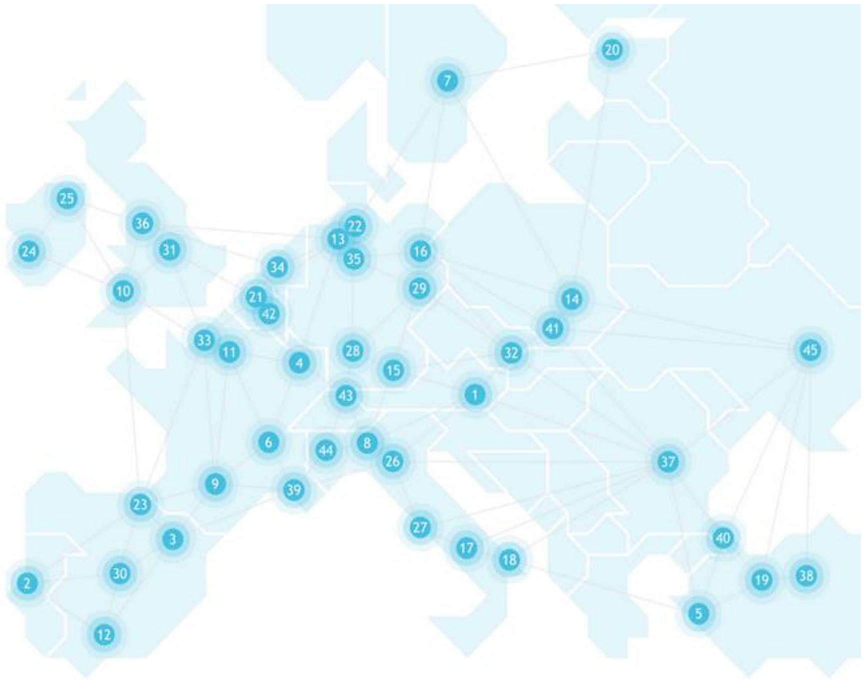

Figure 5-3: Aerospace clusters across Europe

5.4.2.2 Air transport multiplier effects

A 2019 "Aviation Benefits Report"[86] produced by a high-level group formed by the International Civil Aviation Organisation (ICAO) provides an assessment of the economic impacts of the aviation sector. These are linked to its direct impact as well as indirect, induced, and catalytic effects. At a regional level, it is estimated that air transport supports 12.2 million jobs in Europe. 2.6 million of these jobs are 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.

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

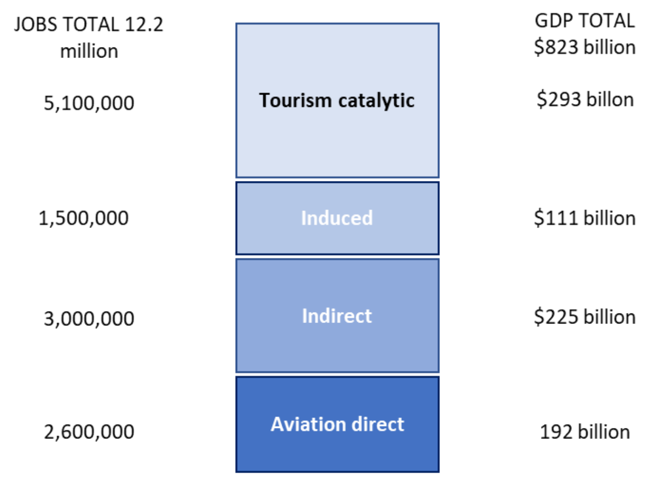

Figure 5-4: Aviation related multiplier effects
Source: Based on: ***https://www.icao.int/sustainability/Documents/AVIATION-BENEFITS-2019-web.pdf***

The potential employment losses associated with a decline in European aviation can be seen by reference to the impacts of COVID-19[87]. 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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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: 1,500 GB workers involved in primer products other than wash or bonding primers and linked chromate treatment processes; and 5,200 GB workers impacted by a cessation of other treatment and manufacturing activities;
- Social costs of unemployment: economic costs of around £549 million for GB due to direct job losses;

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

- Indirect and induced unemployment at the regional and national level due to direct job losses; and
- Direct, indirect, and induced job losses in air transport due to disruption of passenger and cargo services.

5.5 Combined impact assessment

Table 5-9 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 - £301 to 4,369 million	Applicants: Impacts in Pound millions – see Formulation SEA A&D companies - £31 to 452 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]	5,260 jobs lost	
	£550 million	£57 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	£851 to 4,919 million	£88 to 509 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.	

1) Lower bound figures represent lost profit estimates based on loss of jobs, upper bound based on loss of turnover.

Table 5-9: Summary of societal costs associated with the non-use scenario	
Description of major impacts	**Monetised/quantitatively assessed/qualitatively assessed impacts**
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 14:1 to 115:1, which further strengthen the conclusion that benefits of continued use outweigh risks of continued use.

Table 5-10: Sensitivity Analysis

Scenario	Annualised Profit Losses to the A&D industry	Annualised Social Costs due to unemployment	Annualised Human Health Risks	Net Present Value	Ratio of societal costs to residual health risks:
1	£31 million	£57 million	£4 million	£84 million	20:1
2	£452 million	£57 million	£4 million	£505 million	115:1
3	£31 million	£57 million	£6 million	£82 million	14:1
4	£452 million	£57 million	£6 million	£503 million	82:1
5	£31 million	£57 million	£5 million	£83 million	17:1
6	£452 million	£57 million	£5 million	£504 million	96:1

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 primer products other than wash or bonding primers should be "generally available"[88]. 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 primer products other than wash or bonding 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 primer products other than wash or bonding primers are shown in **Figure 6-1**.

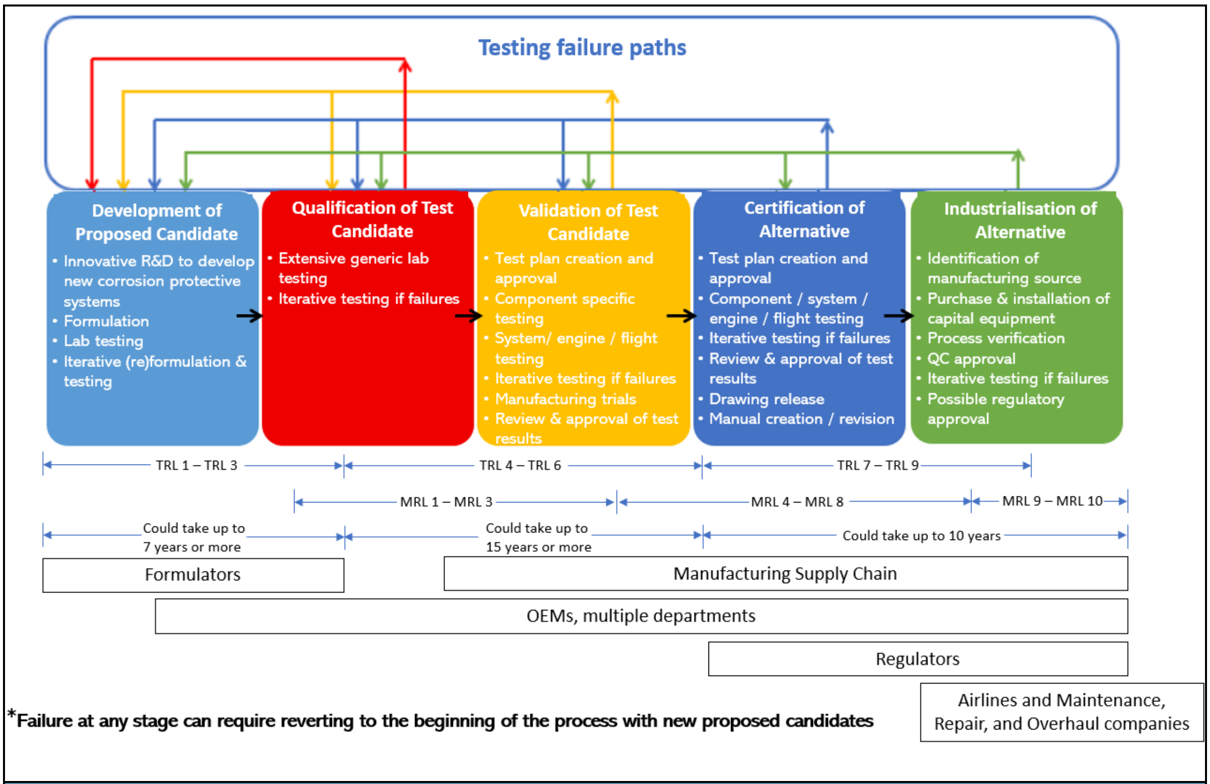

Figure 6-1: Schematic showing the key phases of the substitution process.
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note 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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[88] 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 plans in place to develop test candidates with the intent of replacing primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and/or pentazinc chromate octahydroxide.

As discussed in Section 3.7.2 and shown in **Figure 6-2** below, of the 44 distinct test candidate development plans for primer products other than wash or bonding primers assessed in this combined AoA/SEA, 5% 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 primer products other than wash or bonding primers containing Cr(VI) will no longer be used for the components covered in that development and/or substitution plan.

The proportion of test candidate development plans that are expected to achieve MRL 10 is then expected to progressively increase to 25% in 2030, 77% in 2033, and 90% in 2038. The potential need for more than 12 years has been identified by some OEMs due to their inability to identify any technically feasible alternatives to date, or due to the need by MROs and MoDs for continued use in the maintenance and repair of in-service (legacy) final A&D products. In 2033 (equivalent to seven years beyond the expiry date for the existing authorisations), 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 currently expected to have achieved MRL 10 and are expected to be at the qualification, 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 of 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. For these test candidate development plans (which are from several member companies), there is at this time still expected to be a need for the use of protective primers containing Cr(VI).

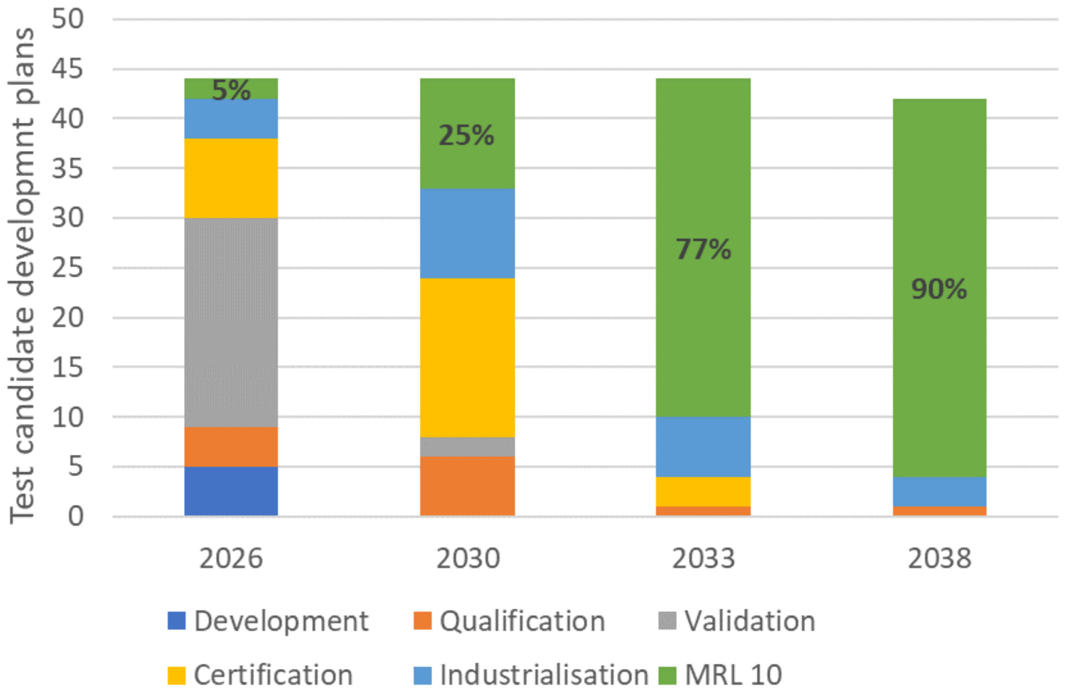

Figure 6-2: Expected progression of Test candidate development plans for the use of primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincate dichromate and/or pentazinc chromate octahydroxide by year.
The vertical axis refers to number of Test candidate development plans (some members have multiple development plans for primer products other than wash or bonding primers). The percentage value shown on each of the green 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

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 primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate 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	£301 to 4,369 million	Monetised excess risks to directly and indirectly exposed workers (£per year over 12 years)	£433,755 to 613,687
Social costs of unemployment	£550 million	Monetised excess risks to the general population (£ per year over 12 years)	£4 to 6 million
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 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): ○ £83 to 504 million - Ratio of societal costs to residual health risks: ○ 17:1 to 96:1		

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 GB formulators and the critical set of key functions provided by primer products other than wash or bonding 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 use primer products other than wash or bonding primers containing the chromates outside GB or shift to suppliers outside of GB

↓

OEMs would shift manufacturing outside GB due to the need use of primer products other than wash or bonding primers to be carried out in sequence with other treatments. It would be inefficient and costly to transport components and products outside GB for application of primer products other than wash or bonding primers 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 use of primer products other than wash or bonding primers containing the chromates, 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 application of primer products other than wash or bonding primers 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 three chromates in primer products other than wash or bonding primers significantly outweigh the residual risks from continued use.

Additionally**, the use of the three chromates in primer products other than wash or bonding primers is required (and may be required beyond 12 years) to ensure the operational capabilities of the military and the ability to comply with international obligations as partner nations 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 20-35 years, while military products typically last from 40 to >90 years. Furthermore, the production of one type of aircraft or piece of equipment may span more than 50 years.

These long investment cycles and long product lives have been recognised in the FWC Sector 26 study on the Competitiveness of the EU aerospace industry[89]. They are a key driver underlying the difficulties facing the sector in substituting the use of strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and pentazinc chromate octahydroxide in primer products other than wash or bonding 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; as it would require testing at multiple levels (components, sub-assemblies, assemblies, final aircraft/defence equipment).

The ADCR consortium would like to emphasise the crucial role every single component within an A&D product play 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 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 strontium chromate, potassium

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[89] 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.

hydroxyoctaoxodizincatedichromate 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 consortium 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 strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and pentazinc chromate octahydroxide across all uses of primer products other than wash or bonding 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 primer products other than wash or bonding 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 literally billions of flight hours' experience with components onto which Cr(VI)-based primer products other than wash or bonding 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 primer products other than wash or bonding 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 strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and 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 OEM will not be able to substitute chromate use in the production of all components and products for at least 12 years, and perhaps longer for those components and products which must meet military requirements (including those pertaining to UK, EEA and US equipment).

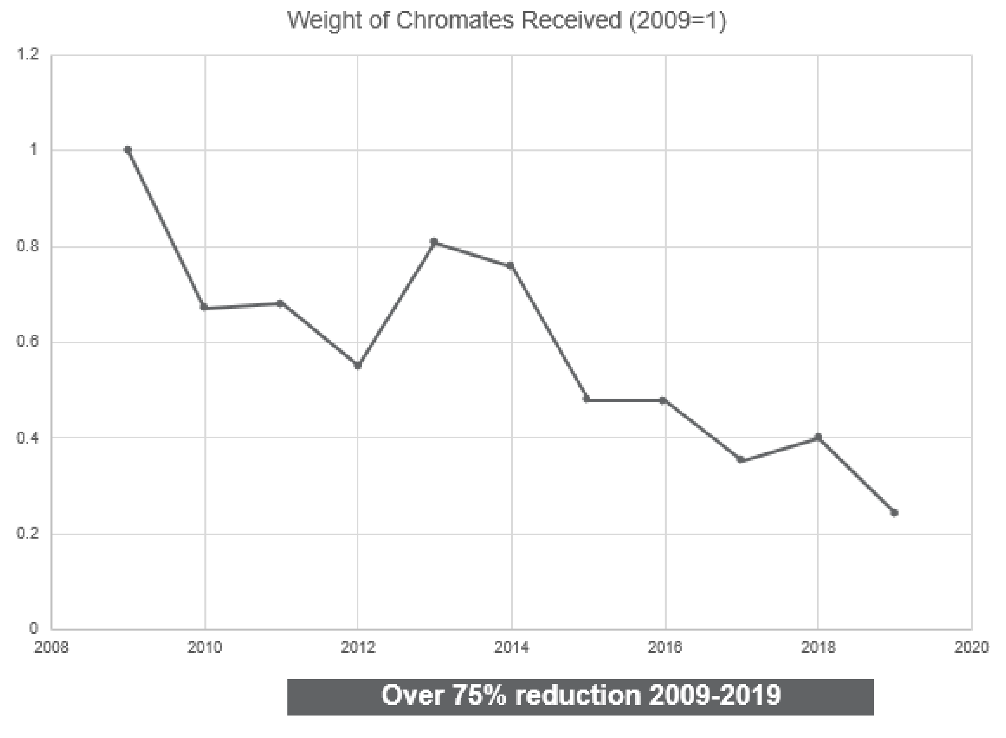

Figure 6-3: Reductions in chromate dependency over the period 2009 -2019 as reported by one OEM.

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)[90].

A PricewaterhouseCoopers (PwC) study[91] 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 primer products other than wash or bonding 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. 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.

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

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

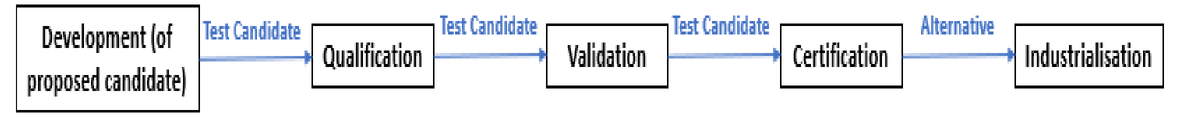

Figure 6-4: Phases of the substitution process

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 primer products other than wash or bonding primers by 2038. Their current substitution plans are designed to ensure they achieve TRL 9 and MRL 10 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 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 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 primer products other than wash or bonding 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, GB defence sectors requires only small quantities of strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and pentazinc chromate octahydroxide in primer products other than wash or bonding 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 primer products other than wash or bonding 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 strontium chromate, 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 strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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[92].

The European aerospace and defence industry is a world-class leader in technology and innovation. They are an essential part of the European economy contributing to job creation (880,000 direct jobs in 2020[93]) and Europe's trade balance (55% of products developed and built in GB 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.[94]

Boeing's 2023 Commercial Market Outlook[95] 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 GB 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.

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[92] 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

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

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

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

This work will continue over the requested review period with the aim of phasing out all uses of primer products other than wash or bonding primers containing strontium chromate, potassium hydroxyoctaoxodizincatedichromate, 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 three chromates used in primer products other than wash or bonding 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 will be submitting 4 Review reports covering the following uses and the continued use of strontium chromate, potassium hydroxyoctaoxodizincatedichromate, and pentazinc chromate octahydroxide:

1) Formulation
2) Use of wash primers
3) Use of bonding primers
4) Use of primer products other than wash or bonding primers

7 References

Airbus SAS (2022) *Laboratory Testing | Engineering & Design Services | Expand | Services | Airbus Aircraft*. Available at: https://aircraft.airbus.com/en/services/expand/engineering-design-services/laboratory-testing (Accessed: 15 August 2022).

CARACAL (2017) *REACH Authorisation - Criteria for longer review periods*.

CCST (2015a) *Potassium hydroxyoctaoxodizincatedichromate, use 2 (0047-02)*. Available at: https://echa.europa.eu/documents/10162/1af648ff-919b-4b6b-9279-3d8b6cfe00f8 (Accessed: 4 April 2023).

CCST (2015b) *Strontium chromate AoA use 2 (0046-02)*. Available at: https://echa.europa.eu/applications-for-authorisation-previous-consultations/-/substance-rev/20625/del/50/col/synonymDynamicField_1512/type/asc/pre/2/view (Accessed: 23 March 2023).

CCST (2017) *Pentazinc chromate octahydroxide, use 2 (0118-02)*. Available at: https://echa.europa.eu/documents/10162/36219676-294d-8066-7bea-b21ab7482439 (Accessed: 4 April 2023).

Charles B Elliott, Moesser, M. and Hoeppner, D.W. (1994) 'THE ROLE OF FRETTING CORROSION AND FRETTING FATIGUE IN AIRCRAFT RIVET HOLE CRACKING-A STATUS REPORT ON TWO FAA GRANT PROGRAMS* Mark Moesser', pp. 241–246.

Civil Aviation Authority (2017) *CAP1570: Corrosion and Inspection of General Aviation Aircraft | Civil Aviation Authority*. Available at: https://www.caa.co.uk/our-work/publications/documents/content/cap1570/ (Accessed: 30 March 2024).

EASA (2012) *European Aviation Safety Agency GOOD PRACTICES Coordination between Design and Maintenance First Installation of a Change to a Product*.

ECHA (2013) *SETTING THE REVIEW PERIOD WHEN RAC AND SEAC GIVE OPINIONS ON AN APPLICATION FOR AUTHORISATION*.

EPO (2020) *EPO - Espacenet: patent database with over 120 million documents*.

EU (2018) *Regulation (EU) 2018/1139 | EASA*. Available at: https://www.easa.europa.eu/document-library/regulations/regulation-eu-20181139 (Accessed: 2 September 2022).

GCCA (2017a) *Dichromium tris(chromate) AoA, use 1 (0116-01)*. Available at: https://echa.europa.eu/fi/applications-for-authorisation-previous-consultations/-/substance-rev/29011/del/50/col/synonymDynamicField_1512/type/asc/pre/4/view (Accessed: 16 August 2022).

GCCA (2017b) *Strontium chromate AoA, use 1 (0117-01)*. Available at: https://echa.europa.eu/documents/10162/b61428e5-e0d2-93e7-6740-2600bb3429a3 (Accessed: 5 April 2023).

Jiang, X., Guo, R. and Jiang, S. (2016) 'Evaluation of self-healing ability of Ce–V conversion coating on AZ31 magnesium alloy', *Journal of Magnesium and Alloys*, 4(3), pp. 230–241. Available at: https://doi.org/10.1016/j.jma.2016.06.003.

Rheinmetall – Systems & Products (no date). Available at: https://rheinmetall-defence.com/en/rheinmetall_defence/systems_and_products/index.php#Milit%C3%A4rischeFahrzeuge (Accessed: 17 August 2022).

Rowbotham, J. and Fielding, T. (2016) 'Intended and unintended consequences of REACH', *Aerospace Coatings*, pp. 26–27. Available at: www.coatingsgroup.com (Accessed: 30 March 2022).

Royal Academy of Engineering (2014) 'Innovation in aerospace', (June 2014), pp. 1–21. Available at: http://www.raeng.org.uk/publications/reports/innovation-in-aerospace.

Royal Navy (2021) *Osprey tiltrotor*. Available at: https://www.royalnavy.mod.uk/news-and-latest-activity/news/2021/april/01/20210401-osprey-mounts (Accessed: 17 August 2022).

8 Annex 1: Standards applicable to primer products other than wash or bonding primers

Table A1-1 lists examples of standards and specifications reported by ADCR members applicable to the use of primer products other than wash or bonding primers. 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.

Table A1-1: Examples of standards applicable to primer products other than wash or bonding primers

Standard Reference	Standard Description	Key function/Standard type
ASTM B117	Standard Practice for Operating Salt Spray (Fog) Apparatus	Corrosion resistance
ASTM D3359	Standard method for measuring adhesion by tape test	Adhesion
BS 2X 33	Specification for two component primer for aerospace purposes	Fluid resistance
BS3900	Method of test for paints	Fluid resistance
EN 3665	Filiform corrosion resistance test on aluminium alloys	Corrosion resistance
ISO 1518-1	Determination of scratch resistance	Mechanical properties (Scratch resistance)
ISO 1519	Bend test (cylindrical mandrel)	Mechanical properties (Flexibility)
ASTM D522	Mandrel Bend Test of Attached Organic Coatings	Mechanical properties (Flexibility)
ISO 1520	Cupping test	Mechanical properties (Flexibility)
ISO 15710	Corrosion testing by alternate immersion in and removal from a buffered sodium chloride solutions	Corrosion resistance
ISO 2409	Cross-cut test	Adhesion to subsequent coating or paint
ISO 2808	Determination of film thickness	Layer thickness
ISO 2812	Determination of resistance to liquids	Chemical resistance
ISO 4628-2	Evaluation of degradation of coatings	Compatibility with sealants
ISO 4628-4	Evaluation of degradation of coatings	
ISO6272-1	Rapid deformation (Impact resistance) tests	Mechanical properties (Impact resistance)
ASTM D2794	Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)	Mechanical properties (Impact resistance)
ASTM D3363-22	Film Hardness by Pencil Test	Mechanical properties (Hardness)
ISO 7253	Resistance to salt spray	No blister and corrosion resistance
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: UK Aerospace sector

10.1 Aerospace

The annual ADS Industry Facts and Figures guide provides an indication of the UK aerospace, defence, security and space sectors' contribution to the economy in 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.

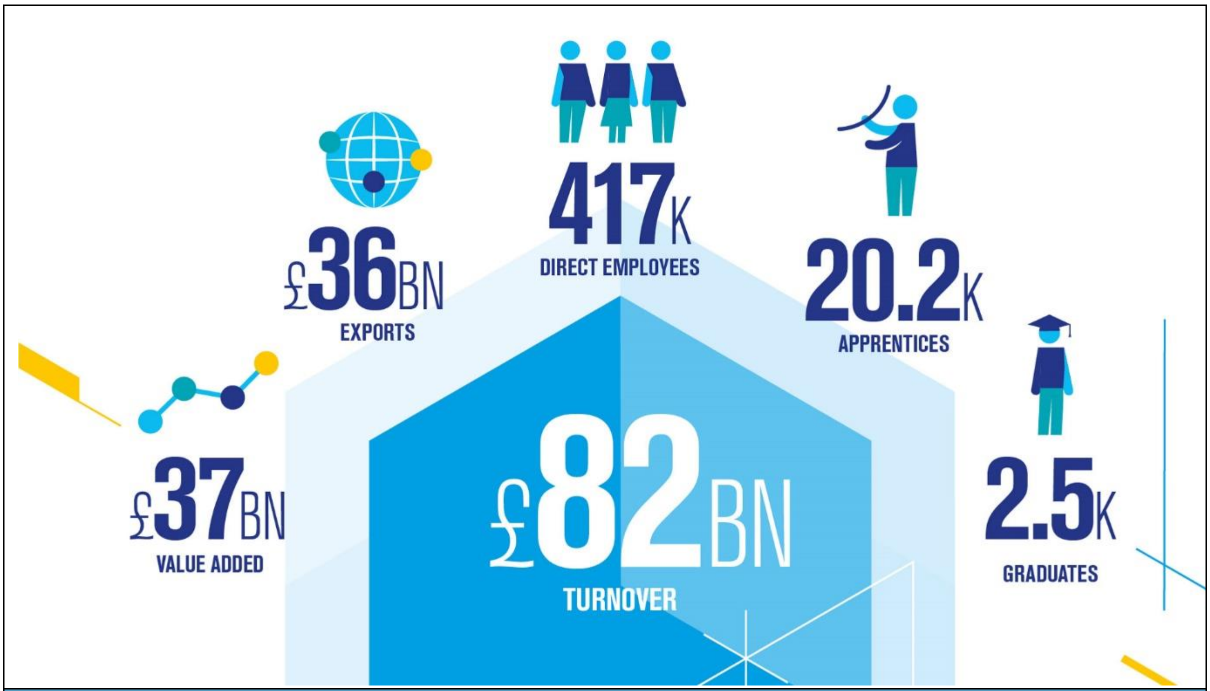

Figure 10-1: Contribution of UK aerospace, defence, security and space sectors to the economy in 2022[96]

The UK aerospace sector is considered by the government to be "hugely important to the UK economy"[97], providing direct employment of over 120,000 highly skilled jobs that pay about 40% above the national average. The sector has an annual turnover of around £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)[98]. To date, this co-funded programme has invested £2.6 billion, across all parts of the UK. It is anticipated that the UK aerospace

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[96] ADS Industry Facts & Figures 2023 - launched! - ADS Group

[97] BEIS, Aerospace Sector Report, undated.

[98] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/763781/aerospace-sector-deal-web.pdf

sector will continue to grow into the future, due to the global demand for large passenger aircraft, as discussed further below.

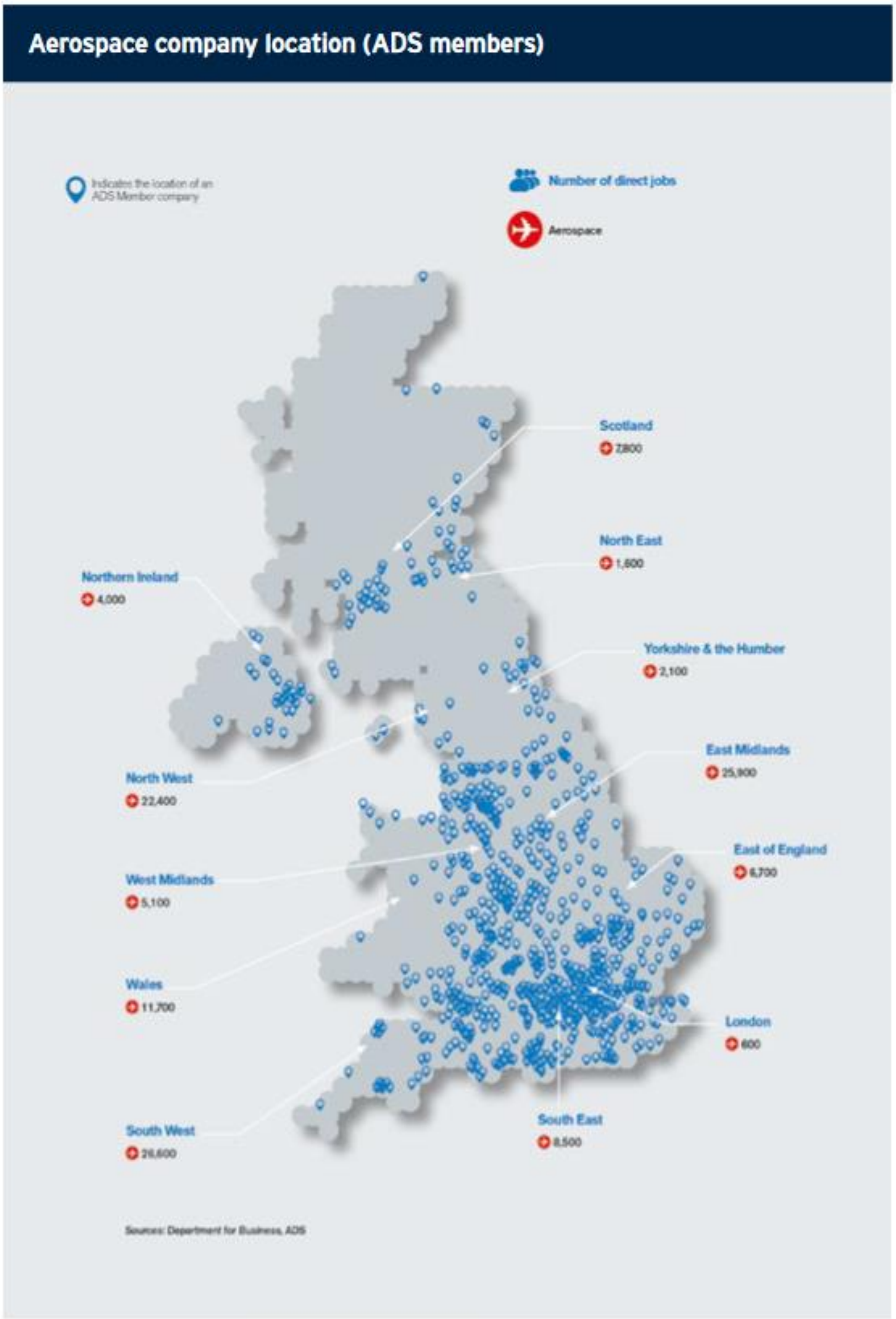

Figure 10-2: Location of aerospace manufacturing sites and associated jobs in the UK[99]

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[99] Sources: ONS, BEIS, ADS Industrial Trends Survey 2020

The National Aerospace Technology Exploitation Programme was created in 2017 to provide research and technology (R&T) funding with the aim of improving the competitiveness of the UK aerospace industry, as well as other supporting measures under the Industrial Strategy. The Government's investment in R&T is through the Aerospace Technologies Institute and is programmed at £1.95 billion in expenditure between 2013 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.

10.2 Defence

With respect to defence, the UK is the second largest defence exporter in the world, with its contribution to employment, turnover, and exports illustrated in **Figure 10-3**[100]. Again, the importance of the sector to UK exports and value added, as well as employment is clear from the figure below.

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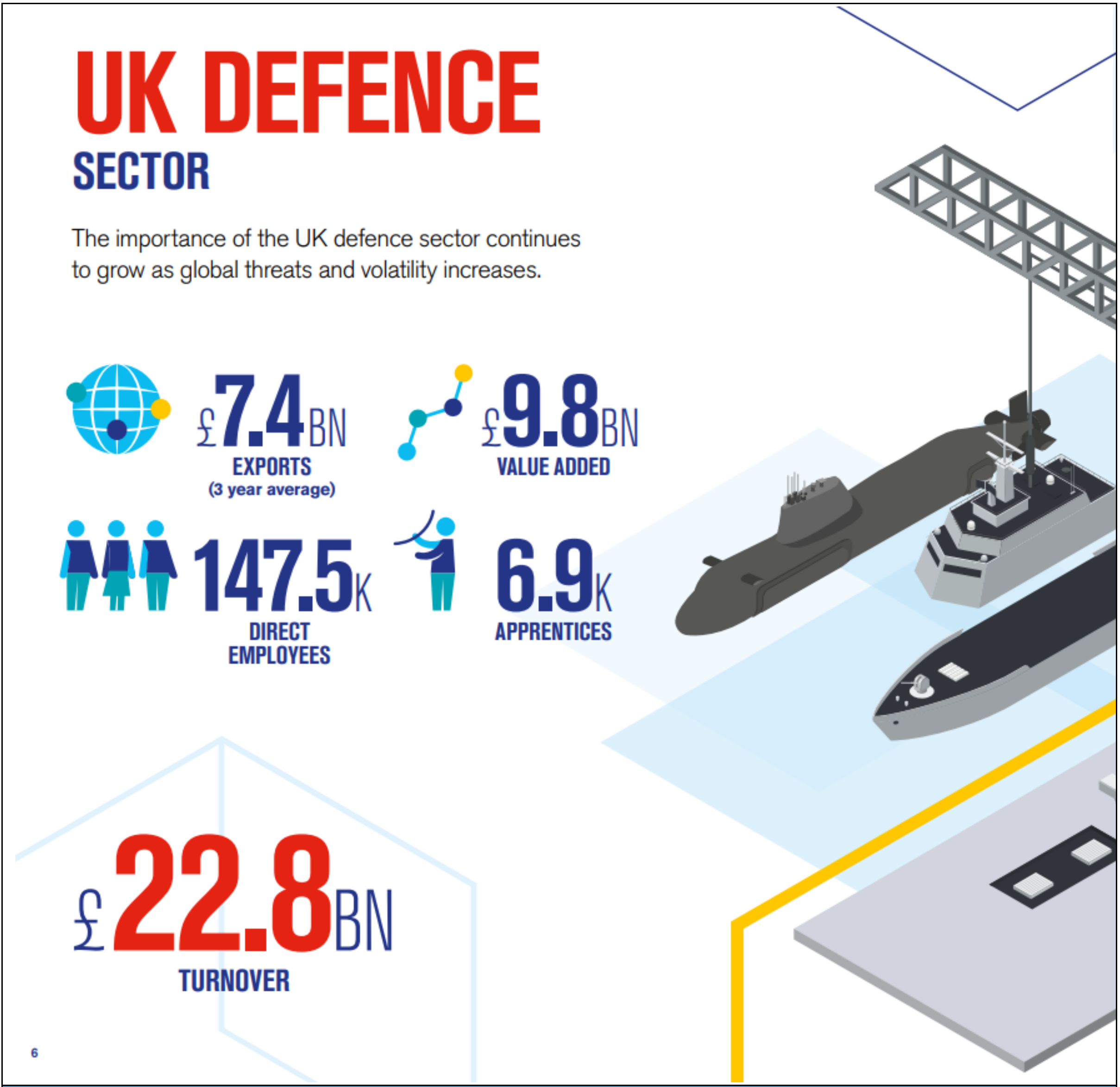
[100] Sources: Industry Facts & Figures 2023 - ADS Group



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 10-3: UK defence sector contribution to the economy in 2021