ANALYSIS OF ALTERNATIVES
and
SOCIO-ECONOMIC ANALYSIS

Complete version

Legal name of applicant(s):	Wesco Aircraft EMEA Ltd
Submitted by:	Wesco Aircraft EMEA Ltd on behalf of the Aerospace and Defence Chromates Reauthorisation Consortium
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Substance:	Chromium trioxide (CT) (includes "Acids generated from chromium trioxide and their oligomers", when used in aqueous solutions) EC 215-607-8 CAS 1333-82-0
Use title:	Slurry coating using chromium trioxide in aerospace and defence industry and its supply chains
Use number:	1

Note

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

Table of contents

List of Tables

List of Figures

Abbreviations

ADCR – Aerospace and Defence Chromates Reauthorisation

A&D – Aerospace and Defence

AfA – Application for Authorisation

AoA – Analysis of Alternatives

AoG – Aircraft on the Ground

BCR – Benefit to Cost Ratio

BtP – Build-to-Print

CAGR – Compound Annual Growth Rate

CCC – Chemical Conversion Coating

CCST – Chromium VI Compounds for Surface Treatment

CMR – Carcinogen, Mutagen or toxic for Reproduction

Cr(VI) – Hexavalent chromium

CSR – Chemical Safety Report

CT – Chromium trioxide

CTAC – Chromium trioxide Authorisation Consortium

CVD – Chemical vapour deposition

DtB – Design-to-Build manufacturer

DtC – Dichromium tris(chromate)

EASA - European Aviation Safety Agency

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

ECHA – European Chemicals Agency

EEA – European Economic Area

ESA – European Space Agency

GCCA – Global Chromates Consortium for Authorisation

GDP – Gross domestic product

GOS – Gross operating surplus

HvE – Humans via the Environment

ICAO – International Civil Aviation Organisation

MoD – Ministry of Defence

MRL – Manufacturing readiness level

MRO – Maintenance, Repair and Overhaul

NADCAP - National Aerospace and Defence Contractors Accreditation Program

NATO – north Atlantic treaty organisation

NUS – Non-use scenario

OELV – Occupational exposure limit value

OEM – Original Equipment Manufacturer

PVD – Physical vapour deposition

RAC – Risk Assessment Committee

REACH - Registration, Evaluation, Authorisation and Restriction of Chemicals

RR - Review Report

SC – Sodium chromate

SD – Sodium dichromate

SEA – Socio Economic Analysis

SEAC – Socio Economic Analysis Committee

SME – Small and medium-sized enterprises

SVHC – Substance of Very High Concern

T&E – Testing and Evaluation

UK – United Kingdom

WCS – Worker contributing scenario

Glossary

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

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

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

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

DECLARATION

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

Also, we request that the information blanked out in the “public version” of the Analysis of Alternatives and Socio-economic analysis is not disclosed. We hereby declare that, to the best of our knowledge as of today 8 February 2023 the information is not publicly and, in accordance with the due measures of protection that we have implemented, a member of the public should not be able to obtain access to this information without our consent or that of the third party whose commercial interests are at stake.

Signature: Date: 8 February 2023

mazin.badri@incora.com

08/02/2023

SES Simple electronic signature
Signed on Skribble.com

1 Summary

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

1.1 Introduction

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

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

The parent authorisations to this review report covered multiple surface treatments and different individual chromates. This combined AoA/SEA covers only one of the currently authorised types of surface treatment slurry coatings – and therefore adopts a narrower definition of "use" compared to the original Chromium trioxide Authorisation Consortium (CTAC) and Global Chromates Consortium for Aerospace (GCCA) applications. The other surface treatments that are still being supported by the ADCR are covered by separate, complementary submissions for each "use."

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

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

1) *Slurry coatings using chromium trioxide in the Aerospace and Defence industry.*

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

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

The “applied for use” involves the continued use of chromium trioxide and across the EEA and the UK for a further 12-year review period.

Chromium trioxide is included into Annex XIV of Regulation (EC) No 1907/2006 due to its intrinsic properties (mutagenic, carcinogenic, and toxic for reproduction; depending on the chromate). According to Article 62 (4)(d) of this Regulation, the chemical safety report (CSR) supporting an Application for Authorisation (AfA) needs to cover only those risks arising from the intrinsic properties specified in Annex XIV. The carcinogenicity, mutagenicity and reproductive toxicities of CT, and its acids, are driven by the chromium VI (Cr(VI)) ion released when the substances solubilise and dissociate.

It is estimated that sites in the EEA and UK consume 3.5 tonnes per annum and 3 tonnes per annum respectively, based on the maximum consumption per site identified in the CSR; it is of note that the Article 66 notifications made to ECHA indicate that actual volumes are lower than these maximum figures.

1.2 Availability and suitability of alternatives

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

- Corrosion resistance (self-healing);
- Thermal resistance;
- Cyclic heat-corrosion resistance/hot corrosion resistance;
- Resistance to humidity and hot water;
- Thermal shock resistance;
- Chemical resistance;
- Erosion resistance and smooth surface finish; and
- Adhesion promotion and flexibility

Other factors which have to be taken into account include pre-treatment and post-treatment compatibility, where appropriate when assessing test candidate alternatives.

The term slurry coating covers two types of coating: sacrificial coatings and high temperature (diffusion) coatings. These are defined by ADCR members as below:

Sacrificial Coatings may be applied by spray or brush application on steel or stainless steel and entail application onto a prepared surface, curing with heat to produce a stable film that is well bonded to the substrate and then post-treating that layer to render it electrically conductive with an electrode potential lower than the substrate;

High Temperature (diffusion) Coatings are applied by spray or brush application on cast and wrought superalloys or high temperature alloys. Application takes place onto a prepared surface and then curing with heat to produce a stable protective coating that is well bonded to the substrate. In certain instances, the cured slurry may be re-heated in a protective environment to melt it into the substrate to form a protective diffused layer.

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

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

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

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

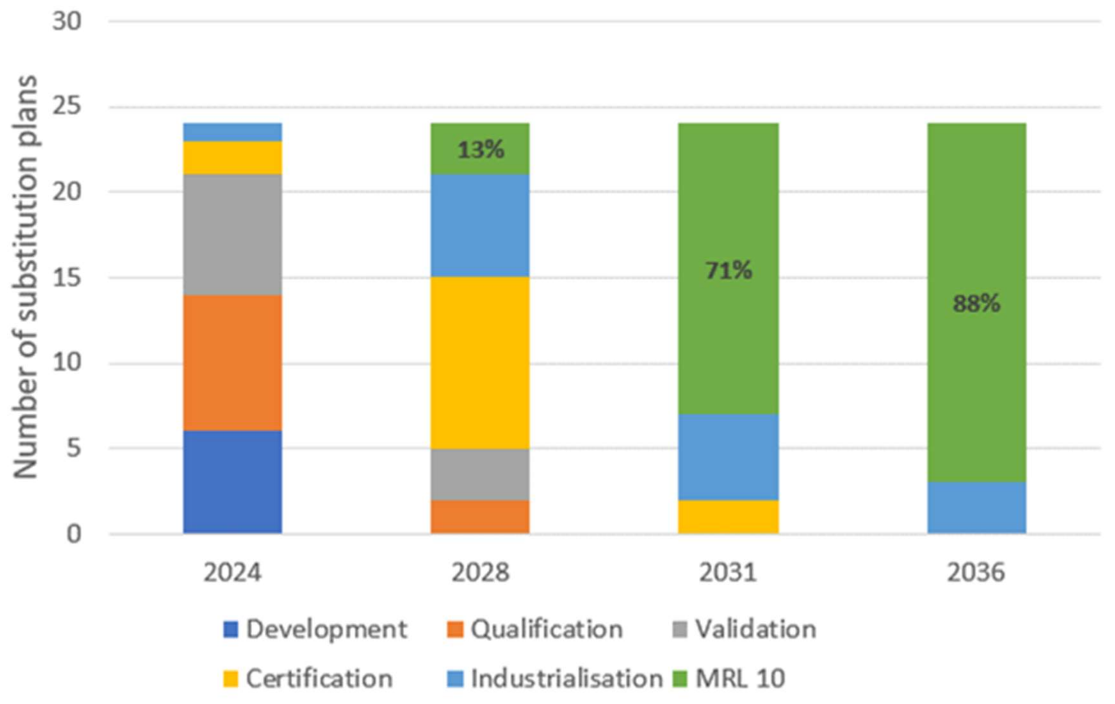

Figure 1-1: Expected progression of substitution plans for the use of Cr(VI) in slurry coating, by year.

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

Source: RPA analysis, ADCR members

1.3 Socio-economic benefits from continued use

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

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

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

- OEMs will be able to rely on the use of chromates by their EEA and UK suppliers and in their own production activities. The profit losses[3] to these companies under the non-use scenario would equate to between €350 and €2,600 million for the EEA and €140 to €1,400 million for the UK, over a 2-year period (starting in 2025, PV discounted at 4%). These figures exclude the potential profits that could be gained under the continued use scenario from the global increase in demand for air transport;

- Build-to-Print (BtP) and Design-to-Build (DtB) suppliers would be able to continue their production activities in the EEA/ UK and meet the performance requirements of the OEMs. The associated profit losses avoided under the continued use scenario for these companies are calculated at between €30 and €40 million for the EEA and €30 to €60 million for the UK over a 2-year period (starting in 2025, PV discounted at 4%);

- MRO companies that provide maintenance and repair services to both civil aviation and military forces would not be forced to move some operations outside the EEA/UK, with the consequent profit losses equating to between €100 and €140 million for the EEA and €70 to €1,300 million for the UK over a 2-year period (starting in 2025, PV discounted at 4%). Such relocation of strategically important activities would run contrary to the EU's New Industrial Strategy;

- Continued high levels of employment in the sector, with these ensuring the retention of highly skilled workers paid at above average wage levels. From a social perspective, the benefits from avoiding the unemployment of workers involved in slurry coatings are estimated at €1,100 million in the EEA and €460 million in the UK. These benefits are associated with the protection of around 9,900 jobs in the EEA and 4,600 jobs in the UK;

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

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

- The general public will benefit from 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.

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

1.4 Residual risk to human health from continued use

The parent authorisations placed conditions on the continued use of chromium trioxide in surface treatment including in slurry coatings. The A&D sector has made huge efforts to be compliant with

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

these conditions, investing not only in risk management measures but also improved worker and environmental monitoring.

Furthermore, significant technical achievements also have been made in developing and qualifying alternatives for use on some components/final products, although there remain technical challenges for other components and final products. As a result, it is projected that from 2024, based on current company-specific substitution plans, where technically and economically feasible, consumption of the chromates by ADCR members and their suppliers will decline significantly over the requested 12-year review period. For the purposes of the human health risk assessment, however, it has been assumed that the quantities used and the number of sites using CT 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 32 EEA sites where chromate-based slurry coatings is anticipated as taking place, an estimated total of 320 workers may be exposed to Cr(VI); for the 20 UK sites where slurry coatings takes place, a maximum of approximately 200 workers may be exposed

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 slurry coatings is considered to take place, an estimated 20,500 people in the EEA and 26,700 people in the UK are calculated as potentially being exposed to Cr(VI) due to chromate-based slurry coatings activities.[4]

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

- EEA: 0.09 fatal cancers and 0.03 non-fatal cancers over the 12-year review period, at a total social cost of around €138,500; and

- UK: 0.07 fatal cancers and 0.02 non-fatal cancers over the 12-year review period at a total social cost of around €98,100.

1.5 Comparison of socio-economic benefits and residual risks

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

- EEA: 11,400 to 1 for the lower bound of profit losses and unemployment costs or 27,640 to 1 for the upper bound profit losses and unemployment costs, where economic impacts are assessed over 2 years and residual risks over 12 years; and

- UK: 7,050 to 1 for the lower bound of profit losses and unemployment costs or 19,136 to 1 for the upper bound profit losses and unemployment costs, where economic impacts are assessed over 2 years and residual risks over 12 years.

The above estimates represent a significant underestimate of the actual benefits conferred by the continued use of chromium trioxide in slurry coatings as carried out by the A&D industry, as it only

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

[5] Discounted over 12 years at 4% per annum.

encompasses benefits that could be readily quantified and monetised. The true benefit-cost ratios must be assumed to also encompass:

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

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

- The avoided impacts on society more generally due to impacts on air transport and the wider economic effects of the high levels of unemployment within a skilled workforce, combined with the indirect and induced effect from the loss of portions of the A&D sector from the EEA and UK as they either cease some activities or relocate relevant operations; and
- The avoided negative environmental impact associated with prematurely obsoleted final products which creates excess waste in the disposal of components, and increased scrappage in the manufacture of the replacements; and

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

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

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

- The sector has reduced the volume of chromates used in slurry coatings, with consumption of chromium trioxide now estimated as a maximum at 3.5 tonnes per annum in the EEA and 3 tonnes per annum in UK (based on maximum identified use at any site multiplied by the estimated number of sites). These quantities are expected to start reducing significantly by 2028 and continue reducing until use is phased-out in 2036;

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

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

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

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

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

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

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

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

- Adoption of alternatives is subject to strict regulatory requirements in order to ensure the continued airworthiness and safety of aerospace and defence final products. This generates additional, complex requalification, recertification, industrialisation activities, all subject to strict regulatory requirements in order to ensure the continued airworthiness of aircraft and the safety of defence equipment (including air, naval and land-based systems). There is no simple or single drop-in replacement for the chromates in slurry coating processes;

- The strict regulatory requirements that must be met generate additional, complex requalification, recertification, industrialisation activities, to ensure the continued airworthiness of aircraft and the safety and reliability of defence equipment (including air, naval and land-based systems). These requirements mean that there is no simple or single drop-in replacement for the chromates in slurry coatings processes, which can be considered "generally available" following the European Commission's definition. The A&D industry has been undertaking R&D into alternatives for the past 30 years. This includes participation in research initiatives partially funded by the European Commission and national governments. Considerable technical progress has been made in developing, validating, qualifying and certifying components for the use of alternatives, however, it is not technically nor economically feasible for the sector as a whole to have achieved full substitution within a four- or seven-year period. Although some companies have been able to qualify and certify alternatives for some of their components, others are still in the early phases of testing and development work due to alternatives not providing the same level of performance to the chromates. They will not be able to qualify and certify a proposed or test candidate for some components within a four- or seven-year time frame. It is also of note that slurry coatings is used throughout the supply chain and by large numbers of smaller suppliers. As a result, sufficient time will be required to fully implement alternatives through the value chain once they have been certified;

- Even then, **it may not be feasible for military MROs to move completely away from the use of the chromates in slurry coatings due to mandatory maintenance, repair and overhaul requirements**. MROs must wait for OEMs or MoDs to update Maintenance Manuals with an appropriate approval for each treatment step related to the corresponding components or military hardware. The corresponding timescale for carrying out such updates varies and there can be significant delays while OEMs or MoDs ensure that substitution has been successful in practice. In this respect, **it is important to note that the use of the substance is required to ensure the operational capabilities of the military and the ability to comply with international obligations as partner nations at the EU level and in a wider field, for example, with NATO**;

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

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

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

2 Aims and Scope of the Analysis

2.1 Introduction

2.1.1 The A&D Chromates Reauthorisation Consortium

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

The use of the chromates in slurry coatings is limited to those situations where it plays a critical (and currently irreplaceable) role in meeting product performance, reliability, and safety standards, particularly those relating to airworthiness set by European Aviation Safety Agency (EASA). This is also true with respect to the use of slurry coatings in defence, space and in aerospace derivative products, which include non-aircraft defence systems, such as ground-based installations or naval systems. Such products and systems also have to comply with numerous comparable requirements including those of the European Space Agency (ESA) and of national MoDs.

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

As a result, the analysis presented here is based on an extensive programme of work funded and carried out by the main OEMs and DtBs, and key suppliers where this includes small, medium, and other large actors within the sector. It is based on sector-specific data and detailed information obtained from the ADCR members (which includes OEMs, DtBs, BtPs, MROs and MoDs) and collected from their A&D suppliers throughout the supply chain. In total, data were collected from companies covering over 260 A&D sites in the EEA and UK, with data for 17 of those sites used in developing this combined AoA/SEA.

In addition, to ensure consistency and continuity of global supply chains under both EU REACH and UK REACH, this document covers the requirements of A&D supply chains in both the EEA and the UK[6]. Where important, information is separated out for the EEA and UK, so that authorities in both jurisdictions have a clear view of impacts.

The downstream users supporting the ADCR consortium have no qualified (from a technical perspective) and economically feasible alternatives for use on all of their components and final products which can be fully implemented before the expiry of the original authorisations; they must continue to use the chromates in slurry coatings activities carried out within the EU and UK, as it is

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

fundamental to preventing corrosion of critical A&D parts and components. It forms part of an overall anti-corrosion process, which may include both pre- and post-treatments, aimed at ensuring the compulsory airworthiness requirements of aircraft and safety of military equipment.

Although the A&D sector has been successful in implementing alternatives for some components with less demanding requirements, the aim of this application is therefore to enable the continued use of chromates in slurry coatings beyond the end of the existing review period which expires in September 2024. It demonstrates the following:

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

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

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

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

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

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

2.2 The parent Applications for Authorisation

This combined AoA and SEA covers the use of the following chromates in slurry coatings:

- Chromium trioxide (CT) (includes "Acids generated from chromium trioxide and their oligomers", when used in aqueous solutions)	EC 215-607-8	CAS 1333-82-0

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

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

This chromate was granted authorisations for use in slurry coatings across a range of applicants and substances. summarises the initial applications which are the parent authorisations for this combined AoA/SEA.

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

Table 2-1: Overview of Initial Parent Applications for Authorisation

Application ID/ authorisation number	Substance	CAS #	EC #	Applicants	Parent Authorisation – Authorised Use
0032-04/ REACH/20/18/14, REACH/20/18/16, REACH/20/18/18	Chromium trioxide	1333-82-0	215-607-8	ChemServices as OR for Brother; Boeing Distribution Ltd; Cromital (CTAC consortium)	Surface treatment for applications in the aeronautics and aerospace industries, unrelated to functional chrome plating or functional chrome plating with decorative character, where any of the following key functionalities is necessary for the intended use: corrosion resistance/active corrosion inhibition, chemical resistance, hardness, adhesion promotion (adhesion to subsequent coating or paint), temperature resistance, resistance to embrittlement, wear resistance, surface properties impeding deposition of organisms, layer thickness, flexibility, and resistivity
0032-05/ REACH/20/18/21, REACH/20/18/23, REACH/20/18/25	Chromium trioxide	1333-82-0	215-607-8	ChemServices as OR for Brother; Boeing Distribution Ltd; Cromital (CTAC consortium)	Surface treatment (except passivation of tin-plated steel (electrolytic tin plating - ETP)) for applications in architectural, automotive, metal manufacturing and finishing, and general engineering industry sectors, unrelated to functional chrome plating or functional chrome plating with decorative character, where any of the following key functionalities is necessary for the intended use: corrosion resistance/ active corrosion inhibition, layer thickness, humidity resistance, adhesion promotion (adhesion to subsequent coating or paint), resistivity, chemical resistance, wear resistance, electrical conductivity, compatibility with substrate, (thermo) optical properties (visual appearance), heat resistance, food safety, coating tension, electric insulation or deposition speed
0096-01/ REACH/19/29/0 17UKREACH/19/29/0	Chromium trioxide	1333-82-0	215-607-8	HAAS GROUP INTERNATIONAL SP. Z.O.O (GCCA consortium)	Chemical conversion and slurry coating applications by the aerospace sector, where any of the following key functionalities or properties is necessary for the intended use: corrosion resistance, active corrosion inhibition, adhesion promotion and reproducibility (for chemical conversion coating), corrosion protection, heat resilience, hot corrosion resistance, resistance to humidity and hot water, thermal shock resistance, adhesion and flexibility (for slurry coating).

2.3 Scope of the analysis

2.3.1 Brief overview of uses

2.3.1.1 Process description

Two types of slurry coatings are distinguished. These are the sacrificial coatings and high temperature (diffusion) coatings. The key functionalities of Cr(VI) for slurry coatings are detailed in the Analysis of alternatives (AoA) section.

Sacrificial coating is a surface treatment where steel components are coated with a slurry paint containing CT and afterwards are cured at temperatures up to 550 °C. Some components such as those made from carburized steel and peened steel are not able to tolerate the high temperature cure. The sacrificial coatings used in these cases are limited to cure temperatures of <137 °C (carburized steel) and < 177 °C (peened steel).

Sacrificial coatings contain metal particles (preferentially aluminium) and a binder, which form a protective coat on the substrate to protect it from corrosive environments. After the slurry coatings application, a chromium oxide layer is formed between the substrate and slurry coat paint, which is improving corrosion and wear resistance of treated components. A chromium oxide layer is also formed on the surface of the sacrificial metal particles within the coating formulation. This formation of a passive oxide layer on the surface of the metal particles serves as protection during the time that the coating is stored before spraying, allowing for consistent functionality in the paint independent of the duration that it has been stored.

High temperature (diffusion) coatings are typically applied to nickel-based alloys and are cured at temperatures around 870-980 °C. In contrast to sacrificial coatings, slurry diffusion coating interacts with the substrate itself. The diffusion coating diffuses into the substrate it is applied to, changing the metal's characteristics, and thereby giving special protective properties (e.g., sulphidation protection) and resistance to higher temperatures than that provided by sacrificial coatings. Due to these reasons, slurry diffusion coating is applied to components which are, for example, used in the hotter areas of the turbine.

For the formation of the chromium oxide layer between the substrate and the slurry coat paint, Cr(VI) is reduced to Cr(III). However, Cr(VI) may still be present in the coating in a small fraction, this is addressed in section 9.2.3. of the CSR. Since no subsequent machining activities on slurry coated components are performed and blasting of slurry coated parts is solely performed in closed systems, these activities are not further included in this assessment.

Both types of slurry coatings are chemical, non-electrolytical processes which are carried out by spray application in spray booths (see Figure 2-1) or by brush application. Typically, the spray booth(s) for slurry coatings are positioned in a paint area, which is separated from galvanic processes potentially also carried out at the premises. The paint area may contain one or several spray booths and working stations where application of primers, paints, lacquers, and coats is conducted; some (e.g., primers) might also involve the use of Cr(VI) although they may be unrelated to the present use.

Depending on the specifications and required thickness (range 8 to 100 µm) of the coating, one or several layers of slurry coatings will be applied.

Figure 2-1: Manual spray application of slurry coating in a spray booth
Source: ADCR

Chromium trioxide is used for slurry coatings in the A&D industry and its supply chains.

2.3.1.2 Relationship to other uses

Normally, slurry coatings with CT is not combined with any Cr(VI)-containing pre-treatment or post-treatment (See Figure 2-2). However, Cr(VI)-free pre-treatments (e.g., cleaning, abrasive blasting, sanding with paper) or post-treatments (e.g., burnishing, sand blasting, paints) may be applied. The application of one or more layers of slurry coatings or various CT-based slurry coatings products are performed according to the respective specification.

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

Figure 2-2: Schematic presentation of treatment steps

2.3.2 Temporal scope

Because of the lack of qualified and feasible alternatives for the use of CT in slurry coating for A&D components, it is anticipated that it will take ADCR members and their supply chains up to a further 12 years or more to develop, qualify, certify, and industrialise alternatives across all components; the longest timeframes are required by MROs/MoDs and companies acting as suppliers of defence products. Over this 12-year period, the temporal boundaries adopted in this assessment take into account:

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

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

Table 2-2: Temporal boundaries in the analysis

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

2.3.3 The supply chain and its geographic scope

2.3.3.1 The ADCR Consortium

The ADCR is composed of 67 companies located in the EEA and the UK that act as suppliers to the A&D industry (17 importers, formulators and distributors), are active downstream users (OEMs, DtBs or BtPs) or are MRO providers (civilian or military) within the industry. Membership also includes Ministries of Defence 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, (DtB) and MROs operating in the EEA and UK. These 24 companies operate across multiple sites in the European Economic Area (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 standards are met. The consortium also includes 21 small and medium sized companies. As stakeholders using chromates within the A&D sector their information and knowledge supplements the aims of the consortium to ensure its success in re-authorising the continued use of the chromates. These companies are involved in BtP, DtB and MRO activities, sometimes acting as a combination of these.

With respect to slurry coating:

- Six of the 24 larger ADCR members (OEMs, DtBs and an MRO) are supporting the reauthorisation of this use in the EEA; this includes for their own use as well as for use by their suppliers in their supply chains; and
- One of the 24 larger members are supporting the reauthorisation of this use in the UK, with five of the smaller members also supporting this use. As for EU REACH, the larger members are supporting both their use and use by their UK suppliers.

2.3.3.2 Suppliers of chromate substances and mixtures

Upon mixing of the formulation during production, a significant chemical reaction takes place between the aqueous formulation components and the relative aluminium particles. This reaction results in the reduction of a large portion of Cr(VI) to Cr(III) and therefore the Cr(VI) content in the final slurry coating product as sold to customers is significantly lower than in the initial aqueous solution before addition of aluminium. With this in mind, Table 2-1 shows a typical composition of a slurry coating at the point of manufacture (i.e., before any reaction takes place)

Table 2–3: General formulation of used in slurry coatings

Typical slurry coating	Aqueous solution of CT Concentration of Cr(VI) based on ranges of CT (1 - ≤6% (w/w)) Aluminium flakes 50% (w/w)

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

2.3.3.3 Downstream users of the chromates for slurry coatings

Slurry coatings 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, assemble and sell engines, aircraft, space and defence equipment to the final customer;
- Design-to-build[7] (DtB) – companies which design and build components;
- Build-to-Print (BtP) – companies that undertake specific processes, dictated by their customers, involving chromates on components; and
- Maintenance, Repairs and Overhaul (MRO) – companies that service aircraft, space and defence equipment.

For the avoidance of any doubt, commercial aircraft, helicopter, spacecraft, satellite and defence manufacturers are involved in the supply chain, and in the use of the CT for slurry coatings.

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

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

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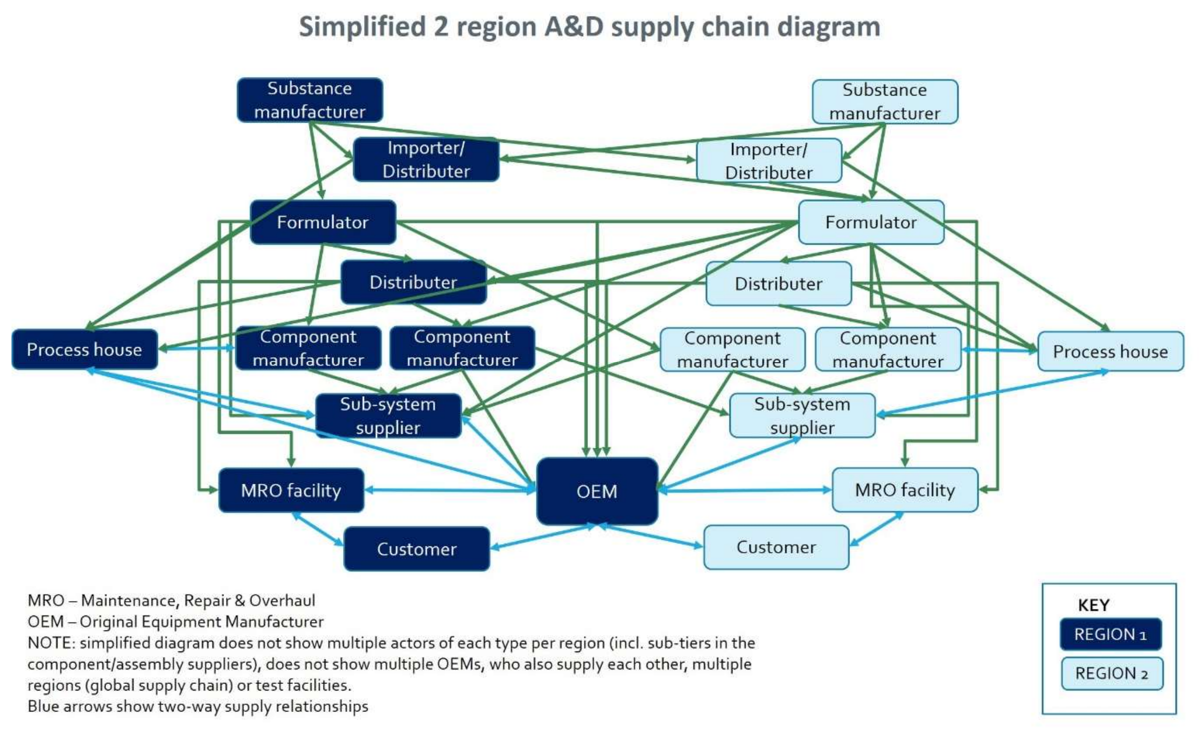
[7] Also referred to as “design and make” or “design responsible” suppliers

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



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

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

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

It is important to note that no design-to-build companies have provided a response to the SEA questionnaire. Therefore, estimates have been made based on the responses from other suppliers.

Table 2–4: Distribution by role of companies providing information on slurry coatings

Role	Number of companies	Number of sites
OEMs	3	10
Design and build	0	0
Build-to-Print	1	1
MRO mainly (civilian and/or military)	3	6
Total	7	17

2.3.4 OEMs, DtB and BtP Manufacturers

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

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

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

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

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

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

2.3.5 Maintenance, Repair and Overhaul

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

A representative life cycle of a typical aerospace product – a commercial aircraft - is illustrated in Figure 2-4. This highlights that: the development of a new aerospace system can take up to 15 years; the production of one type of aerospace system may span more than 50 years; and the lifespan of any individual aircraft is typically 20-30 years. Figure 2-5 provides an overview of the life cycle of weapon systems, which are usually used much longer than the originally projected lifetime. Such life cycles can be significantly longer than 50 years. For such systems, it is extremely costly to identify and replace legacy applications of chromates without impacting performance, where performance has been assured for many decades.

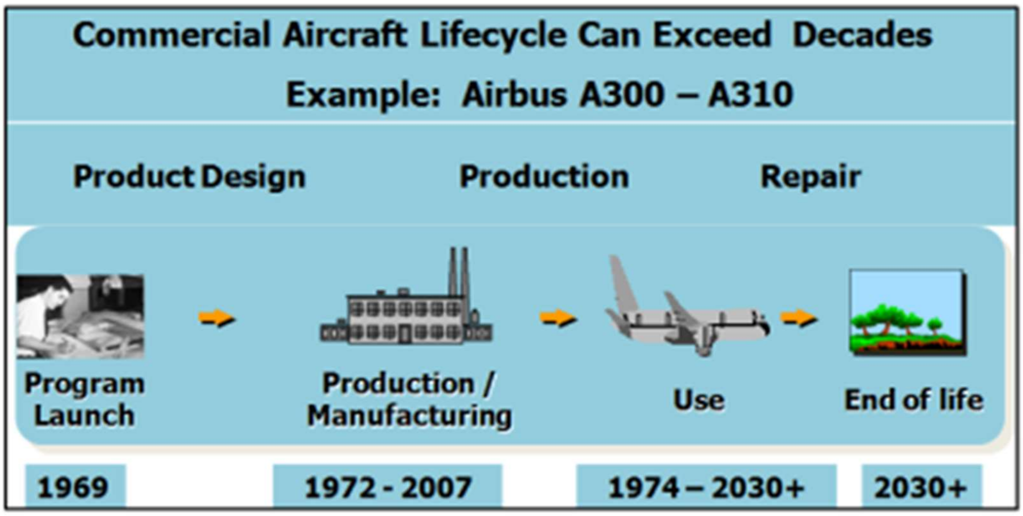


Figure 2-4: Commercial Aircraft Service Life.
From ECHA & EASA (2014)[9]

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

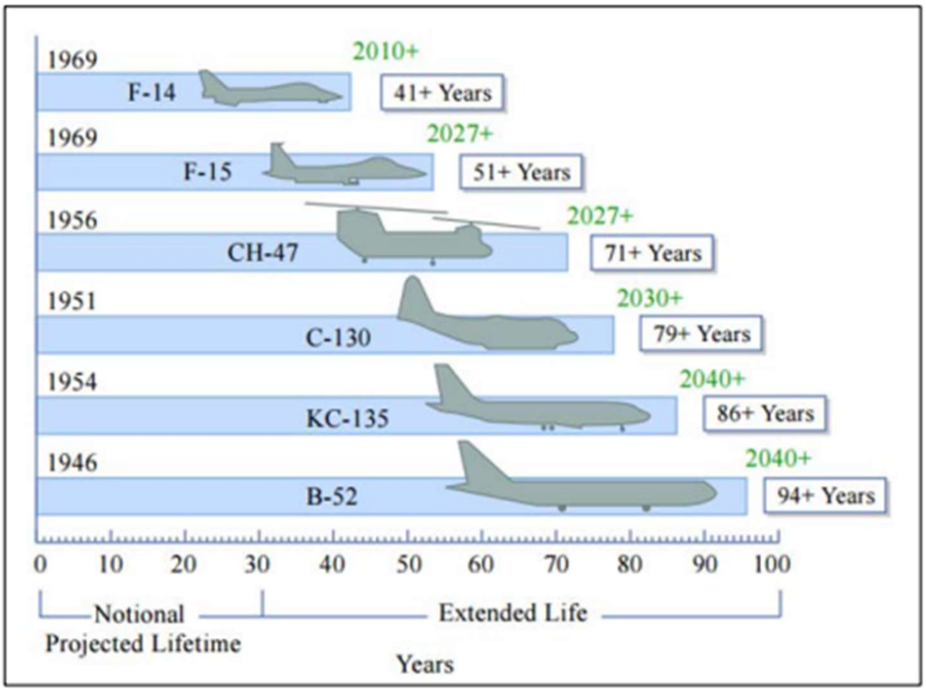

Figure 2-5: Life cycles of defence aircraft, from A Haggerty (2004)[10]

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

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

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

2.3.5.1 Estimated number of downstream user sites

Based on the information provided by the companies, work on turbine blades involving slurry coating for ADCR members is undertaken at a relatively small number of sites across the EU – around 30 in total. Some sites provide slurry coating services to more than one of the larger ADCR members.

For the UK, based on the information provided by the OEMs and DtB companies, as well as reviewing relevant members of the Institute of Materials Finishing and the Surface Engineering Association, it would appear that there are around 20 sites (across the UK) involved in the slurry coatings.

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

Under Article 66 of REACH downstream users covered by an authorisation up their supply chain must notify ECHA of their use. As of 31 December 2021, ECHA had received 282 notifications relating to the REACH Authorisations listed above covering 404 sites across the EU-27 (and Norway). The distribution of notifications by substance and authorisation is summarised below. It is important to note that some sites may draw on more than one Authorisation for use of the same substance.

Since there are more sites than notifications, it is assumed that some notifications cover more than one site[11]. It will be noted that the most notified authorisations cover 'surface treatment' which extends more widely than just slurry coating.

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

With these points in mind, the estimated 32 EEA sites to be covered by this combined AoA/SEA and by the ADCR applicants is believed to be consistent with the ECHA data on Article 66 downstream user notifications[11].

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

Table 2-5: Number of downstream users using Chromium trioxide and Sodium Dichromate notified to ECHA as of 31 December 2021

Substance	Authorisation	Authorised Use	Notifications	Sites
Chromium trioxide	20/18/14-20	Surface Treatment for aerospace	263	357
	19/29/0	Conversion Coating & Slurry coatings for aerospace	19	47
		Totals	282	404

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

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

2.3.5.2 Geographic distribution

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

Table 2–6: Number of sites assumed to be undertaking slurry coatings based on distribution of sites notified to ECHA as of 31 December 2021, ADCR member data and SEA responses

Country	**# Sites**
France, Poland, Germany	7 each
Italy	4
Spain	2
Romania, Malta, Sweden, The Netherlands	1 each
Total EU (plus Norway) sites	**32**
Total UK	**20**

2.3.6 Customers

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

With respect to civil aviation, the global air transport sector employs over 10 million people to deliver in a normal year some 120,000 flights and 10 million passengers a day. In 2017, airlines worldwide carried around 4.1 billion passengers and transported 56 million tonnes of freight on 37 million commercial flights. Every day, airplanes transport over 10 million passengers and around US$ 18 billion (€16 billion, £14 billion) worth of goods. Across the wider supply chain, with subsequent impacts and jobs in tourism made possible by air transport, assessments show that at least 65.5 million jobs and 3.6% of global economic activity are supported by the industry[12]. More specifically to Europe, in 2019 over 1 billion passengers travelled by air in the European Union, with net profits of over US$ 6.5 billion (€5.8 billion, £5.1 billion).[13] These benefits cannot be realised without the ability to undertake regular maintenance works and to repair and maintain aircraft as needed with replacement components manufactured in line with airworthiness approvals.

In 2020, total government expenditure on defence across the EU equated to 1.3% of GDP, with Norway spending around 2% of GDP[14]. Roughly 38% of this expenditure related to military aviation, with an uncertain but significant proportion also spent on non-aviation defence products that rely on the use of slurry coatings.

Focusing on military aircraft, the dynamics of aircraft development and the market are significantly different than for commercial aircraft. Military aircraft are extremely expensive and specialised projects. As a result, to have an effective military force, Ministries of Defence require equipment that is well-maintained and mission-ready. Although the in-service military fleet is expected to grow rapidly in the future, older aircraft and other equipment will continue to require more frequent scheduled

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

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

[14] *Source:* Eurostat (gov_10a_exp)

maintenance to replace components that are reaching the end of their "life", which would not have needed replacing on younger aircraft. Upgrades will also be required to extend the service life of aging aircraft given the costs of new military aircraft. Maintenance of aircraft and products is already reported to face difficulties due to material obsolescence issues over the extremely long service lives of such hardware. A major issue is obtaining readily available components for the vast number of aircraft flying beyond their originally expected lifecycles.

2.4 Consultation

2.4.1 Overview

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

- Consultation with the Applicants (importers and formulators) to gather Article 66 downstream user notifications data, and information on volumes placed on the market and numbers of customers; this has included consultation with the formulators to gather information on their 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 for other applicants/formulators of the chromates for use in slurry coatings.

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

2.4.3 Consultation with downstream users

2.4.3.1 ADCR Consortium members

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

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

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

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

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

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

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

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

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

As a final count, data for 21 sites operated by the ADCR OEMs and their DtB and BtP suppliers provided responses to these questionnaires. The information provided by the companies forms the basis for the SEA component of this document.

2.4.4 Maintenance, Repair and Overhaul suppliers

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

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

3 Analysis of Alternatives

3.1 SVHC use applied for

3.1.1 Overview of the key functions

The use, slurry coatings is defined by the ADCR as follows, it should be noted that this chromate use is categorised according to the mode of action of the protective effect afforded by the treatment i.e., sacrificial coatings, and high temperature coatings.

Slurry coatings: Sacrificial coatings and high temperature coatings

As noted previously, the chromate of relevance to the Applied for Use is:

- Chromium trioxide (includes “Acids generated from chromium trioxide and their oligomers", when used in aqueous solutions)	EC 215-607-8	CAS 1333-82-0

Application methods include spray or brush.

The term slurry coating covers two types of coating: sacrificial coatings and high temperature (diffusion) coatings. These are defined by ADCR members as below:

Sacrificial Coatings may be applied by spray or brush on steel or stainless steel and entail application onto a prepared surface, curing with heat to produce a stable film that is well bonded to the substrate and then post-treating that layer to render it electrically conductive with an electrode potential lower than the substrate;

High Temperature (Diffusion) Coatings are applied by spray or brush on cast and wrought superalloys or high temperature alloys. Application takes place onto a prepared surface and then curing with heat to produce a stable protective coating that is well bonded to the substrate. In certain instances, the cured slurry may be re-heated in a protective environment to melt it into the substrate to form a protective diffused layer.

Sacrificial coatings act as a protective coating comprising metallic particles in an inorganic binder. Many are comprised of a base layer and top-coat, both of which can contain Cr(VI). The basecoat consists of an aqueous inorganic binder combined with fine aluminium particles. After application to the substrate followed by drying and curing, a burnishing process is used to densify the aluminium particles and establish electrical conductivity throughout the coating. The electrically conductive coating provides sacrificial-galvanic corrosion resistance, where the aluminium particles are oxidised preferentially to the substrate itself. Structural integrity of the cured film is enhanced via the formation of an amorphous ‘glass’ when the chromate/phosphate binder is heated (GCCA, 2016). The burnishing step is generally performed using abrasive medias, which can leave grit incrustations on the surface of the coating which may release during operation and cause damage to sensitive moving parts such as bearings. A topcoat layer can be applied to embed the grit and prevent its release[15], as well as to provide a secondary corrosion resistant barrier to further increase the overall corrosion resistance of the coating. The top-coat also provides a smooth surface finish for gas path applications where unimpeded gas flow over the surface is needed.

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[15] ADCR member

The key functions provided by Cr(VI) in slurry coatings are:

- Corrosion resistance;
- Thermal resistance;
- Cyclic heat-corrosion resistance/hot corrosion resistance;
- Resistance to humidity and hot water;
- Thermal shock resistance;
- Chemical resistance;
- Erosion resistance and smooth surface finish; and
- Adhesion promotion and flexibility.

Aluminium and/or silicon metal powder diffusion slurries are used to form protective aluminide/silicide surface layers on cast or wrought superalloy substrates. During processing, the slurries are heated in excess of 870°C, melting the metal components within the slurries allowing a reaction between nickel and cobalt in the superalloy substrate and the diffusion coating. This forms a nickel- or cobalt-aluminide layer on the component. Aluminide coatings produced from these Cr(VI) diffusion slurries, provide robust protection for nickel- and cobalt-based cast, or wrought superalloys in environments with high salt concentrations. Applications of high temperature slurry diffusion coatings include the protection of components that operate above 540°C (GCCA, 2016)

In some cases, a high temperature coating without diffusion can be used. These coatings consist of an aqueous inorganic binder containing Cr(VI), and a high melting point metallic component. These coatings are cured at high temperatures without melting the metallic component. The formed amorphous glass coating is not subjected to a burnishing step like sacrificial coatings, and therefore the coating does not provide sacrificial-galvanic corrosion protection, and rather acts as a ‘barrier’ coating which demonstrates excellent hot corrosion resistance and cyclic heat corrosion resistance properties.

3.1.1.1 Usage

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

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

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

Structural/flight	Propeller/rotor	Engine/power plant	Additional Space- and Defence-specific
Aileron and flap track area	Blade tulip and hub	Auxiliary Power Units (APUs)	Air-transportable structures
Centre wing box	Gearbox and transmission/connecting shafts	Carburettor	Fins
Cockpit frames	High bypass fan components	Data recorders	Gun barrels and ancillaries
Differential	Main and tail rotor head assemblies	Engine Booster and Compressors including Fan Containment	Interstage Skirts
Emergency valve landing gear	Propeller speed controller	Engine control unit	Launchers (rocket, satellite, etc.)

Environmental control systems	Propellers	Engine External components	Missile and gun blast control equipment
External fuel tanks	Transmission housing	Fuel pump	Missile launchers
Flight control systems		Gearbox	Pyrotechnic Equipment
Fuselage		Hydraulic intensifier	Radomes (Radar domes)
Hydraulic damper		Ram air turbine	Rocket motors
Hydraulic intensifier		Starter	Safe and arm devices
Landing equipment		Vane pump	Sonar
Nacelles			
Pylons			
Rudder and elevator shroud areas			
Transall (lightning tape)			
Undercarriage (main, nose)			
Valve braking circuit			
Window frames			
Wing fold areas			
Source: (GCCA, 2017)			

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

Cr(VI)-free alternatives cannot be introduced where they are known to result in a decreased performance, since some or all of the following consequences may occur (GCCA, 2017)

- Substantial increase in inspections, some of which are very difficult or hazardous to perform;
- Increased overhaul frequency or replacement of life-limited components;
- Possible early retirement of A&D products due to compromised integrity of non-replaceable structural parts; 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 planes could fly.

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

Service life and maintenance intervals of parts and assemblies

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

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

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

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

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

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

3.1.2.1 Introduction

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

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

- High utilisation rate (around 16 hours per day for commercial aircraft, whilst critical defence systems must operate continuously for extended periods);
- Normal environmental and service temperatures ranging from below minus 55°C at cruising altitude to in excess of plus 240°C (depending on substrate and location of final product) with some engine areas operating in excess of 1000°C;
- Wide ranging and varying humidity and pressure;
- High and varying loads;
- Fatigue resistance under varying modes of stress;
- Corrosive and abrasive environments (e.g., salt water and vapour, sand and grit, and exposure to harsh fluids such as cleaning solutions, de-icer, fuels, lubricants, and hydraulic fluids at in-service temperatures); and
- Maintained performance in the possible case of a lightning, bird, or other foreign object strike.

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

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

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

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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

formulation/process is used. This can often be hundreds of different components, each requiring testing to ensure performance of the test candidate is acceptable.

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

Military/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 are often very fiscally constrained for such hardware configuration updates. Alternatively, an OEM can attempt to persuade their customers of such hardware changes, but typically are not allowed to spend programme budgets on these hardware changes until expressly directed/contracted by the customer, who again are very fiscally constrained. When OEMs sell the same hardware to multiple defence customers, it is often required to obtain permission from each customer prior to hardware changes and these customers rarely agree. The combination of (a) not mission essential, (b) fiscal constraints, and (c) multiple conflicting customer opinions, greatly complicates any defence OEM effort to make hardware changes to existing designs to meet legislated goals such as Cr(VI) elimination.

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

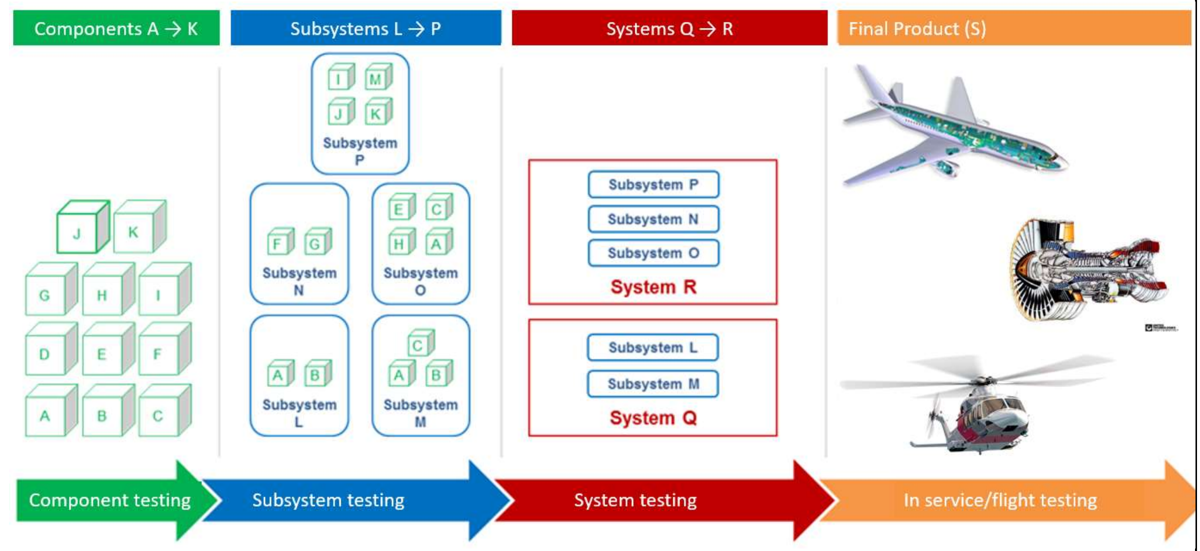

Figure 3-1: Assessment requirements in the implementation of alternatives
Source: Adapted from GCCA white paper

In the substitution process, many ADCR Consortium members use the Technology Readiness Level (TRL) scale as developed by the US National Aeronautics and Space Administration (NASA), and further defined by the US Department of Defence. This scale is used to assess the maturity level of each individual technology, and hence the potential suitability of a test candidate. The scale ranges from TRL 1, basic principles observed, to TRL 9, actual system proven. (Table 3-2)

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

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

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

TRL	Definition	Description
		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)

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

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

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

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

Source: Manufacturing Readiness Level (MRL) - AcqNotes

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

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

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

3.1.2.2 Process, requirements, and timeframe

Identification & Assessment of need for substitution

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

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

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

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

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

Definition of requirements

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

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

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

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

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

- The substitute exhibiting behaviours or interactions which are different to the original product. Where unexpected behaviour is seen, sufficient operational feedback to technically understand the phenomenon and refine the requirements is essential to ensure non-regression;

- Consolidating requirements from multiple customers and suppliers into an existing design;
- Evolution of EHS regulations; and
- Need to substitute multiple chromates to the same timeframe.

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

Key phases of the substitution process

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

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

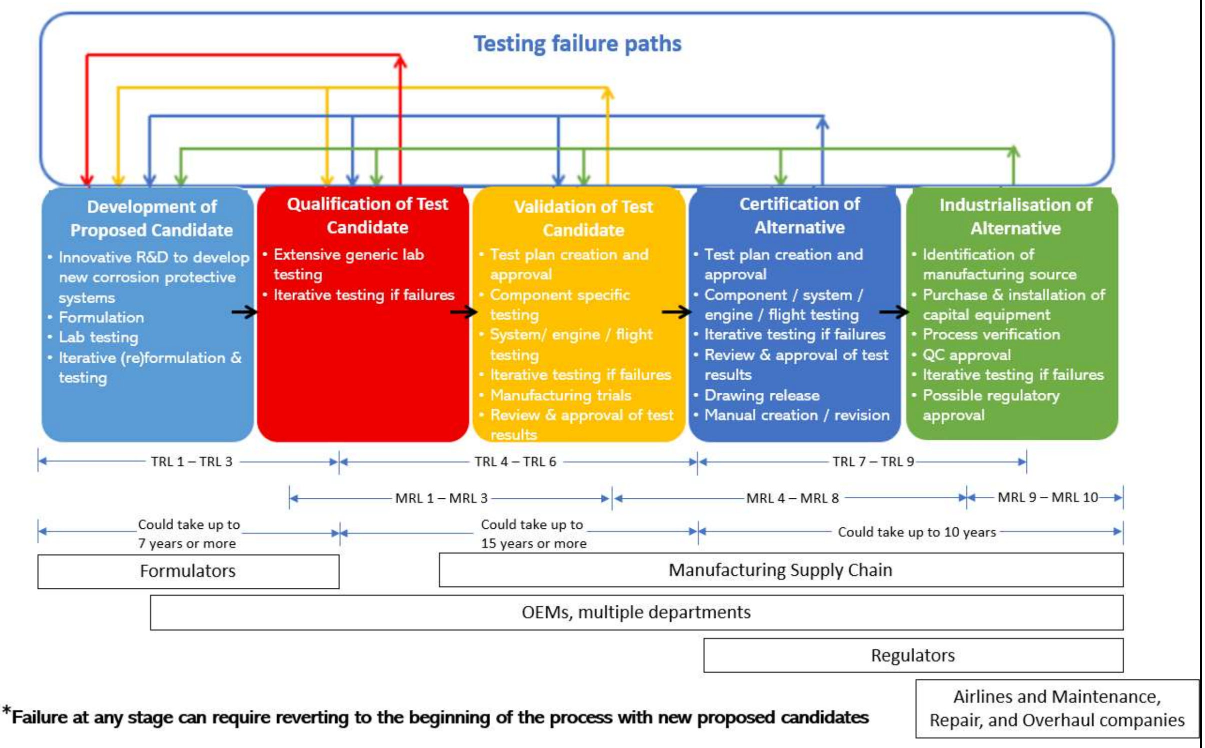

Figure 3-2: Schematic showing the key phases of the substitution process
Typical TRLs and MRLs associated with each stage, and the entities involved in each stage, are also shown. Note that failure of a proposed candidate at any stage can result in a return to a preceding stage including TRL 1. Note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

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

Development of proposed candidates

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

- Innovative R&D to develop new surface treatments;
- Formulation of proposed candidates;

- Laboratory testing of proposed candidates; and
- Iterative re-formulation and testing.

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

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

Development typically involves an iterative process of re-formulation and re-testing to identify one or more proposed candidate. It is important to note that many iterations of these formulas are rejected in the formulator's laboratory and do not proceed to evaluation by the design owner. Formulators estimate that it typically takes two to five years of testing potential formulations before a proposed candidate is identified for submittal to the design owner[18].

Qualification of test candidate

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

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

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

Once proposed candidates are developed by the formulator, the design owner evaluates the formulations by first performing their own screening tests. If the test candidate fails, formulators may choose to reformulate. It is common to iterate multiple times before a test candidate passes the design owners' screening, potentially adding several years to the substitution process (see Figure 3-2 above).

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

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[18] GCCA

Validation of test candidate

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

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

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

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

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

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

Certification of alternative

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

Steps in the Certification stage include:

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

- Maintenance manual creation/revision.

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

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

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

> *"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."*

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

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

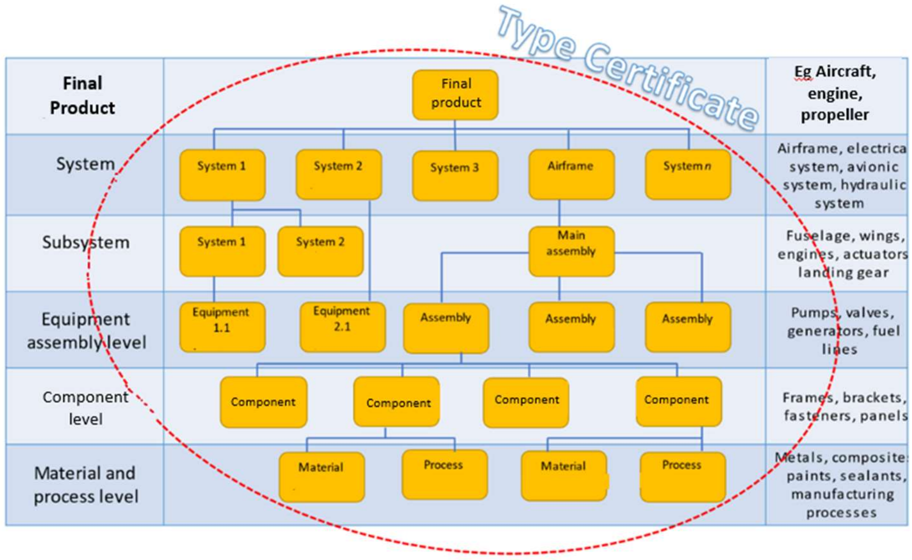

Figure 3-3: System hierarchy of a final product
Diagram shows the interconnection of each level in the system hierarchy, and how changes at a lower level have impacts on higher levels.
Source: ADCR member

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

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

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

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

Industrialisation of alternative

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

Elements of the Industrialisation of alternative process include:

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

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

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

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

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

The industrialisation process includes the creation and approval of process documents or manufacturing/repair documents. These documents allow detailed implementation of the manufacture and/or repair of each component. Using the example of a commercial aircraft, the process, described above and leading to industrialisation of the alternative, is illustrated in Figure 3-4 below. This is a simplified example. In some cases, there are many different types of components all needing validation test and there are instances where different test candidates are used on different parts (to replace a single original Cr(VI) use).

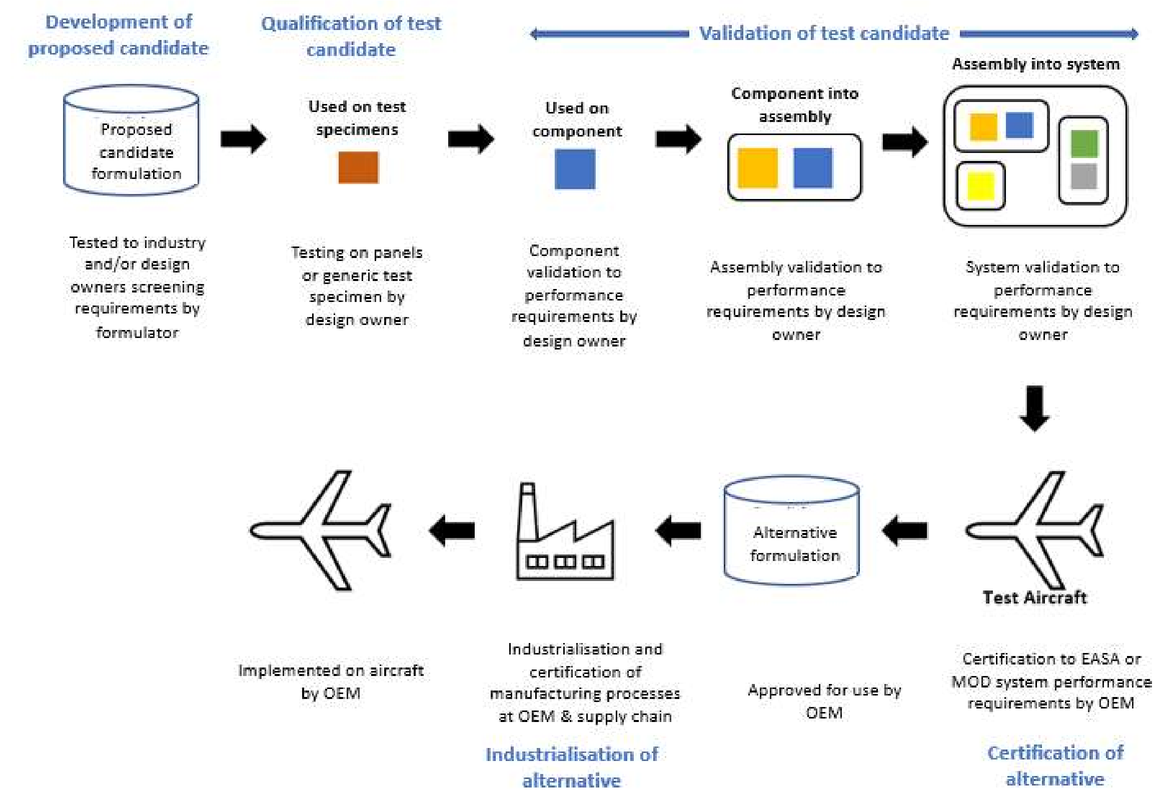

Figure 3-4: Process to Certify a Formulation for use on Aircraft
Formulations used in production have completed this process. New or reformulations must follow same process for use in production.
Source: ADCR member

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

3.2.1 Technical feasibility criteria for the role of the chromates in the applied for use

3.2.1.1 Introduction

The development of technical feasibility criteria for chromates (Cr(VI)) in slurry coating (and proposed/test candidates) has been based on a combination of assessment of the parent AfAs, consultation with ADCR consortium members, and a review of available scientific literature.

Through the use of detailed written questionnaires (disseminated throughout 2021 and 2022) the ADCR consortium members were asked to review the technical feasibility criteria and provide details of the (ideally) measurable, quantifiable technical performance criteria which the chromates meet in this use and that any alternatives (substances and technologies) would also need to impart before they are seriously considered as possible replacements.

In parallel, scientific literature investigating slurry coating and assessing the technical suitability of alternatives to Cr(VI) was collected and analysed (with the assistance of the ADCR consortium members) and has been incorporated into the analysis.

Key functions imparted by slurry coatings in the context of A&D activities are:

- Corrosion resistance;
- Thermal resistance;
- Cyclic heat-corrosion resistance/hot corrosion resistance;
- Resistance to humidity and hot water;
- Thermal shock resistance;
- Chemical resistance;
- Erosion resistance and smooth surface finish;
- Adhesion promotion and flexibility

Based on previous AfAs and feedback from members, it is understood that all of the above are considered to be key functions imparted by slurry coatings, and any suitable alternative must demonstrate non-regression in each. It was reported by members however that some of these functions are considered to be independent of Cr(VI), however, the presence of Cr(VI) may facilitate functions provided by other components of the coating.

In addition to these functionality criteria, it is also imperative for any alternative coating to demonstrate the following performance functionality at the system level:

- Coating thickness which allows conformity to design specifications (dimensions, weight);
- Low cycle fatigue for components sensitive to fatigue debit;
- Reparability (The ability to fully strip and reapply the coating without damaging the underlying substrate);
- Chemical compatibility between coating layers;

The discussion below explains the relevance and importance of each of the criteria and presents in more detail the threshold values (or ranges) that will be used in the analysis of alternatives for the comparison of the shortlisted alternatives to Cr(VI).

For reference, substrates identified by the ADCR members as relevant to sacrificial and high temperature coating include:

- Stainless steel;
- Low and high alloyed steels;
- High strength steels (martensitic);
- Nickel alloys; and
- Cobalt alloys

It should also be noted that, in many instances, technical comparison criteria are strongly interrelated, and it is not possible to consider a criterion independently of several others.

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

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

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

In the context of 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 or is comparable in performance compared to the benchmark Cr(VI) substance.

The role of the specification is limited within the substitution process. It provides a reproducible means of screening proposed candidates, however, 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 more suited to quality control purposes, to evaluation of treated components/sub-assemblies via breadboard integrated components either within the laboratory or larger simulated operational environments. These advanced testing regimes rely upon the use of specialised equipment, facilities, and test methodologies such as test rigs or prototype systems, see Figure 3-5. Attempts to replicate environmental in-service conditions are built upon bespoke testing regimes developed over decades of Cr(VI) experience from laboratory scale test panels to test rigs housed in purpose-built facilities. However, they cannot always reproduce natural environmental variations therefore there can be differences between what is observed in the laboratory and experienced in the field.

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

Examples of standards used for screening proposed candidates within the development phase of the substitution process are presented in Section 3.1.2. As stated above, standards serve to provide a means of reproducible testing within the development phase of the substitution process. Both standards and specifications are tools used to evaluate proposed candidates to identify suitable test candidates.

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

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

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

The GCCA application for authorisation, (GCCA, 2017) considers variables that could impact essentially the same component design which can influence behaviour and compatibility with a treatment system, and therefore delivery of technical feasibility criteria. These variables are listed below[21]:

- Hardware[22] base alloys;
- Contact or mating surfaces with other parts;
- Exposure to fluids;
- Structural stress and strain; and
- External environment.

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

- Exposure to chemicals e.g., de-icers, lubricants, salts, sea water/moisture;
- Temperature;
- Galvanic influences from different metals in contact with one another; and
- Mechanical effects; galling[23], vibration, erosion.

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

3.2.1.4 Technical feasibility criterion 1: Corrosion resistance

Corrosion resistance is important to provide safe and reliable performance and assure the life of the component in service. This is especially important in situations where the component is relatively inaccessible and cannot be easily or frequently inspected. Corrosion resistance is also important to prevent corrosion of the component during intermediate steps in the manufacturing process.

Sacrificial coatings

Corrosion protection in a sacrificial coating is mostly provided by the galvanic mechanism due to the electrically conductive aluminium layer, where the oxidation of the densified aluminium particles occurs at a lower potential than the oxidation of the substrate and therefore in an oxidising environment, the coating will corrode in place of the substrate. Corrosion resistance is also provided by a simple barrier mechanism, where the coating physically prevents corrosive agents from accessing the substrate. A high level of corrosion resistance in a coating is particularly important for the following reasons:

- Reducing premature failures as result of corrosion;
- Reducing costs by increasing intervals between service and maintenance programmes; and
- Increase service life of parts, reducing costs from parts renewal (GCCA, 2016)

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

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

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

When the sacrificial slurry coating is prepared, finely powdered aluminium metal is added to the aqueous solution of chromium trioxide. The high surface area of the aluminium then quickly reduces a portion of the Cr(VI) to form a coating of Cr(III) oxy-hydroxides on the surface of each aluminium particle. This step both increases the 'pot life' (the length of time a slurry coating can be mixed before decomposing) and facilitates galvanic corrosion inhibition. In addition, the remaining Cr(VI) within the slurry coating may react with the substrate itself and provide additional corrosion resistance to the metal by forming a Cr(III) oxy-hydroxide layer between the sacrificial coating and the substrate.

High temperature (diffusion) coatings

High temperature diffusion coatings increase the corrosion resistance of a substrate by diffusing aluminium and/or silicon in the substrate surface. The increased concentration of Al or Si at the surface provides a reservoir of these elements which are then able to form a corrosion resistant alumina or silica layer.

The corrosion resistance of this oxide layer is also in some circumstances increased by the presence of chromium. For nickel-based alloys or superalloys, the proportion of chromium within the substrate required to form a protective Cr_2O_3 layer is approximately 20% wt. and is slightly higher for cobalt-based alloys or superalloys.

In the case where a diffused coating contains both chromium and silicon, chromium tends to have a large affinity for silicon over other constituent elements. The formed chromium silicides can act to further promote corrosion resistance of the protective layer. It is important to note, however, that chromium present within the layer often is derived from either the chromium present in the substrate alloy, or in some cases, from additional chromium metal added to the slurry coating formulation.

The role of Cr(VI) in the high temperature diffusion coating is, in some cases, not intended to provide corrosion resistance to the substrate and is present to improve the stability of the coating during application and storage and provides corrosion resistance to the aluminium particles within the coating formulation.

For slurry coatings without diffusion (slurry barrier coatings), galvanic corrosion protection cannot be provided by the metallic particles, since the coating is not burnished and is non-electrically conductive. Therefore, corrosion resistance is provided mostly by a barrier mechanism where the metallic particles suspended in a ceramic Cr_2O_3 matrix forms a non-porous layer and prevents corrosive materials from accessing the substrate.

3.2.1.5 Technical feasibility criterion 2: Thermal resistance

Sacrificial coatings

The coating must retain adhesion to the substrate at high temperatures and must not show any blistering after extended periods of exposure to heat. Most sacrificial coatings operate below 550°C in order to retain the structure of the densified aluminium coating.

Chromium oxide in combination with other constituents of the slurry coating such as phosphates form a binder which retains its cohesive properties at high temperatures, resulting in a coating with a high bonding strength which is extremely resilient to cracking, blistering, and peeling under high temperature operating conditions.

High temperature (diffusion) coatings

High temperature diffusion coatings must be thermally resistant at a minimum temperature of 750°C and must not form a brittle phase by reaction with the underlying substrate at these temperatures.

For slurry barrier coatings, thermal resistance criteria are met by a similar mechanism to that of sacrificial coatings, where the robust ceramic chromium oxide binder prevents blistering, cracking, and peeling at the >550°C operating temperature of the part.

3.2.1.6 Technical feasibility criterion 3: Cyclic heat-corrosion resistance

Sacrificial coatings

The coating must give corrosion resistance properties to the substrate under real-world operating conditions, where the temperature of the component and the corrosive conditions vary over time between in-flight and stationary periods. In order to qualify a sacrificial coating, it must demonstrate suitable resistance to thermal and corrosion environment cycling. For example, one standard requires that a component must not show excessive corrosion following 20 cycles of two hours in an air circulating oven at 450°C followed by cooling to room temperature and exposure to neutral salt spray for 20 hours.

High temperature (diffusion) coatings

Similar to sacrificial coatings, high temperature (diffusion) coatings must show minimal fatigue or corrosion when cycled at temperatures exceeding 750°C and room temperature.

3.2.1.7 Technical feasibility criterion 4: Resistance to humidity and hot water

The slurry coatings currently used on aerospace components begin as water-based slurries that are sprayed onto parts and subsequently cured with heat. Once cured, these slurries must remain impervious to water and humidity (GCCA, 2016). For example, a coating must withstand immersion in boiling water for 10 minutes without checking or blistering of the coating. After drying, the coating must pass adhesion tests.

3.2.1.8 Technical feasibility criterion 5: Thermal shock resistance

Slurries containing chromium trioxide have demonstrated excellent resistance to thermal shock. Aluminium-filled slurries containing chromium trioxide, for example, experience no blistering, softening, or peeling from the substrate when quenched into room temperature water after 4 hours exposure at 635°C (GCCA, 2016)

3.2.1.9 Technical feasibility criterion 6: Chemical resistance (hydraulic fluids, engine oils, fuel)

Chemical resistance refers to the ability of the component to withstand contact with fluids encountered in the service life of the part, such as lubricants, hydraulic fluids, greases, fuels, solvents, de-greasers, cleaning fluids, and de-icing fluids. Due to its inorganic nature, the chemical slurry coating resists many organic substances, such as solvents, lubricants, and greases.

The principal mechanism for chemical resistance of slurry coatings is the insolubility of their primary constituent, chromium oxide (Cr_2O_3). Inspection of the potential/pH (Pourbaix[24]) diagram for the chromium/chlorine/water system, shows that insoluble Cr_2O_3 is stable and prevails over the potential/pH environmental conditions experienced by aerospace components in most conditions. It

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[24] Pourbaix, M. (1974), Atlas of Electrochemical Equilibria in Aqueous Solutions, National Association of Corrosion Engineers p262

is also apparent that Cr_2O_3 is immune to attack by chloride ions at pH values above 2. A similar chemical resistance holds for other corrosive species.

Chemical resistance against various fluids and fuel, such as jet-fuel, is carried out against BS3900, Part G5. After visual inspection, no signs of softening, blistering, or lifting should be observed (Lanxess et.al. ref 0032-04, 2015a)((Haas Group Int. SCM Ltd) et. al., 2016)

3.2.1.10 Technical feasibility criterion 7: Erosion resistance and smooth surface finish

Slurry coatings on gas path surfaces exposed to hard particles need to demonstrate erosion resistance, whilst components such as turbine vanes and compressor blades may be treated with slurry coatings to both increase operating efficiency by reducing drag, and also provide corrosion and heat resistance (Wesco Aircraft EMEA Ltd (Haas Group Int. SCM Ltd) et. al., 2016).

3.2.1.11 Technical feasibility criterion 8: Adhesion promotion and flexibility

Adhesion promotion refers to the ability of the coating to improve the adhesion of subsequent layers such as paints and primers, adhesives, and sealants. In the case of slurry coatings, this criterion holds the most relevance to adhesion of the top-coat, which is normally applied following curing and burnishing of the base-coat. It also includes the adhesion of the coating to the substrate, and the cohesion of the coating (how strongly the coating adheres to itself). Adhesion promotion is an important function of slurry coatings for both adhesion of the coating to the substrate, as well as adhesion of the ceramic matrix to aluminium particles.

Adhesion of the coating to the substrate is an essential function. It not only ensures the corrosion protective coating is consistent across the whole part during service life, but also ensures an even surface over gas path parts such as turbine blades, where peeling or chipping of the paint would induce turbulent airflow and reduce engine efficiency.

Adhesion of subsequent layers may be a requirement when the slurry is functioning as a primer or base coat. The primer function maintains strong adhesion to both the substrate and also the subsequent coating. Adhesion tests seek to determine the bond strength of the coating should it be subject to a strike from a solid object for example. Alternatively, when used as a primer, the slurry coating must demonstrate good adhesion to both the substrate and the subsequent layer(s) (Wesco Aircraft EMEA Ltd (Haas Group Int. SCM Ltd) et. al., 2016).

Heat curing of the sacrificial coating causes Cr(VI) to be reduced to Cr(III) and combine with phosphate within the formulation to produce a flexible, amorphous, and water-insoluble film with exceptional cohesive and adhesive properties.

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

With regard to the replacement of chromium trioxide in slurry coating, despite the fact that the aerospace sector is widely seen as the instigator of technology change in multiple essential engineering disciplines (including the use of new metals, composites, and plastics) (Royal Academy of Engineering, 2014), this should be set against the diversity of applications of slurry coated 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 3-6. Consequently, the industry requires a diverse range of metal alloys to fulfil all performance requirements that these various applications demand. Considering these factors, combined with the strict safety and certification requirements as described in Section 3.1.2, the pace of research and development will not be uniform across the sector.

Figure 3-6: Examples of end products dependent on Cr(VI) slurry coating (Rheinmetall – Systems & Products, n.d)

As noted by Naden, 2019, "*hexavalent chromium remains the benchmark for corrosion inhibition, providing protection over a wide pH range and electrolyte concentration*". Chromates are both anodic and cathodic inhibitors, restricting the rate of metal dissolution whilst simultaneously reducing the rate of reduction reactions.

With regard to the replacement of chromates, despite the fact that the aerospace sector is widely seen as the instigator of technology change in multiple essential engineering disciplines (including the use of new metals, composites and plastics) (Royal Academy of Engineering, 2014) there has been a lack of viable chromates substitutes that promise engineering quality whilst also ensuring user safety; this is despite extensive research into alternative corrosion inhibitors which has been underway since the 1980s (Naden, 2019).

The significant nature of substitution efforts in the aerospace sector is also noted by (Hughes et al., 2016), who highlights the substantial effort that has been made to develop a suitable alternative to Cr(VI)-based surface treatments, which have a robust performance in processing, corrosion protection and adhesion performance.

As highlighted throughout this AoA-SEA, the substitution of Cr(VI)-based treatments in the aerospace and defence sector is met by particularly strong challenges. (Rowbotham & Fielding, 2016) highlight the nature of such challenges, noting that there are an estimated three million components in each of the 20,000-plus aircraft currently flying. The demanding nature of applications in the aerospace sector, and potentially serious consequences if just one of these should fail, means that great care is being taken to develop and qualify Cr(VI) alternatives.

To further highlight the significant efforts being made by the aerospace and defence sector to substitute Cr(VI), a range of recent and ongoing 'R&D collaborations' are identified below. It is noted that many of these collaborations were mentioned within parent AfAs associated with the ADCR consortium Review Reports, including AfAs developed by the Global Chromates Consortium for Aerospace (GCCA), Chromium trioxide Authorisation Consortium (CTAC) and Chromium VI Compounds for Surface Treatment (CCST). However, efforts have also been made to expand upon the recognised collaborations, as well as to identify and describe additional relevant collaborations.

A short summary of the global collaborations relevant to slurry coating have been included here.

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

Relevant collaborations/projects include:

- **Accelerated Manufacturing with Chrome Free Sacrificial Cermet Coatings in Aerospace (AMSCA)** was a three-year project. The project was partially funded by Innovate UK, beginning in 2014, with the aim to find an alternative to chromated sacrificial slurry coatings for propulsion, systems, manufacturing, materials, process and tools, safety, cost, and environment (Aerospace Technology Institute, 2017). The consortium comprised of members of the supply chain, OEM, supplier, applicators, and from academia.

- **Chrome Free Aluminide Slurry Coatings for Gas Turbines (CASCoat)** was an Innovate UK funded consortium (UK Research and Innovation, n.d.), which evaluated alternatives for the use high temperature diffusion coating. CASCoat was affiliated to the Innovate UK programme "Formulated products - meeting the product and process design challenge" which ran between June 2014 and November 2016. Resulting from this project, a chromium free aluminide diffusion coating was developed which continued to be available for research purposes following the end date of the project.

3.4.2 Consultations with customers and suppliers of alternatives

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

3.4.3 Data Searches

3.4.3.1 High level patent review

To support the background information a patent search was performed with the aim to identify patents related to slurry diffusion coating. The search was performed using Espacenet, 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 (European Patent Office, 2020).

Patent search criteria

Search date: 26 August 2020.

Search term: Slurry diffusion coating chromate free

Scope of publication dates: 1 January 2002 to 31 December 2017

Filters: CPC groups

Results returned: 11

Table 3-4 below summarises selected patents from the above search explored in more detail.

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

Table 3-4: Slurry coating: Patent search expanded review summary

Patent number	Title	Technology
CN106459666A	Binding composition, method for manufacturing a sacrificial coating for protection against corrosion using said composition and substrate coated with such a coating	Sacrificial non-chromate metal oxide, metal phosphate, and hydrolysed organosilane oligomer binder.
CN104619431A	Process for coating metallic surfaces with coating compositions containing particles of a layered double hydroxide	Layered double hydroxide for corrosion resistance and adhesion of subsequent layer.
US2012060721A1	Slurry chromizing compositions	Slurry containing metallic chromium with aluminium in a colloidal silica carrier.
US 2012085261A1	Ceramic particles and coating compositions including said particles	Encapsulation of corrosion inhibitors in ceramic particle carried in primer or other coating.
US2005031781A1	Aluminizing slurry compositions free of hexavalent chromium, and related methods and articles	Aluminium slurry coating free of Cr(VI) incorporating colloidal silica and an organic stabiliser (glycerol).

Applicant: Aeta Mader, CN106459666A, Priority 2014-05-23

Title: Binding composition, method for manufacturing a sacrificial coating for protection against corrosion using said composition and substrate coated with such a coating

Described under Claim 1 of the patent:

> *'An aqueous binder composition for producing a sacrificial anti-corrosive coating, said composition free of chromate, and further preferably free of borate and molybdate, characterized in that said adhesive composition having a pH of less than 6 and comprising a binder, at least one metal oxide particle and at least one metal phosphate, said binder comprising a hydrolysed organosilane oligomer, and in that said at least one the weight ratio of the particles of the metal oxide to the total dry weight of the aqueous binder composition is greater than or equal to 75%.'*

Advantages

The combination of the process of the present invention with the adhesive composition of the present invention means that a sacrificial anti-corrosive coating may be formed wherein the matrix is substantially formed from silica, metal particles and at least one metal phosphate imparting:

- Para. [0203] High temperature corrosion resistance (at 400°C or higher) on damaged or undamaged surfaces, and with salt spray corrosion resistance as specified in ISO Standard 9227.

- Para. [0019] Good adhesion to the support [substrate] and to the primer and coating applied in turn as a top-coat.

Applicant: CHEMETALL GMBH; EADS DEUTSCHLAND GMBH; MANKIEWICZ GEBR. & CO. GMBH & CO. KG; UNIVERSIDADE DE AVEIRO, CN104619431A, Priority 2012-04-17

Title: Process for coating metallic surfaces with coating compositions containing particles of a layered double hydroxide

Description: Para. [0001] A method of coating a metal surface with a coating composition, which uses a pre-treatment prior to an organic coating, a passivation composition, when no subsequent organic coating is expected, and a pre-treatment primer. The composition either uses a primer, a paint or an electrocoating composition.

The term LDH, layered double hydroxide, is described in para. [0025] as:

> *'…typical layered double hydroxide crystal structure or a similar layered double hydroxide crystal structure or may be a modified structure, for example, By at least partial calcination or by partial or complete calcination and subsequent rehydration. All of these LDH crystalline structures vary strongly in composition, interlayer spacing, geometry, size, and/or symmetry of their crystalline units'.*

General formula of the LDH layer; thickness of at least a nanometre based on:

$[M^{2+} (1\pm0.5)-x\ (M^{3+}, M^{4+})\ x\ (OH^-)\ 2\pm0.75\ ]A^{n-}\ x/n\ mH_2O$:

- Para. [0020] M^{2+}, M^{3+} and M^{4+} are each a divalent, trivalent, tetravalent cation selected from the group consisting of Ca^{2+}, Co^{2+}, Cu^{2+}, Fe^{2+}, Mg^{2+}, Mn^{2+}, Ni^{2+}, Zn^{2+}, Al^{3+}, Ce^{3+}, Co^{3+}, Cr^{3+}, Fe^{3+}, Ga^{3+}, V^{3+}, Si^{4+}, Sn^{4+}, Ti^{4+} and Zr^{4+}, in which the presence of the cation M^{3+} or the absence of the cation M^{4+} is not required;

- Para. [0020] '*x'* is the ratio of trivalent plus tetravalent metal cations to the sum of divalent, trivalent, and tetravalent metal cations $(M^{3+} + M^{4+})/(M^{2+} + M^{3+} + M^{4+})$, It is in the range of 0.1-0.5 [0021];

- Para. [0130] A^{n-} indicates the total negative charge of the inserted species 'A', where 'n' is in the range of 0.1-100;

- Para. [0131] Anions 'A' and/or molecules are selected from the group of hydroxides, fluorides, carbonates, nitrates, sulphates, chromates, chromites, molybdates, phosphomolybdates, phosphates, phosphonates, tungstates, vanadates, pyrroles, carboxylates like benzoates, fumarates, lactates, octanoates, oxalates, phthalates, Salicylates, and succinates, dodecylbenzenes, phenolic compounds, anionic surfactants and biomolecular proteins and quinaldine; and

- Para. [0040], the parameter 'm' is usually 4, i.e., 4 H_2O.

Para. [0004] The most common method for surface treatment of metal surfaces is to treat without the intended subsequent organic coating, commonly referred to as passivation, especially for parts, coils or coils made of at least one metallic material, like sheets, and pre-treating the metal surface prior to organic coating (like painting or applying an adhesive).

Such treatment and pre-treatments are generally based on the one hand on the use of chromium (VI) compounds, optionally together with different additives, or, on the other hand, based on phosphates like zinc phosphate/manganese phosphate/nickel phosphate, based on titanium and/or a compound of zirconium, based on silane/silanol/siloxane and/or based on organic polymer/copolymer together with different additives.

[0091] The plate like particles cover the surface of the substrate by planar contact providing 'passive corrosion protection'.

[0180] The flawless coatings that can be produced therefrom, the resulting corrosion resistance results are generally better than today's use; those produced by the chromate containing compositions.

An additional hydrophobicity to the coating is claimed by the use of a separate pyrrole-based corrosion inhibitor such as 2-mercaptobenzothiazole, para. [0181]

Corrosion resistance and paint adhesion claim:

[0235] In Table 5[18], for the pre-treatment composition, the positive effect of the corrosion inhibitor B (E18) added to the LDH particles and optionally another type of corrosion inhibiting anion added separately was clearly demonstrated. The effect of the invention of a) addition of LDH particles and b) addition of a separate corrosion inhibitor B to improved corrosion resistance or to improved corrosion resistance and paint adhesion is shown very clearly.

[0237] The measured neutral salt spray test data is acceptable to excellent.

Applicant: GENERAL ELECTRIC COMPANY, Hazel et al, US2012060721A1, Priority 2003-08-04

Title: Slurry chromizing compositions

Para. [0017]. This technology utilises chromium in its metallic, zero oxidation state form. The inventors also describe the preference of including metallic aluminium in the composition, together with colloidal silica, dispersion of particulate silica in water, preferred or a solvent medium, which acts as the liquid carrier. Colloidal silica may be either acidic or basic in pH and range from 10 – 100 nanometers.

Description: [0002] The present invention generally relates to protective coating systems suitable for components exposed to high temperatures, such as the hostile thermal environment of a gas turbine engine.

More particularly, this invention relates to slurry coating compositions and processes for selectively enriching surface regions of a component, for example, the under-platform regions on a turbine blade, with corrosion-resistant metals such as chromium.

[0010] The slurry coating composition of this invention contains a metallic powder whose bulk composition contains metallic chromium, optionally metallic aluminium in a lesser amount by weight than chromium, and optionally other constituents. The composition further includes colloidal silica, and may also include one or more additional constituents, though in any event the composition is substantially free of hexavalent chromium and sources thereof.

[0007] A drawback of slurry compositions of the type taught by Allen is the reliance on the presence of chromates, which are considered toxic. In particular, hexavalent chromium is considered to be a carcinogen. When compositions containing this form of chromium are used (e.g., in spray booths), special handling procedures closely followed to satisfy health and safety regulations can result in increased costs and decreased productivity. Therefore, attempts have been made to formulate slurry compositions which do not rely on the presence of chromates. For example, U.S. Pat. No. 6,150,033 describes chromate-free coating compositions used to protect metal substrates such as stainless steel.

Many of the compositions disclosed in this patent are based on an aqueous phosphoric acid bonding solution, which comprises a source of magnesium, zinc, and borate ions. However, chromate-free slurry compositions can have various disadvantages, such as instability over the course of several hours (or even minutes), and generation of unsuitable levels of gases such as hydrogen. Furthermore, chromate-free slurry compositions have been known to thicken or partially solidify, rendering them very difficult to apply to a substrate by spray techniques. Moreover, the use of phosphoric acid in the compositions may also contribute to instability, especially if chromate compounds are not present since the latter apparently passivates the surfaces of the aluminium particles. In the absence of chromates, phosphoric acid may attack the metallic aluminium particles in the slurry composition, rendering the composition thermally and physically unstable. At best, such a slurry composition will be difficult to store and apply to a substrate.

Para. [0011] The slurry coating composition of this invention can be employed in a process that generally entails preparing the slurry coating composition, applying the slurry coating composition to the surface region of the substrate to form a slurry coating on the surface region, and then heat treating the slurry coating to remove any volatile components of the slurry coating composition and thereafter cause diffusion of chromium from the slurry coating composition into the surface region of the substrate to form a chromium-rich diffusion coating.

No specific detail as to the performance of the above invention relative to the key functionality criteria is provided. However, the key advantage of the technique is the claimed potential to enrich substrates with metallic chromium, without using Cr(VI) or sources thereof.

Applicant: BARBE CHRISTOPHE; CALDEIRA NANCY MANUELA; CAMPAZZI ELISA; FINNIE KIM SUZANNE; KONG LINGGEN; VILLATTE MARTINE, US2012085261A1, Priority 2009-06-15

Title: Ceramic particles and coating compositions including said particles

This invention employs a method of controlled release of encapsulated corrosion inhibitors.

Description overview: Para. [0011] Due to its strong oxidation properties, hexavalent chromium, or chromate Cr(VI) is currently the most effective way to inhibit corrosion of aluminium alloys.

Para. [0022] The present invention relates to the use of such ceramic particles to encapsulate corrosion inhibitors, to the incorporation of said particles in coating compositions and to the controlled release of the corrosion inhibitors.

Para. [0029] According to a more preferred embodiment of the invention, a corrosion inhibitor is selected from the group consisting of benzotriazole, 2-mercaptobenzothiazole, 8-hydroxyquinoline, 10-methylphenothiazine, cerium (III) salicylate, cerium (III) 2,4-pentanedionate, their derivatives and mixtures thereof.

Para. [0030] More preferably, the ceramic particles comprise silica or organo-silica.

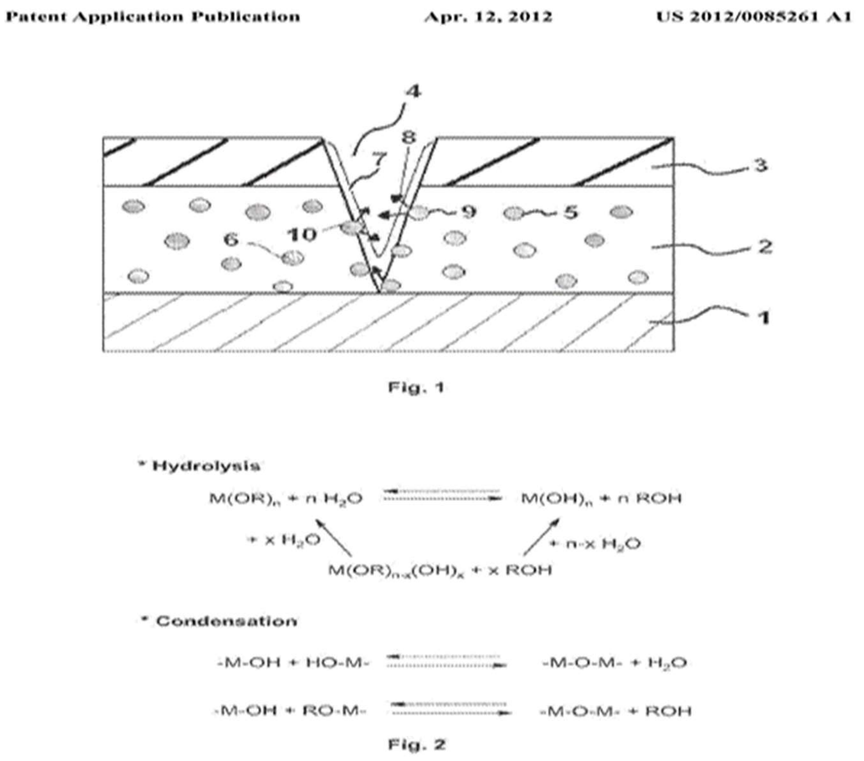
Para. [0034] the release of the corrosion inhibitor from the ceramic particles is triggered by the presence of water.

Para. [0035] Another aspect of the present invention relates to a coating composition, especially for metallic devices such as aircrafts, comprising of ceramic particles, said particles having at least one releasable active material substantially homogeneously distributed throughout each particle.

Para. [0039] More preferably, the coating composition contains at least an organic compound selected among the epoxy silanes and/or an inorganic compound selected among the zirconium alkoxides.

Para. [0042] According to a preferred embodiment of the invention, the coating composition does not contain toxic amounts of hexavalent chromium. More specifically, according to a preferred embodiment of the invention, the coating composition contains less than 0.01% w/w of hexavalent chromium[19]; below the associated CLP generic concentration limit, refer to Table 3.6.2, ECHA Guidance document, version 5.0 ("Guidance on the Application of the CLP Criteria," 2017).

Para. [0048] An object of the present invention is preventing the corrosion of metallic devices, especially aircraft structures.



Patent Application Publication Apr. 12, 2012 US 2012/0085261 A1

Fig. 1

* Hydrolysis

$$M(OR)_n + n\,H_2O \rightleftharpoons M(OH)_n + n\,ROH$$

$$+\,x\,H_2O \qquad\qquad +\,n\text{-}x\,H_2O$$

$$M(OR)_{n-x}(OH)_x + x\,ROH$$

* Condensation

$$\text{-M-OH} + \text{HO-M-} \rightleftharpoons \text{-M-O-M-} + H_2O$$

$$\text{-M-OH} + \text{RO-M-} \rightleftharpoons \text{-M-O-M-} + ROH$$

Fig. 2

Figure 3-7 : Mechanism of corrosion inhibitor release
(BARBE CHRISTOPHE; CALDEIRA NANCY MANUELA; CAMPAZZI ELISA; FINNIE KIM SUZANNE; KONG LINGGEN; VILLATTE MARTINE, 2012)

Figure 3-7 illustrates a typical use and mechanism of release of the corrosion inhibitor. A description of the mechanism illustrated above is provided below.

Para. [0049 – 0064] The aluminium alloy substrate, **1**, part of the aircraft structure, is covered with a primer, '**2**'. The primer is a hybrid organic/inorganic sol-gel coating. Due to its hybrid nature, the adhesion of the primer to the metallic substrate is good enough to spare the use of an inorganic bottom layer, such as an anodising layer or a conversion coating. The primer is covered by a subsequent layer such as a paint.

In the event that the primer and coating are damaged to expose the substrate, 1, beneath, corrosion can occur if in contact with water and oxygen. The corrosion inhibitor carried by the ceramic particles, '**5**' is solubilised from the pores '**6**' of the carrier ceramic particles, '**5'** in contact with water. This mechanism is referred to as a form of 'self-healing'.

Para. [0071] Inorganic corrosion inhibitor. According to a more preferred embodiment of the invention, an inorganic corrosion inhibitor is selected from the group consisting of $Ce(NO_3)_3$, $Ce_2(SO_4)_3$, $Ce(CH_3CO_2)_3$, $Ce_2(MoO_4)_3$, Na_2MoO_4 and mixtures thereof.

Para. [0073] According to a more preferred embodiment of the invention, an organometallic corrosion inhibitor is selected from the group consisting of cerium (III) salicylate, cerium (III) 2,4-pentanedionate (or cerium acetylacetonate) and mixtures thereof.

Para. [0074] & [0075] Preparation of the ceramic particles for water soluble or oil soluble corrosion inhibitors. For water soluble inhibitors such as cerium nitrate, an encapsulation process may involve the preparation of a water-in-oil emulsion with the water-soluble inhibitor dissolved in the water pools of the emulsion. This step may be followed by the addition of a ceramic precursor, which migrates to the water droplet and hydrolyses. The emulsion may then be destabilised by the addition of a polar solvent, which results in the production of submicron microporous particles containing the inhibitor encapsulated inside. Such processes are described in the patent 'Solid Particles from Controlled Destabilisation of Microemulsions WO2006/050579.

Where inhibitors are poorly soluble in water, such as 8-hydroxyquinoline, an encapsulation process may involve the preparation of an oil-in-water emulsion with the inhibitor dissolved in the oil droplets. A hydrophobic precursor, typically an alkoxy silane, more typically a tri-alkoxy silane, may be added to the emulsion. This may be followed by the addition of a catalyst, typically an amino-silane, which catalyses the condensation of the other precursor and leads to the production of submicron microporous particles. Such processes are described in WO2006/133519.

Advantages and functionality aspects

Hardness: Apart from the anticorrosion properties, an advantage of the incorporation of ceramic particles in coating compositions is to increase the scratch resistance of said compositions, by the hardness of said particles, this is not quantified.

Para. [0111] Adhesion: The coatings according to Example III.1, III.2, III.3, III.4, and III.5 were subjected to an adhesion test to ISO 2409. Adhesion results described as 'satisfying' not quantified in open access patent text.

Para. [0112] Corrosion resistance: The coatings according to Example III.1, III.2, III.3, III.4, and III.5 were subjected to a neutral salt spray test to ISO 9227 (336h). All the coatings showed a satisfying corrosion resistance in terms of barrier effect and self-healing.

Disadvantages

Despite the promising claims in this patent, the organic binder materials used in within the invention would decompose at the high operating temperature of most parts subjected to slurry coating. The decomposition of the organic binder would result in the loss of any functionality provided by the binder. Since the substrate used in this patent was aluminium, the maximum operating temperature required by the coating would be lower than coatings which are applied to steel alloys.

Applicant General Electric, US2005031781A1, Priority 2003-08-04, Inventors, Gigliotti et al.

Title: Aluminizing slurry compositions free of hexavalent chromium, and related methods and articles

Para. [0010) This invention generally relates to the protection of metal components exposed to high temperatures in the range of ~650 – 1200°C. Such metals may be utilised in turbine engines, and therefore need to withstand extreme temperatures. Superalloys used in these applications are chosen partly due to their inherent strength. These superalloys incorporate aluminium, which can become depleted if the superalloy is exposed to oxidising temperatures for an extended period of time. Techniques have been developed to compensate for this loss, these contain aluminium containing slurries that usually also involve the use of hexavalent chromium compounds.

Para. [0017] The composition includes colloidal silica and particles of an aluminium-based powder. The aluminium-based powder usually has an average particle size in the range of about 0.5 micron to about 200 microns. The composition is substantially free of hexavalent chromium; concentration unspecified, and contains, at most, restricted amounts of phosphoric acid.

Advantages

Para' [0015] The invention claims not to rely on the use of aqueous phosphoric acid bonding solutions. Phosphoric acid may attack the aluminium present in the slurry preparation when hexavalent chromates are not present; used to passivate the aluminium. Lack of passivation, and subsequent attack from excess phosphoric acid, may render the aluminium component of the slurry coating thermally and physically unstable, compromising storage stability and also application to substrates.

Minimising phosphoric acid concentration, less than 10%w/w, and using an organic stabiliser; glycerol is described in the invention, are claimed to both remove the need for Cr(VI) and also minimise the issues described above associated with elevated concentrations of phosphoric acid.

3.4.3.2 High level literature review (sacrificial coatings)

An online search of open access papers available via the online Science Direct data base was conducted; search term '***chromium free sacrificial coatings*,** search conducted 7th January 2023**.** This search term is intended to return articles which concern alternatives to sacrificial coatings.

A total of 51 results were returned from the above open access search. The section below further explores relevant returned articles and comments on their suitability for aerospace and defence application.

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

Organic coatings and organic-based binders

Introduction

Within the Science Direct search term, articles concerning organic coatings were the most prevalent. Organic coatings normally would not be applicable in the high operating temperature of slurry coated parts due to decomposition. However, a brief commentary on organic coatings is given below in order to understand when organic coatings may be used, and their limitations on being used as alternatives to Cr(VI) slurry coating.

Organic coatings are comprised of polymer materials which can be synthesised from a wide range of monomer building-blocks.

Historically, organic substances have been extensively used in aviation coatings; the most common of which is epoxy resin which currently accounts for 40-60% of the organic aviation coating global market. Organic coatings show good corrosion, abrasion and chemical resistance when applied to metal substrates. However, it is important to note that in some of these organic coating formulations, Cr(VI) has been historically used as an additive to improve corrosion resistance. (ZHANG et al., 2022).

Most organic coatings aim to give corrosion resistance properties by the barrier mechanism, since no electrochemically active component is normally added, galvanic corrosion protection cannot be provided by organic coatings. As such, in the case of coating failure by chipping or delamination, the underlying substrate will not be protected against oxidation by the remaining intact coating. This is a key difference between organic coatings and incumbent sacrificial coatings which utilise Cr(VI).

In addition to epoxy resins, organic coatings can also be based on acrylic or polyurethane polymers. In some cases, additional additives may be included into the coating to enhance properties. These additives can ceramics, graphitic materials, or other insoluble inorganics.

More recently, organic coatings containing fluorinated monomers have become increasingly utilised to further improve the properties of organic coatings. However, fluoropolymers are the target of increasing regulatory action over environmental and human health concerns, and therefore would not be considered an acceptable substitution.

In some instances, a metallic component can be incorporated into the organic coating to provide corrosion protection by the sacrificial mechanism (McMahon et al., 2019). These coatings would be the most technically feasible as alternatives to Cr(VI)-based sacrificial coatings, however these sacrificial coatings are not yet commercially available and would still be subject to the same disadvantages in thermal stability as other organic coatings and therefore would likely not be able to meet technical feasibility requirements.

Degradation of organic coatings

Despite the wide availability and variety of different organic coatings, many are susceptible to degradation under normal operating conditions of an aircraft. Main routes of organic coating degradation include:

- Water diffusion;
- Thermal decomposition;
- UV light radiation; and
- Media corrosion

In the case of water diffusion, slow impregnation of water into microscopic defects in the organic coating layer leads to a build-up of a water film at the coating-substrate interface which can lead to peeling and blistering of the coating over time, which often results in coating failure.

Ultraviolet radiation can also initiate an oxidative radical depolymerisation of the coating, where polymer chains are homolytically cleaved by radiation and react with oxygen present in the air. The cleaved polymer chains are then lower in molecular weight which then may be washed away under normal operating conditions of the aircraft.

For condensation polymer coatings such as polyamides, the resistance to salt solution is of particular concern. The presence of dissolved ions in the solution results in enhanced hydrolytic attack of the polymer by water, which can lead to microscopic defects in the polymer surface and hastens issues relating to absorption of water into the coating.

3.4.3.3 High level literature review (high-temperature diffusion coatings)

The review below encompasses open access papers available via the online Science Direct data base; search term '***chromium free corrosion resistant slurry diffusion coating*'**, search conducted 17 August 2020**.** This search term is intended to return articles which concern alternatives to high temperature diffusion coating.

A total of 15 results were returned from the above open access search. The section below further explores a review article capturing several developments within the metallurgical coatings' technology arena.

These coatings are designed to withstand environmental stresses such as corrosion, irradiation, and oxidation. The paper (Billard et al., 2018) provides an overview of innovations and developments in the field of high- performance metallurgy, focusing upon the following:

- Thin film deposition processes, in particular:
    - PVD (Physical Vapor Deposition); and
    - CVD (Chemical Vapor Deposition)
- Thermal spraying processes:
    - Plasma high velocity oxyfuel;
    - Cold spray
- Diffusion processes:
    - Pack cementation and derivative processes,
    - Powder slurries; and
    - Liquid metals
- Welding processes, including laser cladding.

It should be noted that the following technologies are well established and are used in certain industries where the methodology is technically and economically feasible. Therefore, in addition to a summary of the research, disadvantages of the technique which mean that it is unlikely to replace Cr(VI) slurry coatings are also provided.

Thin film deposition

Physical Vapour Deposition

Sputtering is a term to describe the evolution of metal atoms, or sputtering, from the impact of positively charged noble gas ions, for example argon, which are attracted to the negatively charged 'target'. The evolved metal atom vapour condenses on a substrate forming the thin film coating. *High power impulse magnetron sputtering (HiPIMS)* for physical vapour deposition (PVD), consists in supplying the target with pulses of 10 to 200µs at frequencies of the order of 100 to 500Hz. The instantaneous power dissipated during the pulses can reach about 1 MW, which corresponds to currents of a few thousand amperes for a bias voltage of 600 to 1000V. The average power remains close to a few kW in order to preserve the integrity of the target. Such conditions make it possible to ionize the sputtered metal vapor according to two main mechanisms: by impact of the electrons of the discharge, or by Penning ionization, produced by the collision with the excited metastable argon atoms (Billard *et al.*, 2018).

HiPIMS Advantages:

- Increased performance with regard to erosion by sand and water of aluminium titanium nitride coatings compared to other deposition methods of the same coating thought to be attributed to excellent adhesion and compaction of the coating layer not replicated with some other alternative deposition methods.

- Used in the deposition of high-entropy alloys (HEAs), which have demonstrated high strength coupled with excellent corrosion resistance, good thermal stability, and wear resistance characteristics (Billard *et al.*, 2018)

These methods apply a thin layer of coating which provides corrosion resistance through the barrier mechanism and therefore would not be applicable to sacrificial coatings which provide galvanic corrosion protection in instances where there are localised defects in the coating.

Chemical Vapour Deposition (CVD)

CVD processes generate and transport a reactive vapor phase which upon decomposition in a process chamber deposits a coating on the surface to be covered by heterogeneous (reactants in different phases from one another) chemical reactions. An advantage of a variant of the process, direct liquid injection combined with metal organic precursors (DLI-MOCVD) is a significant reduction in deposition temperatures (Billard *et al.*, 2018). Thermal stability may be an important consideration for less robust substrates or components, as used in aerospace and defence applications.

Research into organometallics using the DLI-MOCVD includes the development of amorphous organo-chromium coatings of the type, a-CrC_x from the precursor bis(arene)chromium. The advantage of this process is that the chromium atom is in the elemental, zero oxidation, state, i.e., Cr(VI) is not formed.

These a-CrC_x coatings exhibit a glass like structure without grain boundaries, with good hardness (20 to 25 GPa), abrasion and wear resistance, coupled with excellent high temperature oxidation resistance. Thermal stability of up to 600°C is reported (Billard *et al.*, 2018). However, these coatings do not show sufficient thermal stability to be used as an alternative to high-temperature diffusion coating, which requires >700°C thermal stability. In addition, galvanic corrosion protection of these coatings would be impossible since the deposited film would be electrochemically inactive towards steel.

A potential disadvantage of the CVD process is from the use of highly reactive precursors that may also be highly toxic necessitating the use of closed loop systems for the recycling of effluents.

For both vapour deposition techniques, it is required that the entire part is placed into a vacuum chamber prior to deposition. Since there is a wide variety of parts to be coated, a number of different vacuum chambers would be required, resulting in issues with economic feasibility. In addition, it is common for vapour deposition chambers to have ‘dead zones’ where coating is not efficient. These ‘dead zones’ would result in an uneven coating distribution, especially for complex parts.

In addition, in some instances it is not possible for CVD methods to deposit the correct combination of elements in the correct proportions to achieve the same functionality as slurry diffusion coatings. Therefore, CVD cannot be used in the place of diffusion coating in all instances where the functionality is provided by a specific and complex mixture of metals.

Thermal spraying

Suspension Plasma Spraying (SPS)

The injection of thin particles (<5µ and most generally between 0.1 and 1µm) through a plasma jet, (see Figure 3-8) The plasma jet operates at 8000 – 14000K typically with a velocity of 800 – 2200m/s, ionizing a carrier gas such as argon, helium, nitrogen, or a gas mixture. Advantages of SPS include the ability to spray compositions, for example of powders in suspension.

A significant disadvantage is that it may not be suitable for substrates that cannot tolerate high temperatures, this may require the addition of cryogenic cooling which may also limit the manoeuvrability of the plasma gun (Billard *et al.*, 2018).

SPS technology has matured within the aerospace sector as thermal barrier, or environmental barrier coatings (TBC or EBCs). Uses include the protection of gas turbine parts and substrates such as nickel based super alloys, where this process can yield good thermal stability at a lower cost compared to Electron Beam Physical Vapour Deposition (EB-PVD) (Billard *et al.*, 2018).

Thermal spraying would not be applicable as an alternative to sacrificial coatings since molten metals such as aluminium or silicon would react with the steel substrate and form a brittle phase rather than a coating.

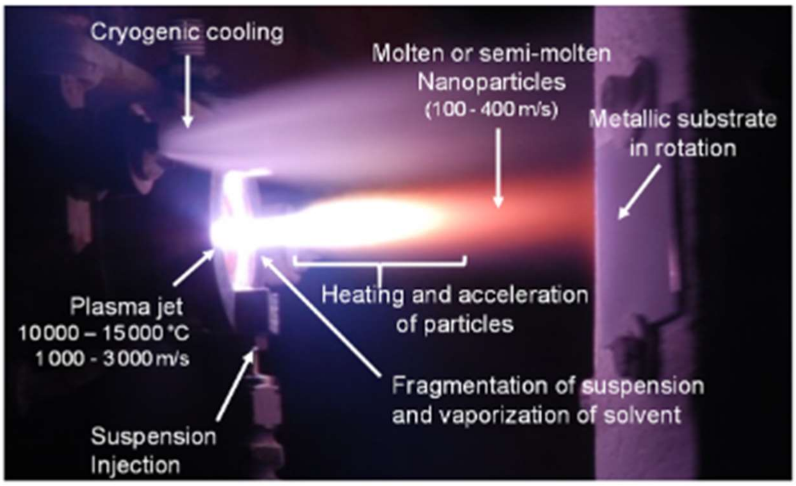


Figure 3-8: Nanoparticles suspension sprayed by suspension plasma spraying technique *(Billard et al., 2018)*

Cold Spray for dense ductile coatings

A kinetic spray process, utilizing supersonic jets of compressed gas to accelerate particles to high velocities. The particles are typically 5 – 50µ and injected into a carrier gas stream at velocities of between 300 and 1500 m/s existing via a de Laval nozzle. This causes deformation of the particles upon impact with the substrate, where they combine to the coating. The coating can be built at up to 1mm/pass

Aside from anti corrosion and wear application, other uses of this technology include:

- Repair, especially of magnesium parts;
- Electromagnetic interference shielding;
- Demanding electric, electronic or thermal applications;
- Deposition of soldering and brazing alloys; and
- Conducting structures on non-metal composite layers

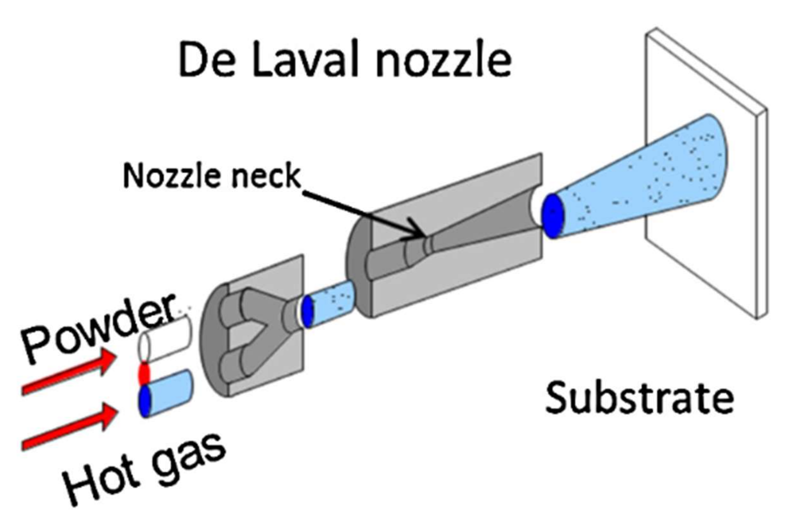


Figure 3-9: Cold-spray principle illustrating de Laval nozzle application.
(Billard et al., 2018)

Advantages include:

- Use of materials that may be temperature, oxygen, and phase sensitive, due to the low temperature of the process;
- Enhances fatigue resistance, described as a function of the micro ‘shot-peening’ effect yielding compressive residual stresses in the deposited material;
- More precise control of the deposited material onto the substrate; less need for masking
- Can be used when dissimilar materials with different thermal tolerances are adjacent to one another;
- High rate of coating, up to 1mm/pass; and
- Strong bonding with substrate.

Disadvantages include:

- ‘Short-peening’ can induce high level of residual stress, requiring restorative post treatments (Billard *et al.*, 2018); and
- The process is a ‘line-of-sight’ process, meaning that parts with complex geometry would be impossible to coat evenly.

Laser Cladding

The laser cladding process consists of a spray of a concentrated powder flow under a laser beam on a substrate surface. The melting of the powder and of the upper part of the substrate surface layer generates a melt-pool. The progressive movement of the cladding nozzle results in the production of a solidified layer of additional material with a typical thickness from 100µm to millimetres. Mixing of several materials is possible in the powder feed under the laser beam allowing the formation of metallic composite cladding materials.

The laser cladding process enhances the physical characteristics of the substrate by depositing a dense heterogeneous layer of a material with improved wear, corrosion resistance and thermal stability properties for example.

Advantages of laser cladding:

- Fine control of the melting zone;
- Variation of the deposit thickness by varying the laser beam properties;
- Production of very fine microstructure materials due to fast solidification;
- Applicable to wider range of materials e.g., metals, ceramics, and polymers; and
- Production of dense and heterogeneous materials.

Laser cladding applications cited include hard facing wear resistance surfaces where variable deposition thickness may be required and also for controlled geometry situations. It is also adaptable for repair conditions (Billard *et al.*, 2018).

As previously discussed, melting of metals used for sacrificial coatings (e.g., aluminium) would result in adverse reactions between the coating and the substrate, resulting in the formation of brittle phases.

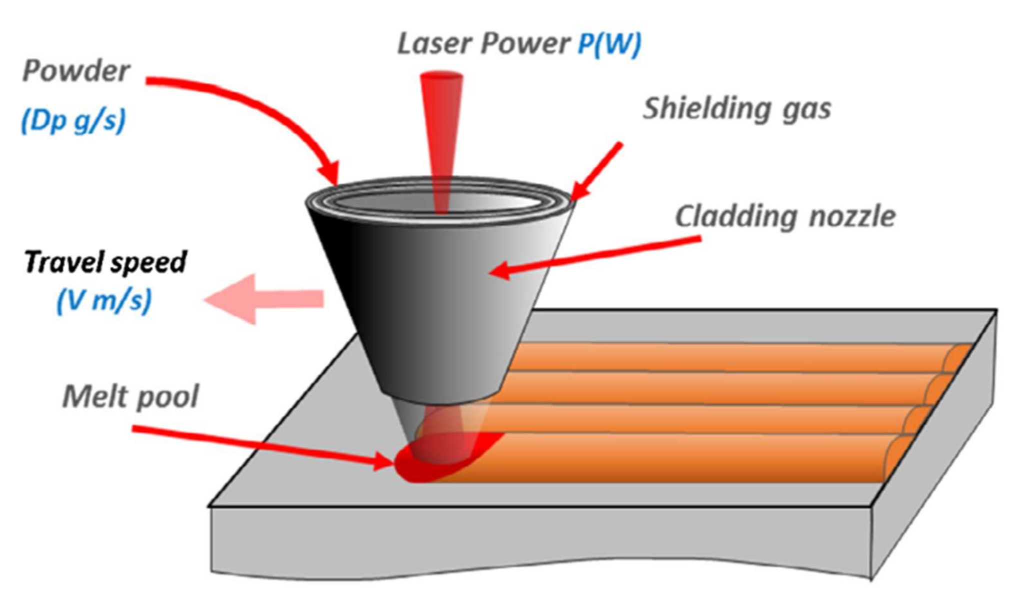


Figure 3-10: Laser cladding principle
(Billard et al., 2018)

Pack cementation

This process was described in the early twentieth century, however not widely adopted until the 1950s. Examples of pack cementation applications includes the production of stage 1 aerofoils coated with aluminium diffusion coatings. This process is described under the chemical vapour deposition (CVD) process; applied in a vacuum, an inert gas atmosphere or under reducing conditions at a temperature of 600 – 1200°C.

The 'pack' is composed of an inert filler, for example aluminium oxide, and activator (halogen donor), and enriching element, for example chromium, other elements may be used such as hafnium, and yttrium, depending on the properties required. Silicon can be added to enhance chemical resistance to sulphur carrying gases. The components to be treated are either embedded 'in-pack' in the treatment, or suspended, 'out-of-pack'. After heating up to 200°C to remove remaining moisture and oxygen. For super alloys the components and 'pack' are heated in a range of 900 – 1100°C, typically between 1 to 10 hours, dependent upon the diffusing element and the tolerance of the substrate (Galetz, 2015).

While pack cementation is used for many A&D components, for some nickel-based alloys, members state that the temperature required by pack cementation may induce irreversible microstructural defects in the component and would therefore be unacceptable as an alternative to high-temperature diffusion coated components. In addition, pack cementation has the same drawback as CVD, where precise delivery of complex mixtures of metals is impossible and therefore would not be considered as an alternative to slurry diffusion coating in many situations.

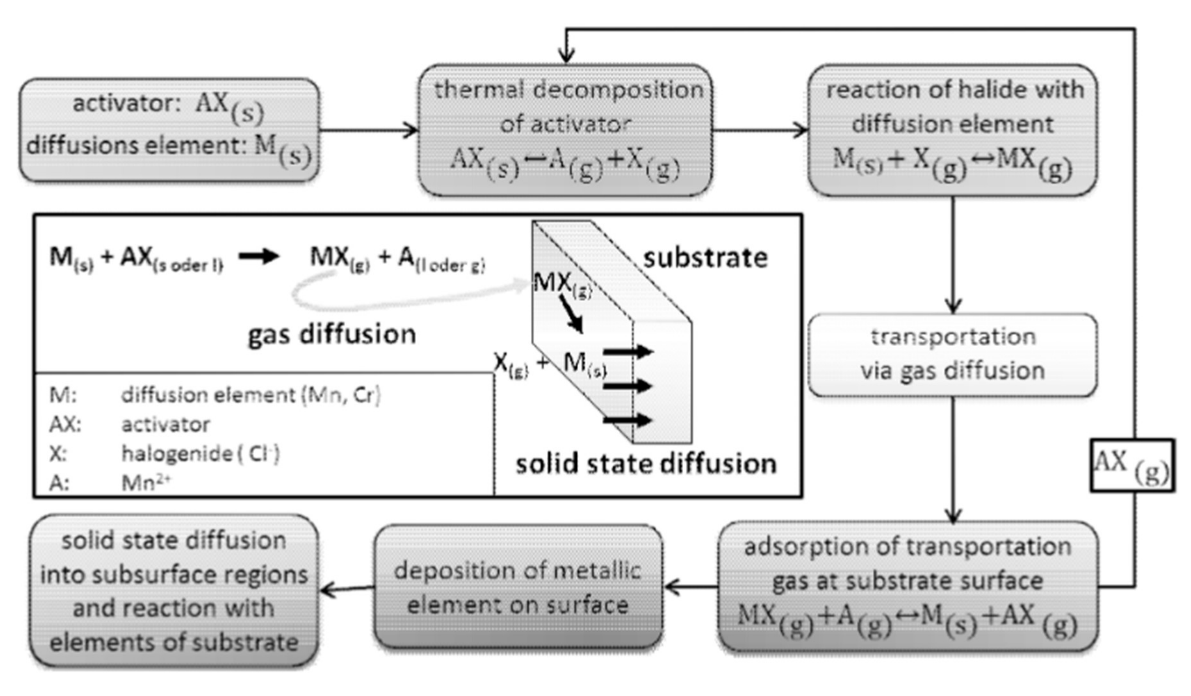


Figure 3-11: Major steps during pack cementation process (Galetz, 2015)

3.4.3.4 Conclusions on scientific literature

Examination of the literature landscape surrounding potential test candidates to both sacrificial and high temperature diffusion coating reveals several different coating technologies which do not rely on the use of Cr(VI). However, all technologies described show significant drawbacks which have ruled them out for further testing or development to replace slurry coatings. For example; organic coatings such as epoxy resins give good corrosion resistance initially, but are subject to chemical degradation upon exposure to the operating conditions of an aircraft particularly in high-temperature applications which are currently subject to Cr(VI)-based slurry coating. Film deposition methods such as CVD or PVD require expensive and bespoke vacuum chambers and are unsuitable for the coating of complex components. Many of the metallurgical coating technologies are applied by 'line-of-sight' methods, which is not feasible for many A&D components which have complex geometry.

While some of the metallurgical coating technologies discussed above may have some limited application as alternatives to high-temperature diffusion coatings, most require melting of the metal which is applied and therefore are not applicable to sacrificial coatings which require the coating to not react with the substrate.

ADCR members have stated that the alternative coating technologies found in the literature were not technically or economically feasible in many cases, and R&D for the development of Cr(VI)-free replacements for slurry coating was directed towards replacing Cr(VI) within pre-existing slurry formulations.

3.4.4 Shortlist of alternatives

Potential test candidates for alternatives to Cr(VI) based slurry coatings are shown below. This list comprises the alternatives which were reported in the parent AfAs. It should be noted, however, that the list of alternatives reported in the parent AfA comprises alternatives to chromium trioxide in both slurry coating and conversion coating 'uses'. As a consequence, the shortlisted alternatives present in the previous application may not have been suitable for further development of only slurry coating.

The progression of the proposed test candidates discussed in this Combined AoA/SEA are:

- Cr(III) based coatings;
- Manganese based processes; and
- Chromium-free aluminium-based coatings

The primary focus of ADCR members in developing a Cr(VI)-free alternative for slurry coating has been in developing chromium-free aluminium-based coatings. This category encompasses a wide variety of specific formulations which are normally developed by external formulators and are provided to OEMs and MROs as a 'ready-to-use' coating.

The progression of these alternative formulations is discussed in more detail in Section 3.5.5.

3.4.4.1 Performance requirements and testing

Performance of test candidates needs to be equal to or better than the incumbent Cr(VI) treatment and this is driven by safety and performance requirements.

It should be noted that members' experience has shown that there can be difficulty in transferring good laboratory test results to an industrial environment. Decades of experience with Cr(VI) has contributed to the design and development of testing methods and protocols by the industry. Nevertheless, it is impossible to exactly reproduce in the laboratory environment the conditions that hardware will experience in its operating environment over its lifetime, or to correlate an accelerated test to actual in-service behaviour. The laboratory tests have been designed to give the best and most realistic information possible, but because of these unavoidable limitations it is necessary, as a minimum, to ensure that results in the laboratory of test candidates are at least as good as Cr(VI). Additionally, service life of equipment can be extended beyond its designed service life, requiring a high amount of effort and approval from stakeholders. This increases the importance that test candidates' performance needs to be at least as good as Cr(VI).

3.5 Assessment of shortlisted alternatives

3.5.1 Introduction

To achieve certification or approval by the relevant authority and/or design owner, each component must meet the required performance and safety requirements provided by the incumbent Cr(VI) based treatment. A complete suite of tests should include evaluation of all alloys subject to slurry coating, thereby highlighting impacts on niche alloys to be addressed prior to adoption of the test candidate.

Approval of the test candidate must include a complete understanding of the influence of the adjacent treatments to slurry coating within the process flow. This is to understand the influence of all processes representing the surface treatment 'system' including pre-treatments and post-treatments where appropriate. Evaluation of the technical feasibility of the test candidate for slurry diffusion coating should consider its behaviour in contact with different alloy substrates, as well as 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 delivering slurry coating, and consequently impact or delay approval of the test candidate for different component designs. This scenario is a leading reason for the graduated implementation of test candidates in combination with different component/design families. Different designs exhibiting varying degrees of complexity have the potential to interact with elements of the treatment system differently and thus effect the performance of the test candidate.

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

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

3.5.1.1 Suitability of a test candidate

When assessing the suitability of a test candidate reference is made to the European Commission note dated 27 May 2020 which clearly defines the criteria by which a test candidate may be judged as suitable[25]. In order to be considered as suitable in the European Union (EU) the alternative should demonstrate the following:

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

To be available, a test candidate should meet the regulatory requirements of placing it on the market. Until the technical feasibility criteria and associated performance requirements of the use and wider treatment system are fulfilled, including all certification obligations as stipulated in the Airworthiness Directives[26], the test candidate cannot be deemed 'available'.

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[25] 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

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

All civil aircraft operating in the EU are subject to Airworthiness Directives issued by the EASA on behalf of the EU and its Member States, and European third countries participating in the activities of EASA. Changes to design of a product are subject to certification (EU, 2018), and can only be made following approval from the Regulator and compliance with the requirements of the appropriate Airworthiness Regulation, such as (EU) 2018/1139[27]. To reinforce this point, a civil aircraft's Certificate of Airworthiness is not valid until the Type Certificate has been approved by the Regulator (EASA, 2012)

Defence equipment is subject to standalone change protocols including approval by the relevant Member State Ministries of Defence. Therefore, a test candidate not deemed available from a regulatory standpoint would not meet all required criteria within the above definition of 'suitable'.

3.5.2 Status reported in original applications

The following sections discuss the progress of the development of test candidates by the ADCR members for use in slurry coating. For context, a short summary of the status reported in the parent Applications[28] in 2015-2016 is presented for each of the test candidates, followed by a description of progress by the ADCR members to date.

3.5.3 Test candidate 1: Cr(III) based slurry coatings

3.5.3.1 Status reported in original applications

Chromium (III) alternatives include three species; sulphate, fluoride, and chloride variants. Reports indicate that Cr(III) does not provide the same scope of functionality for slurry coatings as provided by Cr(VI). Deficiencies relate to the functionalities below (GCCA, 2016).

- Corrosion protection;
- Heat resilience; and
- Flexibility

Protection and other physical properties may only be sufficient for specific applications on steel and nickel substrates. Corrosion resistance is below reported test requirements; 20 cycles between salt spray and high heat without breakdown or excessive corrosion creep from scribed areas (CTAC submission Consortium, 2015)

According to Wesco et.al, chromium (III) alternatives may only demonstrate sufficient corrosion protection for specific applications, although not clearly defined, and are deficient in replicating the performance of Cr(VI) against the key criteria of heat resilience, hot corrosion, humidity, hot water exposure, thermal shock resistance, and adhesion (GCCA, 2016)

It should be noted that proposed test candidates to slurry coating which are not classed as Cr(III) based which are being actively pursued by ADCR members may contain Cr(III) in varying quantities

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[27] REGULATION (EU) 2018/ 1139 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL - of 4 July 2018 - on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency, and amending Regulations (EC) No 2111/2005, (EC) No 1008/2008, (EU) No 996/2010, (EU) No 376/2014 and Directives 2014/ 30/ EU and 2014/ 53/ EU of the European Parliament and of the Council, and repealing Regulations (EC) No 552/2004 and (EC) No 216/2008 of the European Parliament and of the Council and Council Regulation (EEC) No 3922/91 (europa.eu)

[28] CTAC consortium. (2015). *Chromium trioxide AoA, use 4 (0032-04);* GCCA consortium. (2016a). *Chromium trioxide AoA, use 1 (0096-01)*

depending on the specific formulation. However, since Cr(III) is not the principal substance in the delivery of functionalities required by slurry coating, they are not classed as Cr(III) based alternatives.

3.5.3.2 Progression reported by ADCR members

Introduction

To date no members reported pursuing this technology as an alternative to existing sacrificial coatings or high temperature (diffusion) coatings in aerospace and defence applications.

Technical feasibility of Cr(III) based alternatives

No information was provided on the technical feasibility of this test candidate

Economic feasibility of Cr(III) based alternatives

Due to lack of pursuit of this alternative by ADCR members, it is not possible to conduct the economic feasibility of this test candidate.

Health and safety considerations related to using Cr(III)-based treatments

A summary of the key identifiers and hazard properties of Cr(III)-based alternatives is shown below in Table 3-5**.**

Table 3-5: Substances in Cr(III)- based substances - key identifiers and hazard properties

Substance	EC number	CAS number	Hazards (REACH)[a]	Hazards (CLP)[b]
Chromium (III) oxide	215-160-9	1308-38-9	None	May damage fertility or the unborn child, causes serious eye irritation, is harmful if swallowed and may cause an allergic skin reaction
Chromium (III) fluoride	232-137-9	7788-97-8	Toxic if swallowed, causes severe skin burns and eye damage, is very toxic to aquatic life, is toxic to aquatic life with long lasting effects, causes serious eye damage and may cause an allergic skin reaction	Causes damage to organs through prolonged or repeated exposure, is harmful in contact with skin and is harmful if inhaled
Chromium hydroxide sulphate	235-595-8	12336-95-7	Causes serious eye irritation, is harmful to aquatic life with long lasting effects, causes skin irritation and may cause an allergic skin reaction	Harmful if inhaled, causes serious eye damage, and may cause respiratory irritation
Chromium (III) chloride	233-038-3	10025-73-7	Toxic to aquatic life with long lasting effects, is harmful if swallowed, may be corrosive to metals and may cause an allergic skin reaction.	Harmful if swallowed, may cause allergic skin reaction, may be corrosive to metals

(a) – Hazard classification according to the notifications provided by companies to ECHA in REACH registrations
(b) – Hazard classification provided by companies to ECHA in CLP notifications

Table 3-5: Substances in Cr(III)- based substances - key identifiers and hazard properties				
Substance	**EC number**	**CAS number**	**Hazards (REACH)[(a)]**	**Hazards (CLP)[(b)]**
Source: ECHA – Search for chemicals (https://echa.europa.eu/home)				

3.5.4 Test candidate 2: Manganese-based processes

3.5.4.1 Status reported in original applications

As an alternative to chromium trioxide containing slurry coatings, manganese-based products do not provide sufficient:

- Corrosion resistance;
- Heat resilience;
- Flexibility with regard to the specifications; and
- Limited substrate applications; may only be suitable on steel and nickel.

Protection and other physical properties may only be sufficient for specific applications namely on steel and nickel substrates. Corrosion resistance is reported as below rigorous test requirements; 20 cycles between salt spray and high heat without breakdown or excessive corrosion creep from scribed areas (CTAC submission Consortium, 2015)

3.5.4.2 Progression reported by ADCR members

Introduction

No members have reported pursuing this alternative

Technical feasibility of manganese-based alternatives

ADCR members indicated that no manganese-based alternatives were available from formulators for testing. OEMs and MROs do not design or formulate test candidates as alternatives to slurry coatings and therefore have limited scope to design or test candidate alternatives within this category.

Economic feasibility of manganese-based alternatives

Due to lack of pursuit of this alternative by ADCR members, it is not possible to conduct the economic feasibility of this test candidate.

Health and safety considerations related to using manganese-based alternatives

A summary of the key identifiers and hazard properties of manganese-based alternatives is shown below in Table 3-6.

Table 3-6: Summary of hazard properties of potassium permanganate				
Substance	**EC number**	**CAS number**	**Hazard (CLH)[(a)]**	**REACH[(b)]**
Potassium permanganate	231-760-3	7722-64-7	Very toxic to aquatic life (H400), is very toxic to aquatic life with long lasting effects (H410), may intensify fire	Causes severe skin burns and eye damage, causes serious eye damage, is suspected of damaging fertility or the

			(oxidiser) (H272), is harmful if swallowed and is suspected of damaging the unborn child (H361d)	unborn child and may cause damage to organs through prolonged or repeated exposure
(a) – According to the harmonised classification and labelling (b) – Hazard classification provided by companies to ECHA in REACH Registrations *Source: ECHA – Search for chemicals (https://echa.europa.eu/home)*				

Availability of manganese-based alternatives

No members reported pursuing this test candidate and therefore no comments were provided on the expected accessibility on the EU market in the required quantities.

Suitability of manganese-based alternatives

The use of manganese-based processes does constitute a reduction in hazard profile compared to Cr(VI), however given the low technical maturity of this test candidate and the technical feasibility issues that have been encountered, manganese-based processes cannot be considered a generally available and suitable alternative for Cr(VI) based slurry coating.

3.5.5 Test candidate 3: Chromium-free aluminium-based coatings

3.5.5.1 Status reported in original applications

This sub-section summarises the development status of candidate alternatives to Cr(VI) for slurry coating *that were reported in the parent Application in 2016*. This is to provide context to the progress that is reported by members in this combined AoA/SEA (see subsequent Section 3.7)

The substrate considered in the discussion of technical feasibility for chromium-free aluminium coatings in the parent application is stainless steel. As such, the discussion in the parent application applies only to sacrificial coatings.

The alternative comprises aluminium-based particles in Cr(VI) free inorganic binders for applying sacrificial or high temperature (diffusion) coatings to metallic substrates. For sacrificial coatings, corrosion resistance is achieved after curing of the aluminium/inorganic binder ceramic coating via the sacrificial mechanism, imparted by the incorporated aluminium particles.

For high temperature diffusion coatings, corrosion resistance is achieved in the same way as the incumbent treatment, where the metallic component of the coating diffuses or reacts with the substrate to form a corrosion resistant layer.

In the case of slurry barrier coatings, Cr(VI) free alternatives offer corrosion resistance by preventing the access of corrosive chemicals to the surface of the substrate through the barrier mechanism. Various formulations exist, some of which are commercially offered (GCCA, 2016).

Chromium-free aluminium-based coatings were considered the most promising alternative to the incumbent Cr(VI)-based coatings. This is partially due to the broad scope of the class of alternative which includes all Cr(VI) free coatings which use aluminium particles as the primary source of corrosion resistance. As such, in the parent application, it was highlighted that over 100 Cr(VI)-free formulations had been developed with many being commercially available. Despite the large number of formulations available, none were able to progress beyond TRL 3 due to poor corrosion resistance when subjected to salt fog testing.

3.5.5.2 Progression reported by ADCR members

Introduction

Due to the wide range of possible Cr(VI)-free binders, chromium-free aluminium-based alternatives remain to be the most heavily pursued and promising class of alternatives. ADCR members have reported that these alternatives have been pursued for both sacrificial coatings and high temperature (diffusion) coatings. Members report on the use of chromium-free aluminium-based sacrificial coatings for use on steel substrates and nickel and nickel alloy substrates for high temperature (diffusion) coatings.

Multiple types of chromium-free aluminium based proprietary formulations incorporating a range of different binders and additives are available on the market and have been variously investigated by ADCR member companies. Many of these Cr(VI) free formulations contain either phosphate or silicate binders, however a wide range of additives are used in specific formulations. Typically, individual ADCR members have included several of these chromium-free aluminium based formulations in their testing programme, with these testing programmes still ongoing.

Generally, the preparation of the substrate prior to slurry coating requires only physical treatment such as grit blasting or shot peening prior to application of the coating. No chemical pre-treatments were reported by ADCR members to be used prior to application of a slurry coating. Therefore, there are no possible complications arising from chemical incompatibility between pre-treatment steps and the final coating. However, it is possible that increasing the cure times or temperatures of an alternative coating may influence the mechanical fatigue debit of heat treated or shot peened components.

ADCR members have progressed the development of chromium-free aluminium-based alternatives since the parent Application in 2016, with multiple formulations progressing past TRL 3 over recent years, and many are targeted to progress further over the coming years. ADCR members report that corrosion resistance remains to be an issue when developing alternative sacrificial coatings. However, for high temperature (diffusion) coatings, achieving suitable corrosion resistance is less of an issue.

Chromium-free aluminium-based alternatives are by no means fully implemented and further significant testing is ongoing which must extend beyond the current review period. Key technical performance issues that remain to be solved are inadequate corrosion resistance and poor adhesion and flexibility. Barriers to achieve higher TRL levels include the need for acceptance by OEMs or the airlines/Ministries of Defence by demonstration of acceptable performance, lack of vendors to apply the coating, and the necessity to complete the relevant qualification and certification requirements.

Since multiple members are pursuing chromium-free aluminium-based coatings for sacrificial and high temperature (diffusion) coating uses, the feasibility of the alternatives for each of these sub-uses will be discussed separately.

3.5.5.3 Technical feasibility of chromium-free aluminium-based coatings

Sacrificial coatings

A number of technical results from the ongoing development of chromium-free aluminium based alternatives for sacrificial coatings have been reported by ADCR members. These are discussed in the following section.

Of the performance requirements relevant to sacrificial coating discussed in Section 3.2.1 corrosion resistance and adhesion were reported by members as key reasons for failure for these alternatives. However, it is important to note that corrosion protection is generally tested initially. If the coating passes initial corrosion tests, then further testing may be performed to compare against other key performance criteria. For this reason, many coatings are rejected without testing their performance for other functionalities.

Corrosion resistance and performance with alternative formulations

Ongoing corrosion performance testing with chromium-free aluminium-based sacrificial coatings has shown mixed findings across the ADCR membership. Some alternative formulations can meet the required corrosion resistance when exposed to neutral salt spray (NSS) where others do not qualify basic corrosion resistance tests. Coatings which pass low-temperature corrosion resistance tests may then have to demonstrate resistance to 20 cycles of elevated heat then NSS.

It is apparent that despite the fact that galvanic corrosion resistance is mostly supplied by the metallic constituent of the coating, the supplementary corrosion resistance provided by Cr(VI) in the incumbent sacrificial coatings cannot be easily replaced by alternative binder systems.

In addition to providing corrosion resistance to the substrate, another role of Cr(VI) in incumbent sacrificial coating systems is to provide corrosion resistance to the aluminium powder itself, wherein a protective chromia layer protects aluminium particles from corroding in the harsh aqueous environment of the formulation. For Cr(VI) free systems, this protection of the aluminium powder may not be provided. ADCR members have stated that Cr(VI) free aluminium based coatings are provided as two-part mixtures which have pot-lives of only two hours after mixing before the aluminium is decomposed.

Adhesion promotion

Several members have indicated that substrate adhesion properties of the alternative sacrificial coatings can meet ISO2409 standards. However, due to the elevated temperature operating conditions of components subjected to sacrificial coating, it is more appropriate to test adhesion properties at high temperatures and after thermal shocking. These high-temperature tests gave mixed results, where some formulations showed significant loss of adhesion, whereas others showed sufficient adhesion to the substrate even after thermal shocking.

In some cases, thermal shocking tests could only be passed for coatings which were of a lower thickness (<70 µm) and as such would limit its application in a system where a thick coating is required to provide adequate corrosion or heat resistance.

Other technical feasibility considerations

Although there have been improvements in the key functionalities provided by the alternative sacrificial coating systems, there are other technical feasibility considerations which may result in rejection of a test candidate which has otherwise shown good promise. These points of failure are normally at the ‘system’ level and may include:

- Insufficient application qualities (inhomogeneous thickness/coverage on complex components)
- Not easily strippable for MRO activities and reapplication
- Insufficient chemical resistance (hydraulic fluids, fuels, engine oil etc.)
- Insufficient conductivity post-burnishing

Failure of the coating at these system level criteria is often detected only when an alternative has progressed to higher TRLs and therefore results in significant setbacks which further delay the qualification of alternative coatings.

High temperature (diffusion) coatings

A number of technical results from the ongoing development of chromium-free aluminium based alternatives for high temperature (diffusion) coatings have been reported by ADCR members. These are discussed in the following section.

For high temperature diffusion coatings, it has been generally reported that corrosion resistance requirements can be met without the presence of Cr(VI). Since corrosion resistance properties of high temperature diffusion coatings were reported to be independent of Cr(VI) within the formulation, laboratory scale tests proved promising. However, no alternative coatings have yet progressed beyond low TRLs due to reduced stability of the coating. The most promising candidates are predicted to achieve TRL 6 within the next 2-3 years. However, due to significant differences in the spraying, curing and storage requirements when facilitating use of the alternative, more time will be required in order to adapt manufacturing lines, train operators to use the new systems, and develop new technical drawings which allow components to conform when the new coating is applied.

For non-diffusing barrier coatings, coatings comprising of ceramic particles in an inorganic binder have shown good promise in laboratory tests, where corrosion protection, thermal shock resistance and adhesion tests were passed alongside most others. One ADCR member reported achieving TRL 4 for this alternative in 2021 and is now developing scale one tests to promote the candidate further, however the member also reports concerns with the performance of this alternative in hot corrosion tests. In addition, it is uncertain when sufficient supply chains will be in place to provide at-scale implementation of this alternative.

3.5.5.4 Economic feasibility of chromium-free aluminium-based coatings

The direct challenge for the substitution of slurry coating by chromium-free aluminium-based diffusion coating is the overall increase in the operating costs. Even though there are no changes to the process steps or equipment needed, the slurry composition and coating process is more complex than the existing process.

The operational costs will increase due to the following impacts:

Raw material costs: The overall cost of raw materials will rise since the slurry composition is more complex and expensive than non-diffusion-based raw materials for Slurry coating;

Training costs: There will be training costs required since the new process is more complex than the existing one the paint operators will require training;

Other costs: The implementation of a potential candidate involves administrative modifications (blueprint, working instructions, etc.) which will incur additional costs.

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

Some companies have, however, made considerable progress in the substitution implementation of a substitution plan for slurry coating. However, the ADCR members are at a different TRL level. Approximately 50% of the members request a review period between 8-12 years. While 30 % of members each requested a review period of at least 4 years and 20% of members for a review period between 4 to 7 years period.

Another major cost factor identified is related to the certification process. The time required is due to both the tests required for validation and qualification of the use of the potential candidate on components, as well as the process for qualifying or accrediting suppliers against the implementation of the potential candidate. According to many members, the substitution will take time to implement and will not be ready by 2024.

3.5.5.5 Health and safety considerations related to using chromium-free aluminium-based coatings

Several types of chromium-free aluminium-based proprietary formulations with a range of different additives are available. Generally, the alternative binder material which functionally replaces Cr(VI) in incumbent coatings are metal phosphate salts. The difference in hazard properties between this alternative binder system and Cr(VI) compounds therefore represents the key reduction in risk when implementing an alternative system.

The hazard properties of several phosphate salts which may be used as an inorganic binder in alternative slurry coating formulations are listed below in Table 3-7.

Table 3-7: Summary of hazard properties of alternative inorganic binders for slurry coatings

Substance	EC number	CAS number	Hazard (CLH)[(a)]	REACH[(b)]
Aluminium tris (dihydrogen phosphate)	236-875-2	13530-50-2	Eye Dam. 1 (H318)	Causes serious eye damage
Zinc (II) phosphate	231-944-3	7779-90-0	Aquatic Acute 1 (H400); Aquatic Chronic 1 (H410)	Very toxic to aquatic life with long lasting effects

(a) – According to the harmonised classification and labelling
(b) – Hazard classification provided by companies to ECHA in REACH Registrations
Source: ECHA – Search for chemicals (https://echa.europa.eu/home)

In addition to these primary alternative binder substances, multiple other additives may be required to achieve sufficient properties to allow the performance of the alternative coating to match that of the incumbent Cr(VI) based coatings. These additional additives can comprise of simple metal oxides or hydroxides and silane compounds.

While each proprietary formulation is different and can contain variable additives with a range of hazards, it is the consensus among ADCR members that chromium-free aluminium-based coatings present a significant reduction in hazard properties when compared to the incumbent Cr(VI)-based coatings. None of the identified alternative binder components are carcinogenic, mutagenic, or reproductive intoxicants (CMRs).

3.5.5.6 Availability of chromium-free aluminium-based coatings

For sacrificial coatings, it was reported by several members that supply chains were expected to be in place across the EU. The current commercial status of different coating systems varies, with some alternatives being produced in test-scale batches, others are undergoing reformulation at the request of OEMs, limiting availability to those who had already qualified the coating. Some promising alternative formulations are currently in service with several aircraft companies, and as a result have robust commercial activity and supply chains within the EU and globally.

It was the consensus among ADCR members that supply chains for chromium-free alternatives should be in place by the time that the coatings have been qualified across all components. Sacrificial paints are applied to a large number of different components, and in order to ensure sufficient supply chain integrity, the implementation across these components will have to be staggered. A significant number of components will also have to undergo drawing alterations which incur additional time to process and will add complexity to the implementation of the alternative.

3.5.5.7 Suitability of chromium-free aluminium-based alternatives

The use of chromium-free aluminium-based alternatives does constitute a significant reduction in hazard profile compared to the incumbent Cr(VI) based coatings. The use of phosphate and silane based inorganic binders removes the use of any CMR substances within the formulation.

In most cases, alternative slurry coatings can be applied using the same equipment as the incumbent Cr(VI)-based coatings and as such, this will aid in streamlining the transition to an alternative.

While ADCR members have reported promising results for the technical and economic feasibility of chromium-free aluminium-based alternatives, few have yet been reported to have progressed beyond TRL 4. On the other hand, for some specific instances where this alternative has been progressed, an alternative to slurry coating will be implemented by late 2024. The barrier to progression beyond TRL 4 was reported by several ADCR members to be issues with scaling up testing from application on basic test panels to at scale systems. Fulfilling criteria such as corrosion resistance and uniform application on complex components were highlighted as particularly challenging.

For alternative coatings which have thus far shown successful adherence to the performance criteria, significant time is required to progress beyond TRL 4. Specifically, progression to TRL 6 requires a scale-one engine test, which involves the completion of the following tasks:

- Identify all candidate components to be coated and create specific drawings;
- Develop process parameters to fulfil drawing requirements;
- Identify an engine test which is useful to the evolution of the slurry coating in representative operating conditions
- Performing analysis on engine test results

These engine tests must be completed for each technical feasibility criterion and for each candidate alternative coating.

With the complexity of substitution across the A&D sector, coupled with issues in technical feasibility, chromium-free aluminium-based alternatives cannot be considered a generally available and suitable alternative

3.6 Conclusions on suitability of shortlisted alternatives

As discussed in the parent application, a number of test candidates were reviewed based on the current level of development and progress achieved in substitution plans, these are:

- Cr(III)-based;
- Manganese-based processes; and
- Chromium-free aluminium-based coatings.

While no ADCR members reported the development of Cr(III) or manganese-based processes due to poor technical feasibility, all members reported progress with chromium-free aluminium-based coatings. As such, going forwards, the main focus of development of an alternative to replace Cr(VI) in slurry coatings will be various forms of chromium-free aluminium-based coatings, rather than the others reported in the parent AfA.

Some of these test candidates are in use by some ADCR members for some components on some alloys, however significant technical challenges remain before any of these test candidates can be used in all situations. The main limiting factors are failure to meet technical performance requirements, particularly when moving from the use of testing panels to at-scale components and engines.

Consequently, none of these test candidates can be considered a generally available and suitable alternative to all applications of Cr(VI)-based slurry coating.

3.7 Substitution plan

3.7.1 Introduction

3.7.1.1 Factors affecting the substitution plan

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

- Functionality and ability to meet performance requirements (Technical feasibility);
- Availability and suitability of the alternative;
- Process changes such as equipment, training, health and safety (Technical challenges and economic feasibility);
- 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 cost of moving to an alternative and the costs of implementing the alternative across the supply chain; and
- Progress and alignment with other REACH substitution workstreams

Each factor will contribute to the achievement of milestones that must be met to realise delivery of the substitute(s) to Cr(VI) for slurry coating. They require continuous review and monitoring to ensure that the substitution plan progresses through its phases and all changes are clearly documented. Monitoring of progress markers associated with the substitution plan includes a timetable of steps and targeted completion dates, assessment of the highest risks to progression, and how these risks can be reduced (if possible), which may not always be the case.

3.7.2 Substitution plans within individual members

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

3.7.3 Substitution plan for ADCR in slurry coating

Multiple test candidates to replace Cr(VI) in slurry coating have been investigated by members and have been progressed to various stages, with variation arising from different types of components and substrates.

The expected progression of ADCR members' substitution plans to replace Cr(VI) in slurry coating is shown in **Figure 3-12** below. The progressive stages of the substitution plan (development, qualification, validation etc.) as shown in the diagram are described in detail in section 3.1.2. Implementation and progression of substitution plans ultimately leads to reduced Cr(VI) usage. MRL 10 is the stage at which manufacturing is in full rate production/deployment and is therefore where it is expected that Cr(VI) will be fully substituted under the relevant plan.

Recognising the SEAC's need for information which reflects the position of individual companies and their value chains, the substitution plans have been developed based on a granular analysis of the progression made by each OEM and DtB company supporting slurry coating in achieving substitution. As design owners, the 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 TRL9 and MRL10).

The data in **Figure 3-12** shows the expected progress of 24 distinct substitution plans for Cr(VI) in slurry coating, covering different plans across different members, and also multiple plans within individual members. These data have been aggregated to present the expected progress of the substitution of Cr(VI) from slurry coating for the ADCR consortium as a whole.

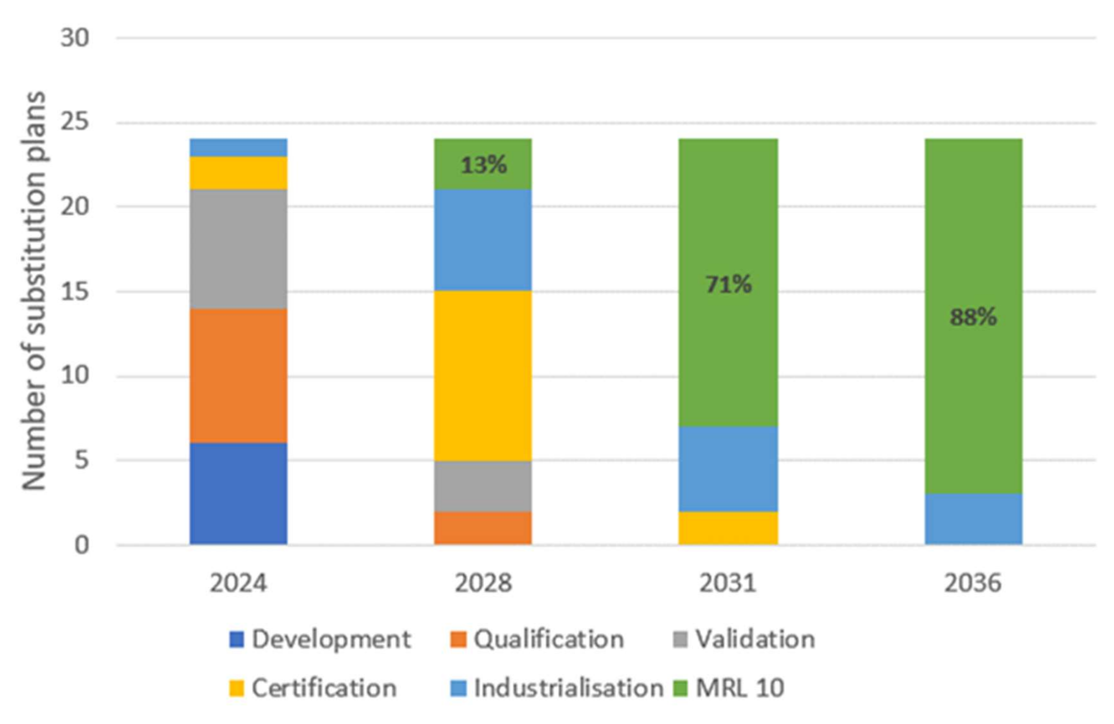


Figure 3-12: Expected progression of substitution plans for the use of Cr(VI) in slurry coating, by year.

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

Source: RPA analysis, ADCR members

The above summary shows:

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

The dates at which each substitution plan is expected to achieve each stage are estimates provided by the members based on each members' substitution plans, and there are uncertainties due to, for example, unexpected technical failures which may only reveal themselves at more advanced stages of testing (see description of TRL stages in Section 3.1.2). Consequently, the expected progress of substitution plans, especially in the outer years 2031 and 2036 where there is more uncertainty, may be slower (or faster) than estimated today, as presented in Figure 3-12. The actual status of the substitution plans 12 years from now could be different to our expectations today.

The potential need for more than 12 years has been identified by some OEMs due to their inability to identify any technically feasible alternatives to date. This is illustrated by the near equivalence between the number of substitution plans at the development phase in 2024, and the number where it is anticipated MRL 10 will not be reached by 2036. 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, as has been illustrated with those test candidates being progressed by other members, iterative re-formulations of a proposed candidate are not uncommon.

Each of these re-formulations results in the timeline for this substitution plan being reset. A proportion of those substitution plans which are not anticipated to progress to MRL 10 until 2036 or beyond are also impacted by the needs of MROs and MoDs for continued use in the maintenance and repair of in-service (legacy) final A&D products.

The timeframes associated with the activities presented in Figure 3-12 result from the requirements of the substitution process which are presented in section 3.1.2. To be noted also is that approval of suppliers cannot always occur in unison; qualification may need to cascade down the supply chain depending upon the number of tiers and actors involved. As resources are not available to action this simultaneously across all suppliers, the timescale for supplier qualification may be extended. Modifications may be required to the supply chain to allow for the installation of new equipment in some cases, although this can be mitigated by sourcing from existing established suppliers familiar with the requirements of qualification protocols.

3.7.3.1 Requested review period

It can be seen in Figure 3-12 that despite ongoing and concerted efforts of the members to develop alternatives to Cr(VI) in slurry coating, it has not proved possible to replace Cr(VI) by the end of the review periods granted in the parent Authorisations (which end in September 2024). It is clear from the chart that in 2031 (equivalent to seven years beyond the expiry date for the existing applications), while many substitution plans are expected to have successfully progressed to MRL 10 and the consortium is expected to have reduced its Cr(VI) use, an equally significant proportion of the substitution plans are not expected to have achieved MRL 10 and are expected to be predominantly at the industrialisation stages, with some substitution plans at earlier stages. For these substitution plans (which are from several member companies), there is still expected to be a need for the use of Cr(VI).

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

4 Continued Use Scenario

4.1 Introduction

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

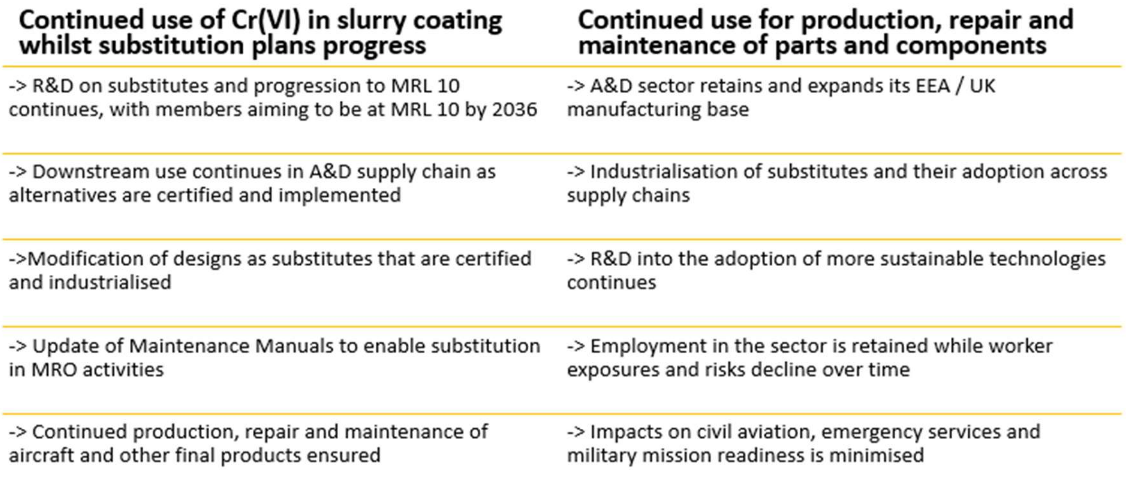
Until alternatives which are compatible also with pre- and post-treatment steps as relevant, and which deliver an equivalent level of functionality (as required), qualified, validated and certified for the production of individual components and products, use of the chromates in slurry coatings will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

In some cases, alternatives are technically qualified and certified, but time is needed to industrialise and implement them across all industrial sites in the value chain. Given the large numbers of BtP suppliers and MROs involved in the use of slurry coatings, implementation itself may take several years.

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 demonstrated by the substitution plan, MRL 10 is expected to be achieved in some cases by 2028, but in other cases is not expected to be reached until 2031 or 2036. Even in 2036, there are some cases where substitution plans are not expected to have reached MRL 10. As a result, the aerospace and defence industry and its supply chains require at least a further 12-years to complete substitution across all components and final products.

The Continued Use Scenario can be summarised as follows:



Continued use of Cr(VI) in slurry coating whilst substitution plans progress	Continued use for production, repair and maintenance of parts and components
-> R&D on substitutes and progression to MRL 10 continues, with members aiming to be at MRL 10 by 2036	-> A&D sector retains and expands its EEA / UK manufacturing base
-> Downstream use continues in A&D supply chain as alternatives are certified and implemented	-> Industrialisation of substitutes and their adoption across supply chains
->Modification of designs as substitutes that are certified and industrialised	-> R&D into the adoption of more sustainable technologies continues
-> Update of Maintenance Manuals to enable substitution in MRO activities	-> Employment in the sector is retained while worker exposures and risks decline over time
-> Continued production, repair and maintenance of aircraft and other final products ensured	-> Impacts on civil aviation, emergency services and military mission readiness is minimised

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

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

4.2 Market analysis of downstream uses

4.2.1 Introduction

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

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

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

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

4.2.2 Overview of the European aerospace and defence sector

In 2020, the European A&D industry was comprised of over 3,000 companies of all sizes and employed over 880,000 highly skilled employees (with these figures including the UK[29]). 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"[30]. Figure 4-1 provides details of turnover and employment for the industry in 2020, based on the A&D Industries Association of Europe (ASD) publication "2021 Facts & Figures".[31] These figures

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

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

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

are lower than the comparable figures for 2019, at around 405,000 jobs and €130 billion in revenues[32], leading to exports amounting to around €109 billion.

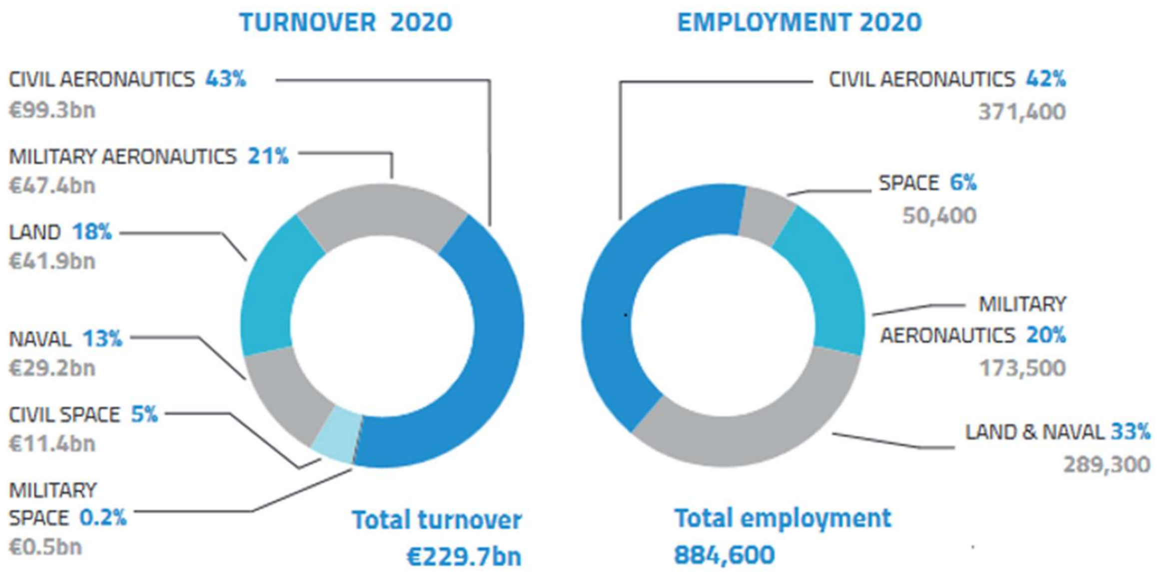

Figure 4-1: Turnover and Employment for the European A&D Industry in 2020 (snip taken from ASD, 2021)

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

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

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

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

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

- Aircraft and other products remain in services over long time periods. For example, the Boeing 747 first entered service in 1970, and continues to be flown and produced in 2022 (although it will now go out of production but remain in service). Given the need to ensure on-going airworthiness and due to certification requirements, there will continue to be a "legacy" demand for the use of chromates in the production of components for

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

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

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

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

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

4.2.3 Economic characteristics of companies undertaking slurry coatings

4.2.3.1 Profile of downstream users

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

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

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

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

SEA questionnaire responses were provided by 7 A&D companies undertaking slurry coating, with these companies operating across 11 sites in the EU and 10 sites in the UK.

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

Table 4–1: Numbers of SEA respondents undertaking slurry coating

Role (and total number of companies)	**Number of companies/sites undertaking slurry coating**				**Company Size[34]**	
	EEA		**UK**		**EEA**	**UK**
	Companies	**Sites**	**Companies**	**Sites**	**Companies**	**Companies**
Build-to-Print		1*	1	1		1 small
Design and build		1*		1*		
MRO only	3	6		1*	2 Large 1 Medium	
OEM	2	3	1	7	2 Large	1 Large
Total	5	11	2	10		
Note: Some of the OEMs members have sites in both the EU and UK. In total, 7 companies provided a response, but some reported for the purposes of both EU and UK REACH. There is therefore overlap in the number of companies but there is no overlap in the figures given for the number of sites. *These are assumed sites for the purpose of the calculations but have negligible outcome.						

4.2.3.2 Economic characteristics

Table 4–1 provides a summary of the number of companies identifying their activities against different NACE codes, which are used here to develop the economic characteristics of the "typical" OEM, DtB, BtP or MRO company. Companies may have indicated more than one NACE code as being relevant to their activities, with the result that the number of relevant NACE code counts is higher than the number of SEA responses relevant to slurry coatings alone. It is notable that most companies identified "treatment and coating of metals" as a relevant NACE code, while at the same time identifying other relevant codes.

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

Turnover is calculated as the weighted average by company size, as this is the most appropriate means of reflecting the level of turnover across the EEA (including UK) linked to slurry coatings and taking into account the size distribution of the companies[35] that are involved in such activities. GVA per employee, numbers of employees, and average personnel costs are given as the sector average and not per company size for several of the NACE codes, so it was not possible to calculate weighted averages for these. Note that the count total is by company and not by site.

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

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

Data on Gross Operating Surplus[36] (GOS) as a percentage of turnover (the GOS rate) is also used here to provide an indication of the profits associated with the turnover generated by these sites. This is based on a figure of 11% which is an average across the various NACE codes weighted by the number of companies declaring each NACE code.

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[36] EUROSTAT defines the GOS rate (i.e., % of turnover) as an indicator of profits. GOS equals gross output (turnover or gross premiums in Eurostat)) less the cost of intermediate goods and services to give gross value added, and less compensation of employees and taxes and subsidies on production and imports. It is gross because it makes no allowance for consumption of fixed capital (CFC).

Table 4–2: Economic characteristics of "typical" companies by NACE in sectors involved in Slurry coatings (2018 Eurostat data, covering the EU 28)

	Number of responses by NACE code	Weighted average turnover per company € million	GVA per employee €	Average personnel costs per employee €	Average GOS as a % of turnover
C2561 - Treatment and coating of metals	2	21	54,000	11	15.5%
C265 - Manufacture of instruments and appliances for measuring, testing and navigation;	1	159	84,000	35	4.80%
C2732 - Manufacture of other electronic and electric wires and cables	1	34	76,000	35	11.1%
C2815 - Manufacture of bearings, gears, gearing and driving elements	1	285	72,000	95	4.8%
C3030 - Manufacture of air and spacecraft and related machinery	3	1,215	98,000	209	7.9%
C3316 - Repair and maintenance of aircraft and spacecraft	4	71	85,000	20	9.8%
Total count	12	306	54,000	317	15.5%
Note: The count total is by number of NACE code identifications by company and not by sites, with 7 companies providing data					

Turnover is calculated as the weighted average by company size, as this is the most appropriate means of reflecting the level of turnover across the EEA (including UK) linked to the slurry coatings and taking into account the size distribution of the companies[37] that are involved in such activities. GVA per employee, numbers of employees, and average personnel costs are given as the sector average and not per company size for several of the NACE codes, so it was not possible to calculate weighted averages for these. Note that the count total is by company and not by site.

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

Data on Gross Operating Surplus[38] (GOS) as a percentage of turnover (the GOS rate) is also used here to provide an indication of the profits associated with the turnover generated by these sites. This is based on a figure of 11% which is an average across the various NACE codes weighted by the number of companies declaring each NACE code.

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[38] EUROSTAT defines the GOS rate (i.e., % of turnover) as an indicator of profits. GOS equals gross output (turnover or gross premiums in Eurostat)) less the cost of intermediate goods and services to give gross value added, and less compensation of employees and taxes and subsidies on production and imports. It is gross because it makes no allowance for consumption of fixed capital (CFC).

As can be seen from Table 4–3, the 52 sites for which data were collected via the SEA questionnaire represent an estimated €31 billion in turnover and €3 billion in GOS as a proxy for profits.

Table 4–3: Key turnover and profit data for market undertaking slurry coatings (based on 2018/2019 Eurostat data)

Sites covered by SEA responses/ Extrapolated number of sites	Estimated turnover based on weighted average € million	Gross operating surplus (estimate based on 11%) € million
11 EEA sites	4,266	469
10 UK sites	8,768	964
Extrapolation to all sites involved in slurry coatings in the EEA or UK		
32 EEA sites	20,679	2,275
20 UK sites	10,728	1,180
Source: Based on SEA questionnaire responses, combined with Eurostat data Note: See Section 2.3.3.6 for basis of extrapolation to the 52 sites in the EEA and UK combined		

4.2.3.3 Economic importance of slurry coatings to revenues

Slurry coatings will only account for a percentage of the calculated revenues, Gross Value Added (GVA) and jobs associated with the given in the above table. To understand its importance to the activities of individual companies, a series of questions were asked regarding other processes carried out, production costs, and the share of revenues generated from the use of chromates in slurry coatings.

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

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

Nevertheless, it is relevant to consider the extent to which the production costs at different companies and/or sites relate to these activities.

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

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

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

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

4.2.4.1 OEMs

The OEMs have carried out R&D into the substitution of the chromates for over 30 years. Further information on the R&D carried out by these companies is provided in section 3.4.

With respect to capital investments relating to slurry coatings, the following investments have taken place:

- Improvements in the slurry coatings line, personal protective equipment (PPE) and ventilation systems equating to €765,000.
- General R&D into chromates, costing more than €8 million over the last 5 years;
- Support engineering for new slurry coatings equipment implementation, at a cost of €4 million;
- Alignment of chromate replacement efforts across companies involved in a defence partnership together with the customers; and
- Investment in a new facility to the cost of €3.65 million.

4.2.4.2 Build-to-Print suppliers

One BtP supplier stated that they had not purchased capital equipment associated with the substitution of chromates. However, ever since 2018, investments have been made into chromate-using production processes. These investments had an original cost €5,000 per site.

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

4.2.4.3 MROs

The MROs have also undertaken significant investments into new equipment related to their use of the chromates, including for waste management and emissions reduction.

More generally, investments have included expenditure to both reduce worker exposures and/or environmental emissions and on R&D aimed at reducing or eliminating the use of the chromates. One of the three MROs of relevance to slurry coatings has spent roughly €40 million on such R&D to date.

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

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

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

4.3.1 End markets in civil aviation and defence

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

Because the use of chromium trioxide in slurry coating cannot be fully substituted at present, it plays a critical role in ensuring the reliability of aircraft and of safety standards. Thus, although the economic importance of chromium trioxide in slurry coating is indirect in nature, its significance is clear with respect to:

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

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

The military importance ensuring that military aircraft, land and naval hardware maintain their mission readiness cannot be quantified in the same manner, however, the involvement of MoDs in supporting this combined AoA/SEA through the provision of information demonstrates the critical nature of slurry coating to on-going mission readiness. In particular, the continued use of slurry coating as part of MRO activities is relevant to military organisations located in the EEA (multiple countries) and UK, as well as to companies servicing them.

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

4.4.1 Civilian aircraft

Demand for new civilian aircraft is expected to grow into the future. Projected global compound annual growth rates (CAGR) for different aircraft classes for the period 2020-2031 are given in the figure below[39], with this suggesting CAGR from 2020 to 2031 of around 2.5%.

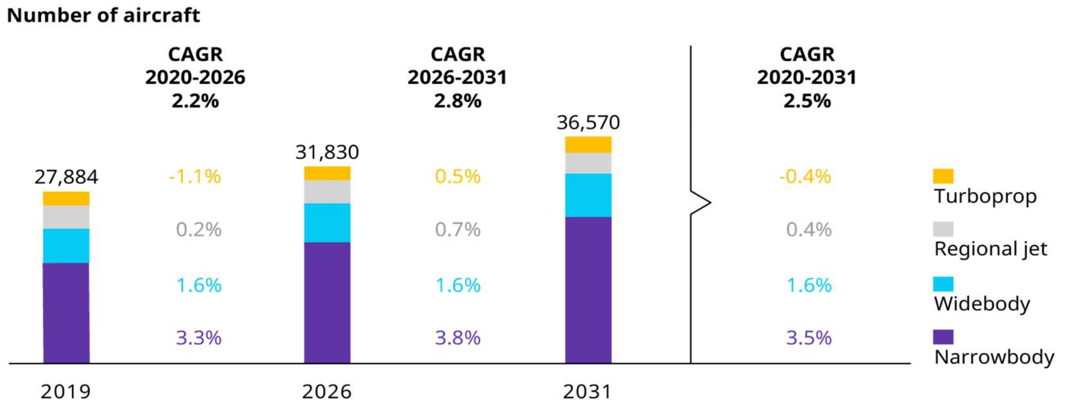

Figure 4–2: Global fleet forecast by aircraft class, 2020-2031
***Source:* Oliver Wyman analysis**

Market reports issued by Airbus and Boeing indicate that future growth is expected to extend beyond 2031. Airbus' Global Market Forecast for 2022-2041 predicts that passenger air traffic will grow at 3.6% CAGR and freight traffic will grow at 3.2% CAGR globally. By 2041, there will be some 46,900 aircraft in service, with this including an estimated 39,500 new passenger and freighter aircraft (and the retirement of some of the older aircraft. This includes delivery of new aircraft for the European market, as well as the Asian and Chinese markets.[40]

Boeing's 2022 Commercial Market Outlook[41] indicates a similar level of increase, noting that the global fleet will increase by around 80% through to 2041 with the forecast value of new airplane deliveries at around US $7.2 trillion (based on a slightly higher growth in traffic at around 3.8% CAGR).

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

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

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

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

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

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

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

When considering these figures, it is important to recognise that the European aerospace sector is a global exporter of aircraft, and A&D products make a significant contribution to the overall balance of trade. For example, France and Germany alone had export markets totalling over US$ 57 billion (€50.4 billion, £44.3 billion) in 2020, while the UK export market was around US$13.2 billion (€11.7 billion, £10.3 billion) in 2020.[42]

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

4.4.2 The MRO market

Not only would the manufacture of new aircraft in the EEA and UK be impacted, but anticipated growth in the aftermarket parts segment would also be affected. The aircraft spare components and final products market encompasses the market for both new and used rotable[43] components available as spares for aircraft and other products. This market was projected to grow with a CAGR of over 4% over the period from 2022-2027, although this rate may now be lower due to COVID-19. Projected 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 5 to 10

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

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

years. Globally, the market is expected to have a CAGR of over 3% over the period from 2022-2027, as illustrated in the figure 4-3 below.[44, 45]

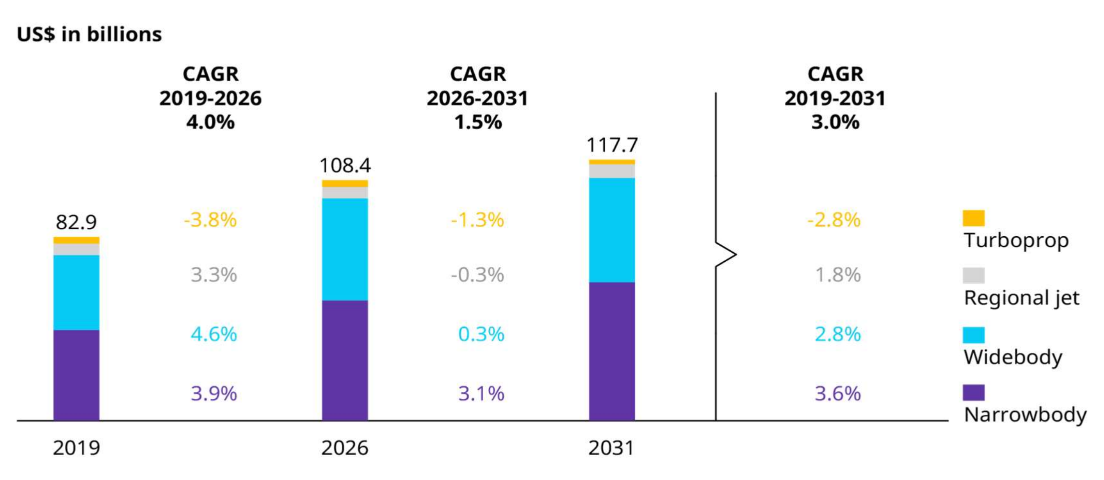

Figure 4–3: MRO market forecast by aircraft class, 2019-2031
Source: Oliver Wyman analysis

This growth is due to three factors:

- 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;
- Airlines face very stringent MRO requirements so are not able to postpone MRO requirements; and
- Increases in fleet sizes over the next 5 years will also lead to a continued growth in demand for maintenance and repair activities.

4.4.3 The defence market

The war in Ukraine has led to several EEA countries and the UK to revisit their defence expenditure. In particular, several countries that are NATO members and which previously did not meet the target of spending 2% of GDP on defence are now committed to meeting that target. This compares to Eurostat figures for total general government expenditure on defence in 202 of around 1.3% of GDP for the EU[46]. The increase in investment will equate to hundreds of billions of Euros (e.g., Germany alone has pledged €100 billion in defence spending).

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

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

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

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

of 3% of GDP by 2030[47]. This equates to an increase in spending of around £157 billion between 2022 and 2030.

Such investment, which will include new spending on existing technologies, may also result in a continued reliance on the use of the chromates for slurry coatings 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%.[48]

4.5 Annual tonnages of the chromates used

4.5.1 Consultation for the CSR

As part of preparation of the CSR, site discussions were held with ADCR members and some of their key suppliers. This work included collection of data on the tonnages of the different chromates used per site. The tonnages assumed in the CSR range from 0.2 to 67kg per site per annum of chromium trioxide resulting in up to 35kg Cr(VI) per site per annum.

4.5.2 Consultation for the SEA

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

Based upon data collected from the SEA questionnaire, the CSR and article 66 notifications it is estimated that 3.5 tonnes per annum of chromium trioxide is used in the EEA for slurry coatings, and 3 tonnes per annum in the UK.

4.5.3 Article 66 notifications data

Under Article 66 of REACH, downstream users covered by an authorisation up their supply chain must notify ECHA of their use. As of 31 December 2021, ECHA had received 282 notifications relating to the REACH authorisations covering 404 sites across the EU-27 (and Norway).

A key difficulty in using the Article 66 data is that reporting is based on tonnage bands rather than actual tonnage information. It is therefore difficult to derive estimates of annual tonnages based on this information, especially as actual tonnages used at individual sites which are making notifications may be significantly lower than the upper limit for each of the tonnage bands. In addition, the

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

[48] 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

notifications data covers multiple treatments and hence its use for slurry coatings alone would be misleading.

The distribution of notifications by substance and authorisation is summarised in Table 4–6 below[49].

Table 4–6: Article 66 Notifications to ECHA

Substance	Authorisation	Authorised Use	Notifications	Sites
Chromium trioxide	20/18/14-20	Surface Treatment for aerospace	263	357
	19/29/0	Conversion Coating & Slurry coatings for aerospace	19	47
		Totals	**282**	**404**

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

Since there are more sites than notifications, it is assumed that some notifications cover more than one site.

4.5.4 Projected future use of the chromates

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

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

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

Two of the OEMs already carry out slurry coatings using non-chromate-based alternatives, where these are technically feasible under current certification.

In terms of expected future usage, the single BtP company within this SEA questionnaire either did not answer or did not know how their usage of chromates was likely to change between 2022 and 2030 (and beyond). It should be noted that BtP suppliers will often have no knowledge of their customers R&D or substitution plans. As a result, one would expect that their consumption of chromates in slurry coatings will decrease at the same rate as for the OEMs and DtBs.

Three MROs (covering multiple sites) did not state whether they had been impacted by COVID-19, in terms of annual consumption rates, or whether they expected consumption to return to normal.

With regard to future trends, one of the MROs indicated that they expected chromate consumption to decrease steadily until it's use was phased out after 2036. Two stated that they expected consumption to remain steady, as it was customer driven and there was a lag between certification of

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

alternatives and the updating of Maintenance Manuals. The fifth company expected consumption to increase (as well as turnover) with the need to service increasing fleet sizes (in part due to the increase in contracts won by this MRO).

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

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

- "*Products in the aviation industry are designed, manufactured and maintained for use phases of several decades. In terms of civil aircrafts, such a use phase typically comprises 30-40 years. Even if new products - placed on the market in the short to medium term - might succeed in dispensing with the use of CrO3 or Cr(VI) containing products; products already placed on the market (or until the expiration of the current review periods) still need to be maintained and repaired by applying binding maintenance specifications (which the user is legally obliged to comply with). These specification entail - among others - processes and materials initially qualified (sometimes decades ago), which form a substantial part of the type certification.*";

- *"Such a long review period is required to allow sufficient time to develop alternatives to CT in slurry coatings and to test them before qualification, certification and implementation.";* and

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

The companies acting as design owners (OEMs and DtB) indicated that they expect on-going reductions in consumption of CT and purposes over the period from 2024 and 2031/2, with all expecting to cease usage by 2036 subject to successful industrialisation throughout their supply chains. It is important to note that this gradual phase-out in usage will also impact on use by DtBs not acting as design owners, BtPs and MROs.

Industrial implementation will usually follow a stepwise approach to minimise technical risks and benefit from lessons learned. This implies that the replacement is not implemented simultaneously in all plants and at all suppliers.

4.6 Risks associated with continued use

4.6.1 Classifications and exposure scenarios

4.6.1.1 Human health classifications

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

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

The hazard evaluation follows recommendations given by RAC [50]:

- 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.

4.6.1.2 Overview of exposure scenarios

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

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

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

- Spray operators;
- Maintenance and/or cleaning workers; and
- Incidentally exposed workers.

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

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

ES number	ES number	ES number
ES1-IW1	Slurry coatings - use at industrial site	
Environmental contributing scenario(s)		
ECS 1	Slurry coatings - use at industrial site leading to inclusion into/onto article	ERC 5
Worker contributing scenario(s)		
WCS 1	Spray operators	PROC 5, PROC 7, PROC 8a, PROC 8b, PROC 9, PROC 10, PROC 28

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

Table 4-7: Overview of exposure scenarios and their contributing scenarios		
ES number	**ES number**	**ES number**
WCS 2	Maintenance and/or cleaning workers	PROC 28
WCS 3	Incidentally exposed workers	PROC 0
Exposure scenario for industrial end use at site: ES1-IW1		

4.6.2 Exposure and risk levels

The CSR provides details of the approach and assumptions underlying calculation of exposures and risks from the use of the chromates in slurry coatings. The calculated exposure levels and associated excess cancer risks are presented below. For further information on their derivation see the CSR.

4.6.2.1 Worker assessment

Excess lifetime cancer risks

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

- WCS1: Spray operators for slurry coatings using CT are usually involved in numerous activities related to the painting process. Most of their working time is spent in a paint area where the spray booths are located and where the painting processes, including preparatory work (e.g., sand blasting and masking) and post-treatments such as curation of components, take place. Activities in the area comprise tasks with direct or without direct Cr(VI) exposure;

- WCS2: Maintenance and/or cleaning workers typical activities include infrequent repairs of equipment as well as maintenance of LEV system (filter change) and cleaning of spray booth related to the use with potential direct exposure to Cr(VI) are described below in Table 4-8 detail together with the working conditions. They are supported by worker air monitoring data covering maintenance activities, if available. In brief summary, internal maintenance workers perform infrequent repair activities in the paint area when defects occur. External maintenance/cleaning workers usually clean the spray booths and maintain the installed LEV systems which also includes filter changing; and

- WCS3: Incidentally exposed workers do not carry out tasks with direct Cr(VI) exposure potential themselves but may incidentally be exposed from such activities due to inhalation background exposure in the work area. Due to the organisation of sites and achieving an efficient work process, incidentally exposed workers must perform their tasks in the paint area, as these are necessary activities related to either slurry coatings or to other processes carried out in the paint area and cannot be located to other areas at the sites.

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

Table 4-8: Excess lifetime cancer risk by SEG

#	SEG	Average number of workers per site	Excess lifetime lung cancer risk [1/υg/m^3]
WCS1	Spray operators	5	1.99E-03
WCS2	Maintenance and/or cleaning workers	3	1.22E-04
WCS3	Inicidentally exposed workers	2	3.28E-04

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

4.7 Humans via the environment

Excess lifetime cancer risks

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

The assessment presented in the CSR is based on measured data for emission to air and wastewater. For this assessment combined exposure of humans via the inhalation (air) and the oral (uptake of water and fish) route is considered. Data were available from 11 sites undertaking slurry coatings to act as the basis for estimating exposure concentrations and associated risks. The resulting 90th percentile risk estimates are presented in the table below.

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

Inhalation		Oral		Combined
Local Cr(VI) PEC in air [µg/m3]	**Inhalation risk**	**Oral exposure [µg Cr(VI)/kg x d]**	**Oral risk**	**Combined risk**
1.45E-04	4.20E-06	8.19E-06	6.55E-09	4.21E-06

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

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

4.7.1 Populations at risk

4.7.1.1 Worker assessment

Numbers of workers exposed based on Article 66 data

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

Taking a simple total of the figures for the number of staff exposed would result in an over-estimate given that some of the Authorisations cover multiple types of surface treatment. These suggest that around 1,600 staff across the EU are covered by Article 66 notifications are exposed during slurry coatings activities.

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

No similar data are publicly available for the UK.

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

Substance	Authorisation number	Use(s)	Staff Exposed
Chromium trioxide	REACH/19/29/0	Slurry coatings and chemical conversion coating	461
	REACH/20/18/14 to REACH/20/18/20	Slurry coatings, passivation of non-Al metallic coatings, Passivation of stainless steel, chemical conversion coating and anodising and anodise sealing	1107

Number of workers based on SEA questionnaire data

Responses to the SEA questionnaire indicated that 110 workers (full time equivalent) are directly involved in slurry coatings across the 21 sites for which data were provided. This is broken down in Table 4–11 below by role in the supply chain, and as extrapolated out to the 32 EU and 20 UK sites.

Table 4–11: Employees linked to slurry coatings activities across all EEA and UK sites					
Number of workers at sites	**Number of sites EEA**	**Number of sites UK**	**No of employees EEA**	**No of employees UK**	**Total employees**
Number of workers 21 sites involved in slurry coatings					
Build-to-Print	1	1	3	3	6
Design-to-build*	1	1	3	3	6
MRO only	6	1	45	8	53
OEM	3	7	5	55	60
Total 21 sites	**11**	**10**	**53**	**58**	**111**
Number of workers at 32 EEA sites and 20 UK sites involved in slurry coatings					
Build-to-Print	1	3	3	9	12
Design-to-build	3	3	9	9	18
MRO only	12	6	90	45	135
OEM	16	8	27	63	90
Total 52 sites	**32**	**20**	**129**	**126**	**255**
Note: No Design-to-Build companies provided a response to the SEA questionnaire, an estimation has been made based on responses from other companies.					

In total, this translates to a potential 130 exposed workers across the 32 EEA sites and 130 across the 20 UK sites, or between 5 to 7 per site. These figures are lower than the CSR assumptions on the number of workers exposed but are consistent with the Article 66 notifications if it is assumed that these workers may also undertake other chromate-based surface treatments.

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

Table 4–12: Number of employees undertaking slurry coatings across the EU and UK				
Worker Contributing Scenarios		**Average No. Exposed from CSR**	**EU sites**	**UK sites**
WCS1	Spray operators	5	160	100
WCS2	Maintenance and/or cleaning workers	3	96	60
WCS3	Incidentally exposed workers	2	64	40
Total		**10**	**320**	**200**

4.7.1.2 Humans via the Environment

Exposed Local Populations

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

- Number of downstream user sites in total and then as assumed in terms of their distribution across the EEA/UK.
- The population density per km^2 for each relevant EEA country and the UK; and

- 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 and are only higher for one of the eleven slurry coating sites used as the basis for the CSR; in these cases, inhalation risks were lower than average. As a result, adopting the EUSES default assumption related to the capacity of local sewage treatment plants would over-estimate the number of inhabitants that may be exposed due to emissions from each site.

The resulting estimates of the number of people exposed within the general population are given in Table 4–13 for the EEA and UK. The allocation of sites is based on information collected from the SEA questionnaires and from ADCR members on the location of their supply chains. The estimated total number of humans exposed via the environment in the EEA is around 20,500, with the UK figure being under 27,000 (with the UK figure appearing disproportionately high due to its high population density).

Table 4–13: General public (local assessment) exposed population from slurry coatings

Countries with DUs	No. Sites per country	Population density per km^2	Exposed local population within 1000m radius
France	7	118	2595
Germany	7	232	5102
Italy	4	200	2513
Spain	2	92	578
Poland	7	123	2705
Sweden	1	23	72
Netherlands	1	421	1323
Romania	1	82	258
Ireland	1	69	217
Malta	1	1633	5130
Total EEA	**32**		**20,492**
UK	**20**	**424**	**26,641**

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

4.7.2 Residual health risks

4.7.2.1 Introduction

Under the Applied-for-Use Scenario, use of chromates in slurry coatings will continue after the end of the Review Period for a total of 12 years.

In December 2013, the Risk Assessment Committee (RAC) agreed lifetime (i.e., for 40 years and 70 years of exposure) mortality risk estimates associated with carcinogenicity for workers and humans via the environment exposed to Cr(VI) substances[51]. 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.

4.7.2.2 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[52] cancer cases were derived from the Cancer Today database, see Table 4-14 below.

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

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

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

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

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

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

In a similar fashion, the figures from Cancer Today reported in Table 4-14 above are applied to the estimates to calculate the total number of additional fatal and non-fatal intestinal cancer cases[53].

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

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[51] 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).

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

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

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

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

4.7.3 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 4-9). These risk estimates reflect the additional safety measures that have been implemented due to the conditions placed on continued use by the initial authorisations. The number of excess cancer cases is calculated by multiplying the number of workers assumed to be exposed in each task by the value of the excess cancer risk given above adjusted for the requested review periods, i.e., over 12 years. This value is then multiplied by the number of workers exposed in each WCS to calculate the total excess cancer cases arising from the continued use of chromates in slurry coatings. Table 4-15 and Table 4-16 provide a summary of the results across all WCS for EEA and UK workers.

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

WCS	Number of persons exposed	LUNG CANCER - Excess lifetime cancer risk	Excess number of lifetime cancer cases	LUNG CANCER - Number of excess lifetime fatal cancer cases	LUNG CANCER - Number of excess lifetime non-fatal cancer cases
WCS1	160	1.99E-03	**0.32**	**0.25**	**0.07**
WCS2	96	1.22E-04	**0.01**	**0.01**	**0.00**
WCS3	64	3.28E-04	**0.02**	**0.02**	**0.00**
		Years - Lifetime	**40.00**	**0.28**	**0.07**
		Years - Review period	**12.00**	**0.08**	**0.02**
		Years - Annual	**1.00**	**0.01**	**0.002**

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

WCS	Number of persons exposed	LUNG CANCER - Excess lifetime cancer risk	Excess number of lifetime cancer cases	LUNG CANCER - Number of excess lifetime fatal cancer cases	LUNG CANCER - Number of excess lifetime non-fatal cancer cases
WCS1	100	1.99E-03	**0.20**	**0.16**	**0.04**
WCS2	60	1.22E-04	**0.01**	**0.01**	**0.00**
WCS3	40	3.28E-04	**0.01**	**0.01**	**0.00**
		Years - Lifetime	**40.00**	**0.17**	**0.05**
		Years - Review period	**12.00**	**0.05**	**0.01**
		Years - Annual	**1.00**	**0.004**	**0.001**

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

The total number of people exposed as humans via the environment as given in Table 4-10 is multiplied by the excess cancer risk estimates to calculate the total excess cancer cases arising under the Continued Use scenario. The results are given in Table 4–17. The basis for estimating the number of people exposed per country is the percentages of Article 66 notifications made to ECHA per country, as described in Section 4.2.

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

Countries with DUs	No. Sites per country	Population Density per km2	Exposed local population	Combined excess lifetime cancer risk	Excess number of lifetime cancer cases	Number of excess lifetime fatal cancer cases	Number of excess lifetime non-fatal cancer cases
France	7	118	2595	4.21E-06	1.09E-02	**0.01**	**0.00**
Germany	7	232	5102	4.21E-06	2.15E-02	**0.02**	**0.00**
Italy	4	200	2513	4.21E-06	1.06E-02	**0.01**	**0.00**
Spain	2	92	578	4.21E-06	2.43E-03	**0.00**	**0.00**
Poland	7	123	2705	4.21E-06	1.14E-02	**0.01**	**0.00**
Sweden	1	23	72	4.21E-06	3.04E-04	**0.00**	**0.00**
The Netherlands	1	421	1323	4.21E-06	5.57E-03	**0.00**	**0.00**
Romania	1	82	258	4.21E-06	1.08E-03	**0.00**	**0.00**
Ireland	1	69	217	4.21E-06	9.13E-04	**0.00**	**0.00**
Malta	1	1633	5130	4.21E-06	2.16E-02	**0.02**	**0.00**
Total	**32**		**20492**	**4.21E-06**	**8.63E-02**	**0.07**	**0.02**
			Years – Lifetime cases		**70.00**	**0.07**	**0.02**
			Years - Review period		**12.00**	**0.01**	**0.00**
			Years - Annual		**1.00**	**0.001**	**0.0003**
UK	**20**	**424**	**26641**	**4.21E-06**	**1.12E-01**	**0.09**	**0.02**
					70.00	**0.09**	**0.02**
					12.00	**0.02**	**0.00**
					1.00	**0.001**	**0.0003**

4.7.5 Economic valuation of residual health risks

4.7.5.1 Economic cost estimates

In order to monetise human health impacts, a timeframe that goes from 2024 (inclusive of the end of 2024) to the end of 2036 (i.e., a 12-year review period) has been adopted and a 4% discount rate has been employed for calculating net present values[54]. It has been assumed that the levels of exposure to Cr(VI) for workers and members of the general population remains constant throughout the length of the review period, even though this is a very conservative assumption. In fact, downstream users will gradually reduce the amount of Cr(VI) consumed as the transition to the alternative (CFPA) 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[55] 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[56]. The values used are:

- Value of statistical life for the avoidance of a death by cancer: €3.5 million (2012 prices); and
- Value of cancer morbidity: €0.41 million (2012 prices).

It is appropriate to update these two figures to 2021 prices (updated to second and third quarter values of 2021, more recent data are not available). This has been achieved by use of the Eurostat EU GDP deflator[57]. This suggests that the aforementioned figures should be multiplied by a factor of 1.12. Thus, the following values are employed in the analysis below:

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

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

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

[55] 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.

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

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

Table 4-18: Alternative estimates of medical treatment costs

Study	Year for prices	Average direct costs in original units (per annum)	Direct costs in € 2021
Lung cancer[58]			
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)[59]			
Luo et al (2010)	2000 (assumed)	US$29,196	€36,230
Lang et al (2009)	2006	US$28,626	€31,740
York Health Economics Consortium (2007)	2004	£8,808	€12,180
York Health Economics Consortium (2007)	2004	£12,037	€16,410

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

These average medical costs are annual figures and apply to survivors over the period of time that they continue to be treated. With respect to lung cancer morbidity cases, we have taken a percentage survival of 32% after 1 year since diagnosis, 10% after 5 years, 5% after 10 years[60]. With respect to intestinal cancer morbidity cases, we have taken a percentage survival of 76% after 1 year since diagnosis, 59% after 5 years, 57% after 10 years. Based on these time periods, the net present value (NPV) of average future medical costs per lung cancer case is estimated at €30,110 in 2021 prices, using a 4% future discount rate. The NPV of average future medical costs per intestinal cancer case is estimated at €82,620 in 2021 prices. It is noted that a large percentage of people survive intestinal cancer after a period of 10 years and any stream of health care costs incurring after that is not incorporated in our calculations. However, such costs are not likely to be relevant considering that those surviving after such a long period of time can either be considered as definitely cured or probably only in need of a small degree of medical attention.

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

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

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[58] 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.

[59] 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.

[60] 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.

(4) (δ × (€ 3,920,000)) + (η × (€ 460,000 + €84,790)) = Total intestinal cancer costs

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

Table 4-19 applies the economic value of the associated health impacts to these additional statistical cases of cancer to generate the total economic damage costs of the excess lung cancer cases. Under the Continued Use scenario, the present value costs are €121,400 for the EEA and €75,900 for the UK, based on the assumption that chromate-based slurry coatings continue at the current level of use over the entire review period; this will lead to an overestimate of the impacts as the sector transitions to the alternatives over the 12-year period.

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

	EU Workers		UK Workers	
	Mortality	Morbidity	Mortality	Morbidity
Total number of lung cancer cases	8.32E-02	2.21E-02	5.20E-02	1.38E-02
Annual number of lung cancer cases	6.93E-03	1.84E-03	4.33E-03	1.15E-03
Present Value (PV, 2024)	€ 117,745	€ 3,673	€ 73,591	€ 2,296
Total PV costs	**€ 121,418**		**€ 75,886**	
Total annualised cost	**€ 28,030**		**€ 17,519**	

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

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

Table 4-20 applies the economic value of the associated health impacts to the additional statistical cases of cancer for the general population (humans via the environment) to generate the total economic damage costs of the excess cancer cases. Under the Continued Use scenario, the present value costs are roughly €17,100 for the EEA and €22,200 for the UK, based on the assumption that slurry coatings continues over the entire review period at 2024 tonnages; as indicated above, this reflects an overestimate of the levels of exposures as use declines with a transition to the alternatives over the 12-year period.

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

	EU General Population		UK General Population	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cancer cases	1.17E-02	4.04E-03	1.52E-02	4.04E-03
Annual number of cancer cases	9.74E-04	2.59E-04	1.27E-03	3.36E-04
Present Value (PV, 2024)	€ 16,533	€ 563	€ 21,493	€ 732
Total PV costs	**€ 17,096**		**€ 22,225**	
Total annualised cost	**€ 3,947**		**€ 5,131**	

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

4.7.8 Human health impacts for workers at customers sites

Slurry coatings with chromates results in no hexavalent chromium being present on the end components or products. The machining of surfaces for either production or repair activities following slurry coating by workers in the A&D sector has been accounted for in the worker estimates presented in Table 4-15 above.

4.7.9 Environmental impacts

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

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

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

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

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

4.7.10 Summary of human health impacts

Table 4-21 provides a summary of the economic value of the human health impacts across the worker and local populations. When considering these figures, it should be remembered that they relate to use of the chromates in slurry coatings activities across the sector at an estimated 32 EEA sites and 20 UK sites covered by this combined AoA/SEA.

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

	EEA		UK	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cancer cases	0.09	0.03	0.07	0.02
Annual number of cancer cases	0.01	0.00	0.01	0.00
Present Value (PV, 2024)	€ 134,277	€ 4,236	€ 95,083	€ 3,028
Total PV costs	**€ 138,514**		**€ 98,111**	
Total annualised cost	**€ 31,977**		**€ 22,650**	

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

5 Socio-Economic Analysis of Non-Use

5.1 The Non-Use Scenario

5.1.1 Summary of consequences of non-use

The inability of companies to undertake slurry coatings activities across the EEA and in the UK using chromium trioxide would be severe. This use is critical to corrosion protection, heat resistance and the other key functionality across a broad range of components and assemblies. This includes application to newly produced components and for ensuring on-going corrosion protection, and other beneficial properties, following maintenance and repair activities.

If slurry coatings was no longer authorised and where qualified and certified alternatives are not available, Design Owners (i.e., OEMs and DtB companies) would be forced to re-locate some or all of their component production, aircraft manufacturing and maintenance activities out of the EEA or UK.

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

↓

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

↓

OEMs would shift manufacturing outside the EEA/UK due to the need for slurry coatings to be carried out in sequence with other treatments. It would be inefficient and costly to transport components and products outside the EEA/UK for chemical conversion coating only (and especially so for touch-up repairs)

↓

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

↓

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

↓

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

↓

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

↓

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

↓

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

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

5.1.2 Identification of plausible non-use scenarios

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

These discussions acted as the basis for a series of questions in the SEA questionnaire aimed at pulling out information on the role of different types of companies, how these impacts on why they use chromates in slurry coatings, 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.

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

Table 5-1 below presents the choices presented in the SEA questionnaire and a count of the number of companies selecting each (7 companies in total provided responses, covering the 52 sites).

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

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

Table 5-1: Company responses to SEA survey on most likely non-use scenarios				
	OEM	Build-to-Print only	Design-to-build only	MROs – only
The decision is up to our customer			N/A	
We may have to cease all operations as the company will no longer be viable	1		N/A	1
We will focus on other aerospace uses or on non-A&D uses			N/A	
We will shift our work outside the EEA/UK	1		N/A	1
We will stop undertaking use of the chromate(s) until we have certified alternative	1	1	N/A	1
Number of responses (companies)	3	1	N/A	3

5.1.2.1 OEMs

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

With respect to the plausibility of the different non-use scenarios identified above, the following are clear from consultation with the OEMs across the 10 sites for which data was provided in the SEA questionnaire responses:

- **We will shift our work involving Chromates to another country outside the EEA.** This is the most plausible scenario for one of the OEMs directly involved in slurry coatings. Given the reliance on the use of chromate-based slurry coatings in supply chains, it is also the most likely response for those OEMs companies who rely on suppliers carrying out slurry coatings. This would be accompanied by losses in turnover of an average of 75% as reported by the OEMs. The ability of one of these OEMs to shift its manufacturing relevant to slurry coatings outside the EEA/UK may be restricted, however, as it manufactures final products for the defence sector;

- **We will stop using the chromates until we have certified alternatives:** It is clear that in most cases substitution activities and especially the industrialisation phase of moving to alternatives will not be completed for at least four years and for a significant number of parts/products for 12 years (or even longer). One of the OEMs indicated that this would be their most plausible scenario. For the other OEMs identifying this as the most plausible scenario, losses in turnover would be between 30 - 50%. For the other companies, the potential duration of such a production stoppage would not be economically feasible; and

- **We may have to cease all operations as the Company will no longer be viable.** If shifting work to countries outside the EEA/UK is unacceptable due to the costs or timeframe involved in setting up the required manufacturing sites and supporting infrastructure, a cessation of all operations may be the ultimate outcome for some of the OEMs or divisions of them. It is important to note that this scenario translates to a cessation of aircraft production within the

EEA/UK, with consequent reductions in revenues from aircraft assembly operations; the loss of this turnover would result in other operations (R&D, Engineering, Sales, etc.) also becoming non-viable with the final outcoming being a shut-down of all activities. It is not technically nor economically feasible for A&D OEMs 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. As a result, this is not a plausible option for any of the companies.

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

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

5.1.2.2 Build-to-Print

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

Once an alternative is qualified, validated and certified for use in the production of components by their customers, they would therefore be able to work with them to adapt to new production requirements. Respondents noted that their priority is to help find a substitution solution,

Estimates for turnover losses were provided by the sole build to print company, from 10 – 25% annual turnover lost from a refused Authorisation and affected activities.

5.1.2.3 MROs

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

When components enter under the services of an MRO, the required maintenance effort, including which surface treatment processes may be required, is not directly foreseeable. Very often, the level of work required only becomes clear after disassembling the component. The surface treatment steps required for any given component is dependent on its condition and can differ for each maintenance event. As a result, not every component will pass through all potential surface treatment processes. Even when they do, levels of throughput are also dependent on the size and complexity of the component - processing times can range from 5 minutes to several days. Within these process flows, even if slurry coatings are only required to a very limited extent, it may remain essential as part of maintenance and repairs carried out to ensure that airworthiness regulations are met.

The inability to undertake slurry coatings to the requirements 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 substances and mixtures for slurry coatings. Where these requirements mandate the use of chromium trioxide, the MRO must use the chromate as instructed unless the manuals also list a qualified alternative.

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

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

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

As noted by one of the MROs:

> "*Without use of the chromates, the entire repair process of part had to be subcontracted. The disassembly and assembly processes without part repairs would not be viable."*.

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[61], MoDs and the European Space Agency (ESA), or from an engineering perspective taking airworthiness safety requirements into consideration.

As noted in the parent application for Authorisation, the scenario of moving to a poorer performing alternative would mean that OEMs would not accept an alternative that is less efficacious in delivering corrosion protection where no alternative provides an equivalent level of performance to the chromates. The use of a less effective alternative would downgrade the performance of the final product, and the reduction in the functional performance of the alternative would give rise to several unacceptable risks/impacts:

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

In an inadequately performing surface treatment, corrosion pits can form. These can turn into fatigue cracks which potentially endanger the whole final product. 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 coatings would necessitate shorter inspection, maintenance and repair intervals to prevent failures, and flight safety obligations preclude the aerospace industry from introducing inferior alternatives on components.

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

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

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

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[61] 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.

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

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

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

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

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

Overseas production followed by maintaining EEA/UK inventories

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

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

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

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

- The costs of building adequate warehouse facilities in the EEA and the UK would be prohibitive and would not be economically feasible. In the UK, an industrial warehouse without climate control (which would be required for the storage of some A&D inventory) costs around €1000 per m^2 to construct (a conservative estimate). It is assumed that warehouses that would act as a hub for storing inventory would be around 10,000 m2 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.[62] If such facilities are required at around 100 sites across the EEA and UK (to cover civilian and military requirements for storage of passivated and other components affected by a refused authorisation), then warehousing costs alone would lead to €1 billion in expenditure. These costs would be on top of the losses in profits that would occur from the need to subcontract manufacture to companies located outside the EEA/UK and the consequent profit losses and increased costs of shipping, etc.;

- Facilities do not have enough production capacity to build up multi-year inventories, while also meeting current demand. Even if production capacities could be increased and adequate quantities of standard components be produced, there would be idle inventories for years beyond their need, which would in turn increase product costs for years. Importantly, the need to store this inventory under optimum conditions to avoid corrosion or damage over extended periods of stockpiling, would lead to further increases in costs. Also building up inventories prior to authorisation expiry runs counter to the objectives since it will force more exposures that will otherwise happen if producing to order under an authorisation (less volume likely overall);

- 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

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

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 a non-EEA country for repair. If the plane is not airworthy, the effort and cost relating to transportation alone (e.g., from Belgium to Egypt) would be overwhelming;

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

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

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

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

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

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

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

5.1.4 Conclusion on the most likely non-use scenario

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

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

1. OEMs directly involved in slurry coatings would move a significant proportion of their manufacturing operations outside the EEA/UK, with the consequent loss of significant levels of turnover and employment. In particular, they would move manufacturing activities which are reliant on the use of slurry coatings where there is: a) no qualified alternative; or b) where after qualification and certification have been achieved implementation across suppliers is expected to require several years after the end of the current review period. The losses to the EEA/UK would range from around 30% - 50% of manufacturing turnover for some sites, rising to 65% - 100% of manufacturing turnover at others. On average it is assumed losses at affected sites would be around 75% of manufacturing turnover, with associated losses in jobs.

2. OEMs who do not carry out slurry coatings themselves may still move some of their manufacturing operations outside the EEA/UK due to the desire to have certain treatment and production activities co-located within a region (i.e., to form clusters). This would facilitate the integration of manufacturing activities and associated maintenance and repair activities. As a result, there would be losses in turnover and employment associated with these companies also relocating.

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

4. In some cases, these newly located supply chains would be developed using DtB (and BtP – see below) suppliers who have moved operations from the EEA/UK to their countries in order to continue supplying the OEMs. Those DtBs that undertake surface treatments for sectors other than A&D, and also using non-chromate-based alternatives where these are certified, are less likely to cease activities in the EEA/UK and hence as a group would be associated with a reduced level of profit losses. Overall, for the DtB companies, it has been assumed that turnover losses of around 50% would be realised based on the SEA data and discussions with key design owners. It must be recognised that this level of turnover loss implies that some companies losing a high percentage of turnover would still be able to cover their fixed costs and to remain financially viable.

5. Given the interdependency of these companies with decisions made by the OEMs, it has been assumed that turnover losses across the BtP suppliers of around 50% would occur.

6. MRO sites that carry out slurry coatings as part of their services will also be severely hit and the larger operators indicated that they will either cease trading or move operations outside the EEA, due to the need to maintain vertical integration across the surface treatment processes that they are able to carry out. On this basis, it is estimated that 65% of turnover at affected sites would occur.

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 due to the inability to carry out repairs and/or maintenance activities according to manufacturers' requirements.
9. Taken together there would be significant economic impacts from the loss of manufacturing and maintenance to both the EEA and UK economies, together with the loss of highly skilled jobs (and potentially a highly skilled labour force) and the benefits derived from the R&D carried out by a high-tech sector.

The justification for this NUS takes into account the following factors. Although OEMs are working on substitution of the chromates in slurry coatings, they will not have all components with certified alternatives which have been fully implemented across their supply chains by September 2024. Many will require a further 12 years to have fully implemented alternatives across all components/final products and EEA/UK supply chains. The regulatory requirements placed on the sector mean that unless components have certified alternatives there is no substitute which can be considered "generally available"[63].

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

The impacted operations and socio-economic impacts to industry under the non-use scenario will therefore go far beyond production of just the specific stainless-steel components, but also high temperature (diffusion) coating typically applied to nickel/cobalt alloys that require slurry coatings. 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 slurry coatings 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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[63] 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)

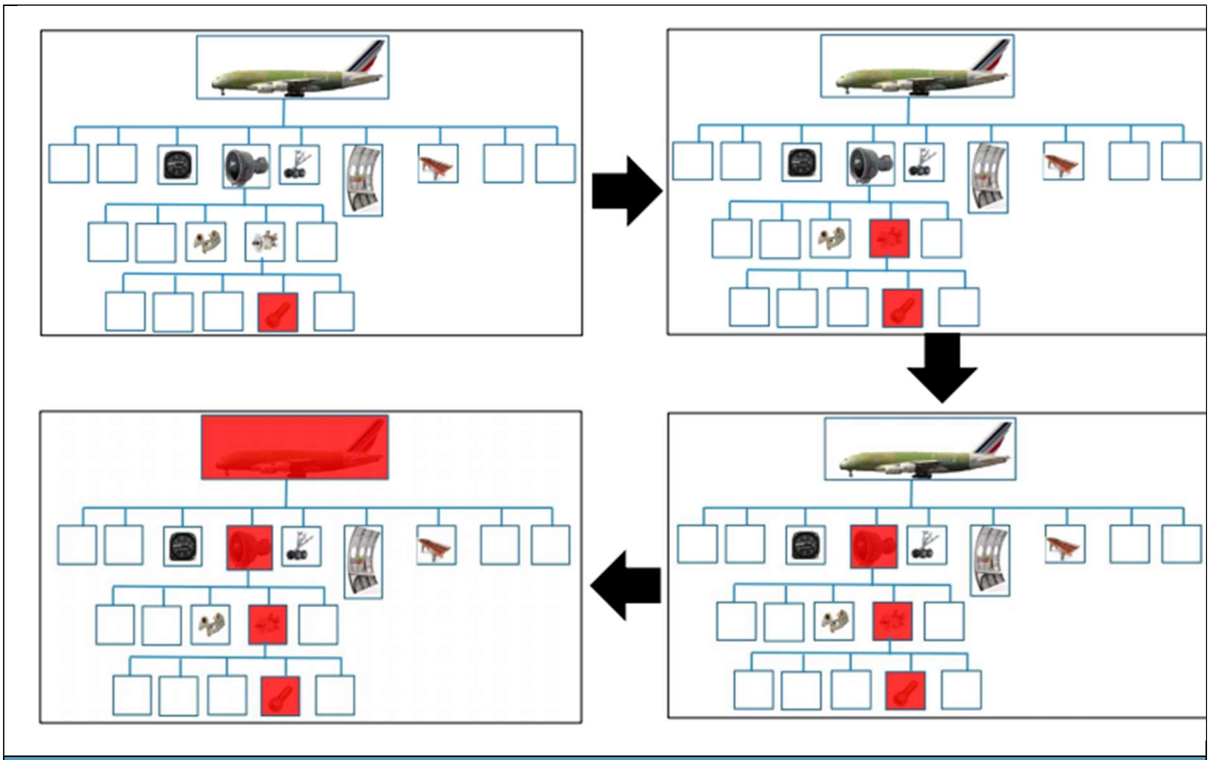

Figure 5–1: Interdependency of component availability in the manufacture of a final product
Source (GCCA (AfA 0116-01))

MROs will be similarly affected. It is technically not possible (or economically feasible) to carry out repairs to large components outside the EEA/UK, and then ship it back for reassembly in a final product in the EEA/UK. Apart from the fact that the surface of the component could be damaged during transport, adding to the technical infeasibility of this situation, the very tight turnaround times and budgets are impossible to hold in such a scenario.

Finally, although this is considered the most plausible scenario, OEMs note that the obstacles that would have to be overcome may make it overly optimistic. The infrastructure of the sector is based in part around manufacturing clusters or hubs (see also Table 5-2), with smaller suppliers located around the sites operated by the larger OEMs. Not all of these smaller sites, including those of critical suppliers, would be able to shift their activities outside the EEA/UK, leading to OEMs having to create entirely new supply chains outside the EEA/UK. This scenario also implies a huge economic investment would be carried out by the OEMs as well as their EEA/UK suppliers. This level of investment is unlikely to be feasible and hence the OEMs would be likely to cease manufacturing activities until the new industrial facilities were in place and ready to operate outside the EEA/UK.

5.2 Economic impacts associated with non-use

5.2.1 Economic impacts on applicants

Under the non-use scenario, all applicants and the formulators of the slurry coated products would be impacted by the loss of sales of CT or of imported formulations containing the chromates for use in slurry coatings. At the specific supplier level, these impacts may vary in their significance, as the importance of the different chromates used in formulations to their revenues varies across the suppliers (as does the level of supply of chromates for use in other treatment processes).

In the short term (i.e., first 2 years under the non-use scenario), the losses will be in the order of (Euro /Pound sterling) tens of millions per annum to the applicants and their downstream formulators.

Over time, as consumption of the chromates reduces in line with companies' substitution plans, sales and hence revenues will continue to decrease. However, the formulators producing the chromate-based slurry coatings formulations are also the same companies that will be providing formulations based on the alternatives. As a result, sales of alternative formulations once they are certified and implemented across value chains would be expected to offset profit losses from declining demand for the chromate-based formulations.

No quantitative estimates for 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 be theoretically possible to move slurry coatings outside the EEA/UK due to already existing supply chain sites in other countries, for example, the USA, Canada, China, Mexico, Morocco, etc. and to outsource manufacturing as the supply chain is spread around the world. There are several obstacles to such a scenario, however, which would make this economically unattractive even if it is the most plausible scenario. Firstly, the due diligence principle will continue to apply to the supply chain and obligations would be exacerbated in case of relocation out of EEA/UK. Secondly, when activities are shifted to another site, there is an inevitable phase of technical and industrial preparation (site design, capital procurement and installation, worker training, pilot trials) and qualification to ensure the sustainability of these activities, including an assessment of the technical capability to deliver stringent airworthiness and certification requirements. Moreover, once the qualification phase is over, it is essential to get the right ramp up in order to meet the manufacturing rate objectives.

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

5.2.2.2 Approach to assessing economic impacts

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

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

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

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

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

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

5.2.2.3 Estimates based on loss of jobs (and GVA lost)

The SEA questionnaire collected data on the number of employees who would lose their jobs under the NUS. This includes both those whose job directly involves use of the chromates and those whose jobs would be affected due to a cessation of production activities or due to companies moving outside the EU. The resulting figures collected for the 21 sites are presented in Table 5-2 below.

The job losses reported by respondents, which range from a few per site where only slurry coatings would cease to all employees in the event of closure are significant:

- Extrapolated out to the total 52 sites expected to be carrying out slurry coatings across the EEA: 14,400 jobs (around 9,900 in the EEA and 4,600 in the UK) due to the cessation of slurry coatings and linked to manufacturing activities across product lines or to the cessation of MRO services, including as a result of companies moving operations outside the EEA.

Table 5-2: SEA survey responses and extrapolations on numbers of jobs lost under the Non-Use Scenario						
By role	No. of Company Responses		Direct job losses – workers undertaking processes linked slurry coatings		Additional direct job losses – due to a cessation of manufacturing/MRO activities	
From SEA Survey	EEA	UK	EEA	UK	EEA	UK
Build to Print (1 site)	0*	1	3	3	0	0
Design to Build	0*	0*	39	39	174	174
MROs (6 sites)	6	0*	233	39	1,046	174
OEMs (10 sites)	3	7	40	749	1,210	1,547
Total (21 sites)	**11**	**10**	315	830	2,430	1,895
Job losses - **Extrapolation of job losses under the Non-Use Scenario to the estimated 52 sites undertaking slurry coatings treatments**						
Build to Print (4 sites)	1	3	3	9	0	0
Design to Build (6 sites)	3	3	117	117	522	522
MROs (18 sites)	12	6	466	234	2,092	1,044
OEMs (24 sites)	16	8	213	856	6,453	1,768
Total sites (52 sites)	**32**	**20**	799	1,216	9,067	3,334
Total EEA direct and indirect across 32 sites			**9,867**			
Total UK direct and indirect across 20 sites			**4,550**			
*Where no companies responded, an estimation has been made.						

Table 5-3: GVA losses per annum under the Non-use Scenario

By role	GVA per worker assumed by role		GVA lost due to direct job losses € million		Additional GVA lost due to due to a cessation of manufacturing/MRO activities - € million	
	EEA	UK	EEA	UK	EEA	UK
Build to Print (1 site)	68,000*	68,000*	0.20	0.20	-	-
Design to Build	68,000*	68,000*	2.65	2.65	11.83	11.83
MROs (6 sites)	85,000	85,000	19.81	3.32	88.91	14.79
OEMs (10 sites)	98,500	98,500	3.94	73.78	119.19	152.38
Total (21 sites)			26.60	79.95	219.93	179.00
		Total EEA	**€ 246.53 million per annum**			
		Total UK	**€ 258.95 million per annum**			
GVA losses - Extrapolation to the estimated 52 sites undertaking slurry coatings treatments						
Build to Print (4 sites)	68,000*	68,000*	0.20	0.61	-	-
Design to Build (6 sites)	68,000*	68,000*	7.96	7.96	35.50	35.50
MROs (18 sites)	85,000	85,000	39.61	19.89	177.82	88.74
OEMs (24 sites)	98,500	98,500	21.01	84.32	635.65	174.15
Total sites (52 sites)			68.78	112.77	848.97	298.38
		Total EEA	**€ 917.78 million per annum**			
		Total UK	**€ 411.17 million per annum**			
*Weighted average GVA calculated for Build-to-Print and design-to-build companies as the GVA by NACE code multiplied by the NACE code counts across responding companies, divided by the total number of relevant NACE responses. MRO and OEM GVA figures from Eurostat (2018).						

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

By role	Total GVA losses - € millions per annum		Total personnel costs associated with lost jobs - € millions per annum*		Implied operating surplus losses € millions per annum	
	EEA	UK	EEA	UK	EEA	UK
Build to Print	0.2	0.2	0.1	0.1	0.1	0.1
Design to Build	14.5	14.5	9.6	9.6	4.9	4.9
MROs	108.7	18.1	72.1	12.0	36.6	6.1
OEMs	123.1	226.2	88.3	162.1	34.9	64.1
Total (21 sites)	**246.5**	**258.9**	**170.1**	**183.8**	**76.4**	**75.1**
Operating surplus losses - Extrapolation to the estimated 32 EU and 20 UK sites undertaking slurry coatings treatments						
Build to Print	0.2	0.6	0.1	0.4	0.1	0.2
Design to Build	43.5	43.5	28.7	28.7	14.7	14.7
MROs	217.4	108.6	144.3	72.1	73.2	36.6
OEMs	656.7	258.5	470.7	185.3	186.0	73.2
Total sites (52 sites)	**917.8**	**411.2**	**643.8**	**286.5**	**274.0**	**124.7**

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

The estimated losses in GVA equate to:

- €920 million per annum across the EEA and €410 million per annum for the UK, extrapolated out to the 32 EU and 20 UK downstream user sites.

For comparison, turnover for the EU A&D industry is around €259 billion[64] per annum, while that for the UK A&D sector is around €57 billion (£50 billion) in 2020[65]. Thus, although these figures appear high, they are considered to be underestimates by the ADCR members (particularly the OEMs) given the potential for much larger segments of the sector to move outside the EEA /UK should chromate-based slurry coatings no longer be permitted.

In order to convert these GVA losses to an estimate of lost operating surplus (profits), personnel costs for each lost job are subtracted. The results of this calculation are given in Table 5-4. Personnel costs are based on Eurostat data for the relevant NACE codes, with an average weighted personnel cost adopted for BtP and DtB; the average personnel costs by NACE code from Eurostat for OEMs and MROs are adopted in these cases.

The estimated (implied) values of lost operating surpluses generated by this GVA-based approach equate to:

- €270 million per annum across the EEA and €120 million per annum for the UK, extrapolated out to the 32 EU and 20 UK downstream user sites.

5.2.2.4 Estimates based on lost turnover

The SEA questionnaire also asked companies to provide information on the impacts that a refused authorisation would have on turnover/revenues. Fewer companies responded to this question, although the responses provided by the OEMs (as the end customer) and MROs enable estimates of the likely percentages of turnover lost by role to be developed. These estimates take into account the number of companies indicating that they also carry out activities other than chromate-based slurry coatings for the A&D sector, as well as surface treatment and other processes for other sectors. They also account for potential loss in turnover from subsequent manufacturing and assembly activities.

Estimates of lost revenues per site are based on Eurostat data by NACE code with weighted averages used for BtP and DtB companies, and NACE code specific data for OEMs and MROs. Note that the weighted averages exclude micro-enterprises as few suppliers within the sector will fall into this size category. Gross operating surplus losses are then calculated by applying GOS rate data for the different NACE codes from Eurostat for 2019. The resulting losses are given in Table 5-5.

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

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

Table 5-5: Turnover and GOS losses under the Non-Use Scenario – (avg. 10.6% losses across all roles)

	Turnover lost per annum € millions		GOS losses per annum € millions	
	EEA	UK	EEA	UK
Build to Print	49	49	5	5
Design to Build	49	49	5	5
MROs	278	46	27	5
OEMs	2,733	6,377	261	609
Total (21 sites)	**3,108**	**6,520**	**298**	**624**
Extrapolation of turnover and GOS losses to the estimated 52 sites undertaking slurry coatings treatments				
Build to Print	49	146	5	15
Design to Build	146	146	15	15
MROs	556	278	55	27
OEMs	14,576	7,288	1,392	696
Total sites (52 sites)	**15,326**	**7,857**	**1,467**	**753**
*Weighted average turnover and GOS calculated for Build-to-Print and design-to-build companies as the GOS multiplied by the NACE code counts across responding companies, divided by the total number of relevant companies. MRO and OEM figures direct from Eurostat (2018) for EU/UK as available.				

5.2.2.5 Comparison of the profit loss estimates

The figures presented in Table 5-5 are higher than those given in **Error! Unknown switch argument.** for both the EEA and UK, with the greatest differences being in the estimates for OEMs and MROs. This is considered to be due to the turnover-based estimates taking better account of the loss in associated manufacturing, maintenance or repair activities, given the importance of chromate-based slurry coatings to both of these sets of companies.

- GVA based approach estimates of lost operating surplus:
    - Losses of €270 million per annum for the EEA
    - Losses of €120 million per annum for the UK

- Turnover based approach of lost operating surplus:
    - Losses of €1,500 million per annum for the EEA
    - Losses of €750 million per annum for the UK

These two sets of figures are used in this SEA to provide lower and upper bound estimates of losses in producer surplus, with the ratios between the two sets of estimates for the different roles shown in Table 5-6. It is important to note that these losses apply to commercial enterprises only. No data was provided by any of the military organisations reliant upon the continued use of chromate-based slurry coatings which could be used in this analysis. These organisations simply stated that they would have to cease undertaking MRO related activities in their home country, resulting in severe impacts on their military forces.

Table 5-6: Comparison of profit loss estimates from the two methods

	Total job losses at sites undertaking slurry coating		% Turnover lost		Ratio of lost profits based on turnover to lost operating surplus based on jobs (Based on €billions lost)	
	EU	UK	EU	UK	EEA	UK
Build to Print	3	9	50%	50%	72.59	72.59
Design to Build	639	639	50%	50%	1.02	1.02
MROs	2,558	1,278	65%	65%	0.75	0.75
OEMs	6,667	2,624	75%	75%	7.48	9.51
Total sites (52 sites)	**9,867**	**4,550**	**€ 15,326 million**	**€ 7,857 million**	**5.35**	**6.04**

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 4 - 12 years, with any such investment in new equipment would be focused on facilitating substitution (while the capital equipment associated with the continued use of the chromates over the next 7 - 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 EU and UK assets. However, given the potential scale of the impacts of a refused authorisation for the sector as a whole, any possible market for redundant equipment is likely to be overwhelmed by the number of sites ceasing activities, including related processes. As a result, it is not possible to estimate the potential scrappage value of equipment (e.g., spray guns, booths and equipment), especially as its current use for chromate-based treatments may further reduce its value.

Because this is a sectoral application and the ability to shift to alternatives is driven by qualification and validation by OEMs and obtaining certification approval by airworthiness authorities, the issue of potential impacts on rival firms undertaking slurry coatings using alternatives is not relevant. The OEMs determine whether there are alternatives that can be used, not individual downstream users. Furthermore, as previously indicated, the ADCR is a sectoral consortium and downstream user members include competitors, which may also act as suppliers to each other, while the larger companies share many of the same BtP and DtB suppliers (an estimated 15-25% overlap in suppliers exists across some OEMs). Relationships between the OEMs and BtP and DtB are developed over time and often reflect long-term commitments given the need for OEMs and DtB companies to certify their suppliers in the manufacturing of components. As a result, rival suppliers cannot readily step in and replace their production activity.

The economic losses are therefore based on consideration of losses in operating surplus/profits only. These have been estimated over three time periods in line with SEAC's new guidance for those cases where there are not suitable alternatives available in general. Discounted losses over 1, 2, 4, 7 and 12 years are given in Table 5-7.

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

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

	Lost EBITDA/Profit - € millions		GVA-based Operating Surplus Losses	
	EU	UK	EU	UK
1 year profit losses (2025)	1,467	753	274	125
2-year profit losses (2026)	2,766	1,421	517	235
4-year profit losses (2028)	5,324	2,735	994	453
7-year profit losses (2031)	8,803	4,522	1,644	748
12-year profit losses (2036)	13,764	7,071	2,571	1,170

5.2.2.7 Other impacts on Aerospace and Defence Companies

Under the Non-use Scenario there would be an enormous impact on the A&D sector in the EEA /UK, leading to a second wave of negative impacts on the EEA/UK market. These impacts have not been quantified here but would include as a minimum:

- Cancelled future orders and loss of contracts for new products if supplies are significantly interrupted;
- Customer penalties for late/missed delivery of products;
- Extended durations of maintenance, repair and overhaul operations for products in service leading to e.g., “aircraft on the ground” (AoG) and other out-of-service final products, with consequent penalties and additional impacts on turnover;
- Increased logistical costs; and
- Reputational damages due to late delivery or cancelled orders.

5.2.3 Economic impacts on competitors

5.2.3.1 Competitors in the EEA/UK

This Combined AoA/SEA has been prepared so as to enable the continued use of CT in slurry coatings across the entirety of the EEA and UK A&D sectors. It is non-exclusive in this respect. It has been funded by the major (global) OEMs and DtB manufacturers in the EEA and the UK, with additional support provided by their suppliers and by Ministries of Defence, so as to ensure functioning supply chains for their operations.

As a result, there should be no economic impacts on competitors, especially as the major global OEMs and DtBs act as the major design owners which determine the ability of all suppliers to move to an alternative. As design owners they validate, qualify and certify components and products with new alternatives and gain new approvals (e.g., approvals from EASA, ESA or MoDs). Once these design owners have certified new alternatives in the manufacture of parts and components, these alternatives will be implemented throughout their value chain.

5.2.3.2 Competitors outside the EEA/UK

Under the NUS, it is likely that some of the major OEMs and DtB suppliers would move outside the EEA/UK, creating new supply chains involving BtP and MROs. This would be to the detriment of existing EEA/UK suppliers but to the advantage of competitors outside the EEA/UK. These competitors would gain a competitive advantage due to their ability to continue to use chromate-based slurry coatings treatments and due to their proximity to the OEMs and DtB, thus minimising logistic and transport issues.

5.2.4 Wider socio-economic impacts

5.2.4.1 Impacts on air transport

Under the Non-Use Scenario there would be significant impacts on the ability of MROs to undertake repairs and to follow normal maintenance and overhaul schedules. As indicated previously, MROs are legally bound to adhere to the requirements set out in the OEMs' manuals under airworthiness and military safety requirements. Where maintenance, repair or overhaul activities would require chromate-based slurry coatings they would have to be performed outside the EEA/UK until the OEMs have gained approvals and certifications for the use of alternatives on components and have adapted the Maintenance 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 EU/UK for repairs, with dramatic financial and environmental impacts.

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

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

The need to have maintenance carried out outside the EEA/UK would also lead to additional operational costs being incurred through increased fuel use. Small planes (e.g., business jets) that do not have the fuel capacity or airworthiness approvals for long haul flights would need to make multiple stops enroute to non-EEA MRO facilities and back to the EEA/UK. The impacts for larger aircraft would also be significant. For example, flying from Western Europe to Turkey or Morocco adds approximately 3,000 km each way and for a Boeing 737 this would take slightly less than four hours. For an airline which has 50 aircraft requiring a "D check" (heavy maintenance inspection of the majority of components, carried out every 6-10 years), this would involve 400 hours of flight time (return trip) or 20 days of foregone revenue, equivalent to €1.4 million per annum. Scaling this up to the EU passenger aircraft fleet, which stands at approximately 6,700, suggests lost revenues in the tens of millions per annum 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 US$500,000/month in 2021 (€421,500, £362,250)[66],, 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[67] a -49 to -50% decline in world total passengers in 2021 compared to 2019. 2020,figures for Europe show a -58% decline in passenger capacity, -769 million passengers and a revenue loss of -US$100 billion. In addition, COVID-19 caused a 74% decrease in passenger demand for international travel in 2020 compared to 2019. The trend though is for the aircraft industry to continue expanding globally, with pre-covid estimates suggesting that demand for air transport would increase by an average of 4.3% per annum over the next 20 years, as illustrated in Figure 5–2 below. Similar growth is expected in air freight transport. If this growth path were to be achieved, by 2036 the air transport industry would contribute 15.5 million in direct jobs and US$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.

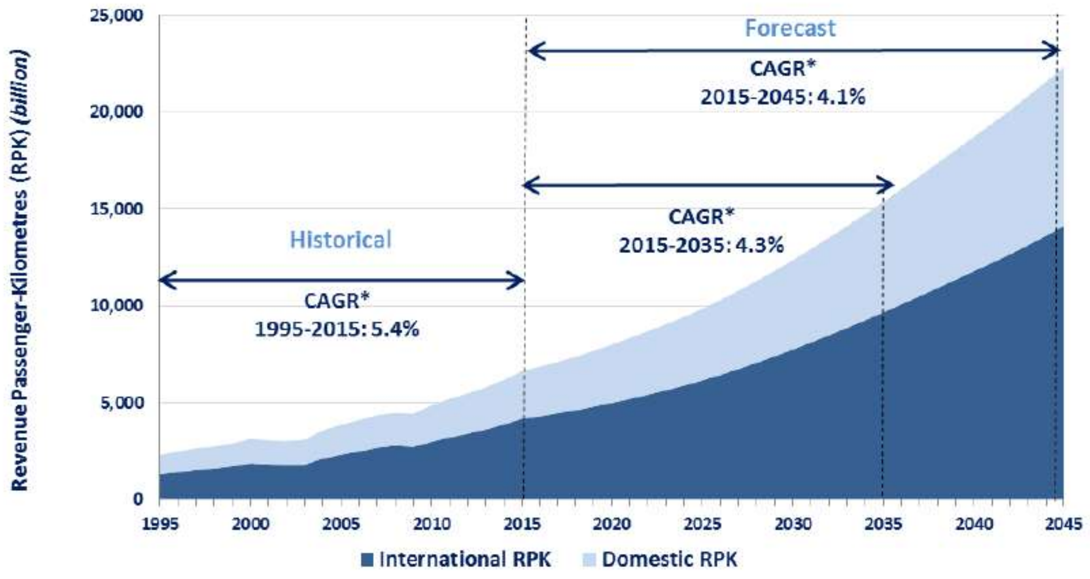

Figure 5–2: Forecast compound annual growth rates – Revenue Passenger-kilometres

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.[68] The impact of COVID has resulted in an expected 2-year lag in growth, but the forecast remains unchanged with passenger numbers expecting

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

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

[68] Airbus (undated): Airbus Global Market Forecast 2021 – 2040. Available at: Global Market Forecast | Airbus

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[69] (covering inter-regional and intra-regional/domestic) for the period between 2018 to 2038.

This level of growth in EU air traffic, together with the jobs and contributions to GDP that it would bring, could be impacted under the NUS. In particular, impacts on the ability of MROs to undertake repairs and carry out maintenance where this would require the use of chromate-based slurry coatings to ensure the continued airworthiness of aircraft could impact on the realisation of such growth. No quantitative estimate of the level of impact can be provided, but it is clear that the closure of EU-based MRO operations in particular could impact on the availability of aircraft and hence passenger and freight transport until substitution has taken place as expected over the review period (unless airlines responded by buying more planes or stockpiling of components, which would inevitably give rise to increases due to the costs of holding spares and/or bringing spare planes on-line).

5.2.4.2 Defence-related impacts

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

Two national Ministries of Defence have provided information regarding their use of slurry coatings, with SEA responses also provided by defence suppliers. In addition, MROs providing services to MoDs have also provided information to ensure that they are able to continue to maintain and repair military final products into the future. The implications of having to cease these activities are significant. Military final products which could not be maintained to appropriate safety standards would have to be removed from service. Not only would this impact on the availability of key equipment in the case of a military emergency, but it would also affect the mission readiness of operational forces in particular.

It is also worth noting that Governments are likely to be reluctant to send military final products to MRO facilities located in non-EU countries, although the US, Canada and Turkey are NATO members, and as such may be suitable candidates to service European military aircraft. There would be impacts on mission readiness if repairs cannot be done locally. This could, in fact, be far more impactful than the economic impacts linked to the defence sector

As a result, it is likely that under the NUS, companies manufacturing components for and servicing military products would have to apply for defence exemptions; although for some companies, the turnover generated by military contracts alone may not be sufficient to maintain current production levels and it may not be economically feasible to operate dual manufacturing lines for military and civilian customers.

Companies in the European defence sector represent a turnover of nearly €100 billion and make a major contribution to the wider economy. The sector directly employs more than 500,000 people of which more than 50% are highly skilled. The industry also generates an estimated further 1.2 million jobs indirectly. In addition, investments in the defence sector have a significant economic multiplier effect in terms of 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

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

the Seventh Framework Programme (FP7) generated approximately an additional €11 of estimated direct and indirect economic effects through innovations, new technologies and products.[70]

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).[71] The aim will be to support high-end defence capability projects such as the next generation of fighter aircrafts, tanks and ships, as well as critical defence technologies such as military cloud, Artificial Intelligence, semiconductors, space, cyber or medical counter-measures. It will also spearhead disruptive technologies, notably in quantum technologies and new materials and tap into promising SMEs and start-ups. Some of these gains may not be realised if the main EU defence OEMs have to divert resources into shifting part of their manufacturing base outside of the EEA.

However, under the NUS, companies manufacturing components for, and servicing military aircraft and other derivative defence 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. If some production moved out of the EEA/UK under the NUS, as indicated by some OEMs as their most likely response, then the above multiplier effects would be lost.

If Governments did allow the manufacture and servicing of military aircraft and other defence products to move out of the EEA/UK under the NUS, then some proportion of such multiplier effects would be lost to the EU/UK economy. In addition, the ability of the EEA/UK to benefit from some of the innovations and technological advances in products ahead of other countries could be lost, if the shift in manufacturing remains permanent and extends to new products.

5.2.5 Summary of economic impacts

Table 5-8 provides a summary of the economic impacts under the Non-Use scenario.

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

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

Table 5-8: Summary of economic impacts under the Non-Use scenario (12 years, @ 4%)

Economic operator	Quantitative	Qualitative
Applicants	- See Formulations SEA	Not assessed
A&D companies	- Annualised lost profits: ○ EEA: €270 – 1,500 million ○ UK: €130 – 750 million - 12-year lost profits: ○ EEA: €2,600 – €13,800 million ○ UK: €1,200 – €7,000 million	Relocation costs, disruption to manufacturing base and future contracts, impacts on supply chain coherence, impacts on future growth in the EEA and UK sectors, loss of skilled workforce, impacts on R&D (and potential to deliver new more sustainable technologies)
Competitors	Not anticipated due to sectoral coverage of the application	Not anticipated due to sectoral coverage of the application
Customers and wider economic effects	Not assessed	- Impacts on airlines, air passengers, customers, cargo and emergency services, and thus society as a whole - Impacts on military forces' operation capacity and mission readiness - Lost employment multiplier effects due to impacts on civil aviation and loss of defence sector spending - Loss of spin-off effects – innovation and new technologies

5.3 Environmental impacts under non-use

As well as leading to increases in operating costs and lost revenues to airlines, the increased distances that airlines would need to fly planes in order for them to undergo normal maintenance and overhaul schedules would lead to significant increases in fuel consumption and hence CO_2 emissions.

The most plausible non-use scenario in the event of a refused Authorisation - even if it may not be practical and would involve huge levels of investment - would be to shift slurry coatings to another country (outside the EEA or UK).

Under this scenario, as noted above, the environmental impacts would be real and the effects enormous. If manufacturing activities using chromates and not using chromates are separated on both sides of the European border, huge logistics and transport related requirements would have to be introduced with dramatic impacts on the aerospace and defence sectors' environmental footprint.

For MRO activities, each time an aircraft would need a repair requiring the use of chromate-based slurry coatings, it would force the manufacturer to go to a non-European site. In the case of a major repair, aircraft that could not fly would become stranded or, less likely, would have to be dis-assembled for transport to a non-European site. Some stranded final products would become obsolete prematurely, due to the lack of the parts 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 parts and assemblies. The industry has been active in trying to decrease buy-to fly ratio (the ratio of material inputs to final component output), and the non-use scenario would significantly undermine these efforts as the more frequent production of new components would increase the waste and scrappage generated. Scrap is material that is wasted during the production process.

Today, the civil aviation industry strives to develop new technologies to reduce the amount of CO_2 emissions by 15 - 20% on each generation of in-service aircraft (make aircraft movements emission-free), since it is well aware that aviation continues to grow significantly.

Even despite the impact that the COVID-19 pandemic had on air traffic and the whole civil aviation industry, aviation is expected to double in the next 20 years. Consequently, a refused authorisation renewal would lead to aircraft manufacturing and MRO activities involving chromate uses to move outside the EEA. In addition to the socio-economic consequences this would have, the drastic increase in CO_2 emissions, would outweigh all the benefits achieved by aviation efforts to reduce fuel consumption and CO_2 emissions of in-service aircrafts.

5.4 Social impacts under non-use

5.4.1 Direct and indirect job losses

5.4.1.1 Estimated level of job losses

The main social costs expected under the NUS are the redundancies that would be expected to result from the cessation of production activities (all or some) and the closure and relocation of sites. As indicated in the assessment of economic costs, the estimated reduction in job losses is based on responses to the SEA questionnaires covering 17 sites in total. Direct job losses will impact on workers at the site involved in slurry coatings and linked pre-treatment and post-treatment processes as well those involved in subsequent production steps and related activities (e.g., lab workers, etc.). These are all referred to here as direct job losses (for avoidance with confusion of multiplier effects).

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

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

Estimates of the direct job losses that would arise at downstream users' sites under the NUS were presented above. For ease of reference, the totals are repeated in Table 5-9 below. The magnitude of these figures reflects the importance of slurry coatings to the production of aluminium and other components, as well as to maintenance and repairs of such parts at a subset of MRO facilities. No consideration is given to job losses at those companies providing services that are contracted to provide cleaning and other services to the BtPs, DtBs, MROs and ORMs.

As context, the civil aeronautics industry alone employees around 405,000 people in the EU, with the defence sector employing more than 500,000 and supporting a further 1.2 million[72]. The figures in

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

Table 5-9 indicate that approximately 14,400 of these A&D company jobs could be in jeopardy under the NUS.

Table 5-9: Predicted job losses in aerospace companies under the NUS

Role	Total job losses due to cessation of manufacturing activities or relocation under the NUS	
	EEA	UK
Build to Print	3	9
Design to Build	639	639
MROs	2,558	1,278
OEMs	6,667	2,624
Total sites (52 sites)	9,867	4,550

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[73]).

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[74] as a whole that varies according to the mean duration of unemployment. These vary by country, with the mean duration of unemployment weighted by the number of employees for each country relevant to A&D sector productions sites varying from 7 months to 1.6 years.

These figures are combined with the ratio of social costs per job loss provided in Dubourg (2016) and annual wages to calculate the social costs per lost job. Data were collected in the SEA questionnaire on the average salary for workers involved in the use of the chromates. The typical range given is from €30k to 50k, rising to an average maximum of around €76k, across all of the companies and locations. For the purposes of these calculations, a figure of €40k has been adopted and applied across all locations and job losses. This figure is based on the NACE code data provided by companies but may underestimate the average salary given that A&D jobs are higher paid than those in other industries.

The resulting estimates of the social costs of unemployment are given in Table 5-10 based on consideration of the geographic distribution Article 66 notifications, the location of SEA respondents, and the location of suppliers in the ADCR members' supply chains, as well as MROs. The estimated social costs under the NUS are around €1.1 billion for the EEA and €460 million for the UK due to the cessation of the slurry coatings and linked manufacturing activities.

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[73] 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

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

Table 5-10: Social Cost of Unemployment – Job losses at A&D companies under the NUS

Country	Employment losses due to cessation or relocation of manufacturing	Social costs of unemployment (€)
France	2,171	275,240,533
Poland	2,171	204,042,667
Italy	1,283	155,459,200
Germany	2,171	225,749,333
Spain	592	66,304,000
Ireland	296	29,008,000
Netherlands	296	27,824,000
Sweden	296	26,403,200
Romania	296	28,297,600
Malta	296	24,035,200
Total EEA	**9,867**	**1,062,363,733**
United Kingdom	**4,550**	**456,456,000**
Grand Total	**14,417**	**1,518,819,733**

5.4.2 Wider indirect and induced job losses

5.4.2.1 Aerospace and defence related multiplier effects

Employment in one sector is often the input to employment in another sector, so that fluctuations in employment of the latter will inevitably affect the former. It is clear that, under the NUS, there could be significant wider impacts on jobs given the likelihood that some of the largest players in the EEA/UK A&D sector would relocate their activities elsewhere with a partial or full cessation of manufacturing in the EEA/UK.

A UK Country Report on the “Economic Benefits from Air Transport in the UK” produced by Oxford Economics (2014) indicates the following with respect to the aerospace sector’s contribution to UK employment in 2012:

- Indirect employment effects: 139,000 jobs implying a multiplier effect of 1.36 indirect jobs for every direct job;
- Induced employment effects: 86,000 jobs implying an additional multiplier effect of 0.84 induced jobs for every direct job.

Indirect employment effects will to a degree be captured by the estimates of lost jobs presented in Table 5-9 given that it includes the loss of jobs at suppliers to the aerospace OEMs. The figures exclude other service providers to these companies whose services would no longer be required. Induced effects are not captured by the above estimates and an employment multiplier of 0.84 suggests that they may be significant given the predicted numbers of jobs that would be lost across the key countries in which aerospace-related manufacturing takes place.

The loss of jobs within those companies that serve the defence industry would have their own multiplier effects. The external evaluation of FP7 referenced above[75] quotes an employment multiplier of between 2.2 to 2.4, with this covering both indirect and induced employment effects. The sector is identified as bringing a major contribution to the wider economy.

These combined multiplier effects may be regionally significant. The European Aerospace Cluster Partnership[76] has members located in over 45 aerospace clusters across 18 countries. Figure 5-3 below is a "snip" taken from their website highlighting the location of these different hubs across the EU and UK, to provide an indication of where effects may be experienced at the regional level.

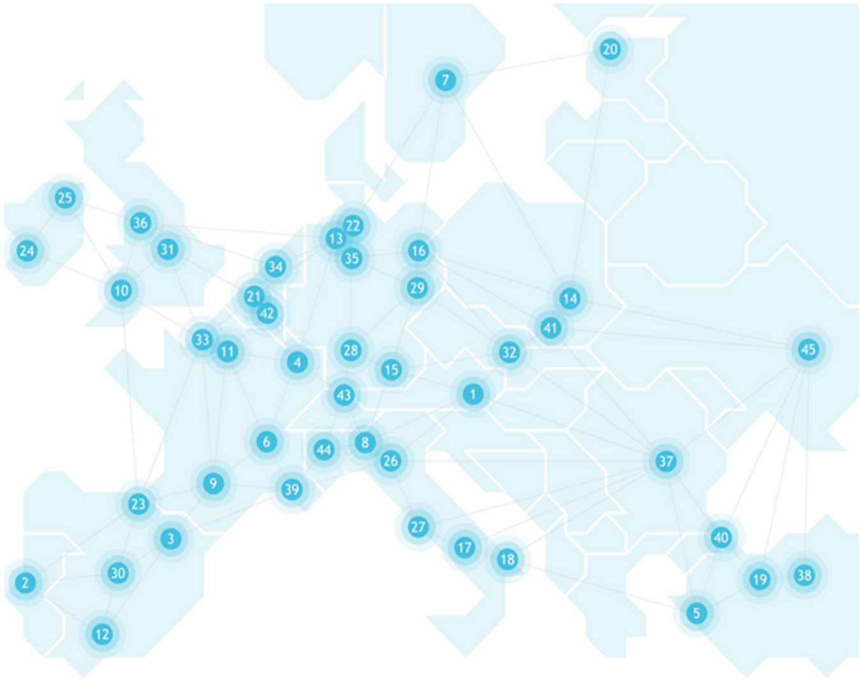

Figure 5-3: Aerospace clusters across Europe

5.4.2.2 Air transport multiplier effects

A 2019 "Aviation Benefits Report"[77] produced by a high-level group formed by the International Civil Aviation Organisation (ICAO) provides an assessment of the economic impacts of the aviation sector. These are linked to its direct impact as well as indirect, induced and catalytic effects. At a regional level, it is estimated that air transport supports 12.2 million jobs in Europe, 2.6 million of these jobs

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[75] 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

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

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

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

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

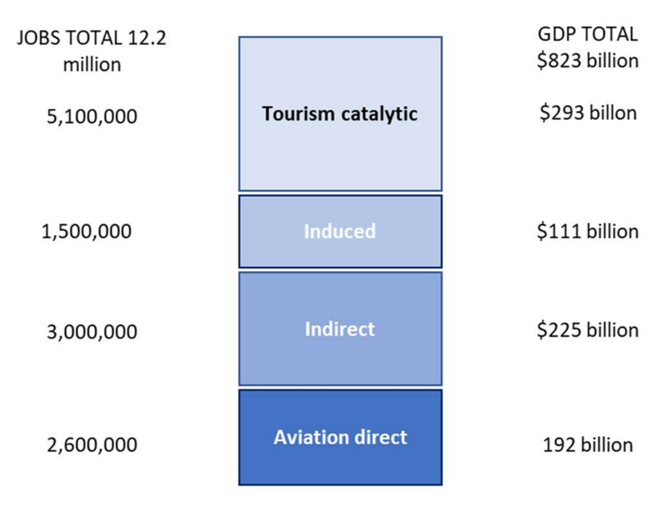

Figure 5-4: Aviation related multiplier effects
Based on: **https://www.icao.int/sustainability/Documents/AVIATION-BENEFITS-2019-web.pdf**

The potential employment losses associated with a decline in European aviation can be seen by reference to the impacts of COVID-19[78]. 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-19 to 2.1 million jobs post-COVID (i.e., at the end of 2021); and
- 13.5 million jobs in supported employment pre-COVID-19 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 slurry coatings alone, it is clear that a disruption to civil aviation could have significant employment impacts.

5.4.3 Summary of social impacts

In summary, the social impacts that would arise under the NUS include the following:

- Direct job losses:
    - Around 9,900 jobs in the EEA due to the loss of slurry coatings and linked assembly and/or manufacturing activities, and
    - Over 4,600 jobs in the UK due to the loss of slurry coatings and linked assembly and/or manufacturing activities.

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

- Social costs of unemployment:
  - €1,100 million for the EEA associated with direct job losses and
  - €460million for the UK associated with direct job losses;
- Indirect and induced unemployment at the regional and national level due to direct job losses; and
- Direct, indirect and induced job losses in air transport due to disruption of passenger and cargo services.

5.5 Combined impact assessment

Table 5-11 sets out a summary of the societal costs associated with the Non-Use scenario. Figures are provided as annualised values, with costs also presented as a PV over a 2-year period as per ECHA's latest guidance; note that restricting losses to only those occurring over the first two years of non-use will significantly underestimate the profit losses to the A&D companies as well as the applicants. Most A&D companies would incur losses for at least a 4-year period, with over 60% incurring losses for 7 years and 25-30% for the full 12-year period as design owners work continues towards development, testing, qualification, validation, certification and industrialisation of alternatives.

Table 5-11: Summary of societal costs associated with the Non-Use Scenario		
Description of major impacts	**Monetised/quantitatively assessed/qualitatively assessed impacts**	
1. Monetised impacts	**PV @ 4%, 2 years**	**€ annualised values**
Lost producer surplus[1]: Impacts on applicants - Lost profits EEA - Lost profits UK Impacts on A&D companies[1]: - Lost profits EEA - Lost profits UK	Applicants: See formulation SEA A&D companies EEA: €520 –2,800 million UK: €240 – 1,400 million	Applicants: See formulation SEA A&D companies EEA: € 270 – 1,500 million UK: €130 – 750 million
Relocation or closure costs	Not monetised	Not monetised
Loss of residual value of capital	Not quantifiable	Not quantifiable
Social cost of unemployment: workers in A&D sector only[2]	EEA: €1,100 million UK: €460 million	EEA: €530 million UK: €230 million
Spill-over impact on surplus of alternative producers	Not assessed due to sector level impacts	Not assessed due to sector level impacts
Sum of monetised impacts	EEA: €1,600 – 3,900 million UK: €690 – 1,900 million	EEA: €810– 2,000 million UK: €350 – 980 million
2. Additional qualitatively assessed impacts		
Impacts on A&D sector	Impacts on R&D by the A&D sector, impacts on supply chain, impacts on technological innovation	
Civilian airlines	Wider economic impacts on civil aviation, including loss of multiplier effects, impacts on airline operations, impacts on passengers including flight cancellations, ticket prices, etc.	
Ministries of Defence	Impacts on the operational availability of aircraft and equipment, premature retirement of aircraft and equipment, impacts on mission readiness	
Other sectors in the EU	Loss of jobs due to indirect and induced effects; loss of turnover due to changes in demand for goods and services and associated multiplier effects. Loss of jobs in other sectors reliant on aeroderivative uses of the chromates, such as the energy sector (e.g., use of slurry coating on turbine blades and engine components including wind turbines) Impacts on emergency services and their ability to respond to incidents Impacts on cargo transport	
1) Lower bound figures represent lost EBITDA estimates, upper bound lost operating surpluses. 2) Estimated using the approach set out by Dubourg		

6 Conclusion

6.1 Steps taken to identify potential alternatives

When creating a Substitution plan for substances subject to Authorisation, suitable alternatives to Cr(VI) for slurry coatings should be "generally available"[79]. At present, this condition has not been met, as there are not alternatives which have met the strict regulatory requirements within the A&D industry for all components onto which slurry coatings 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 slurry coating are shown in Figure 6-1:

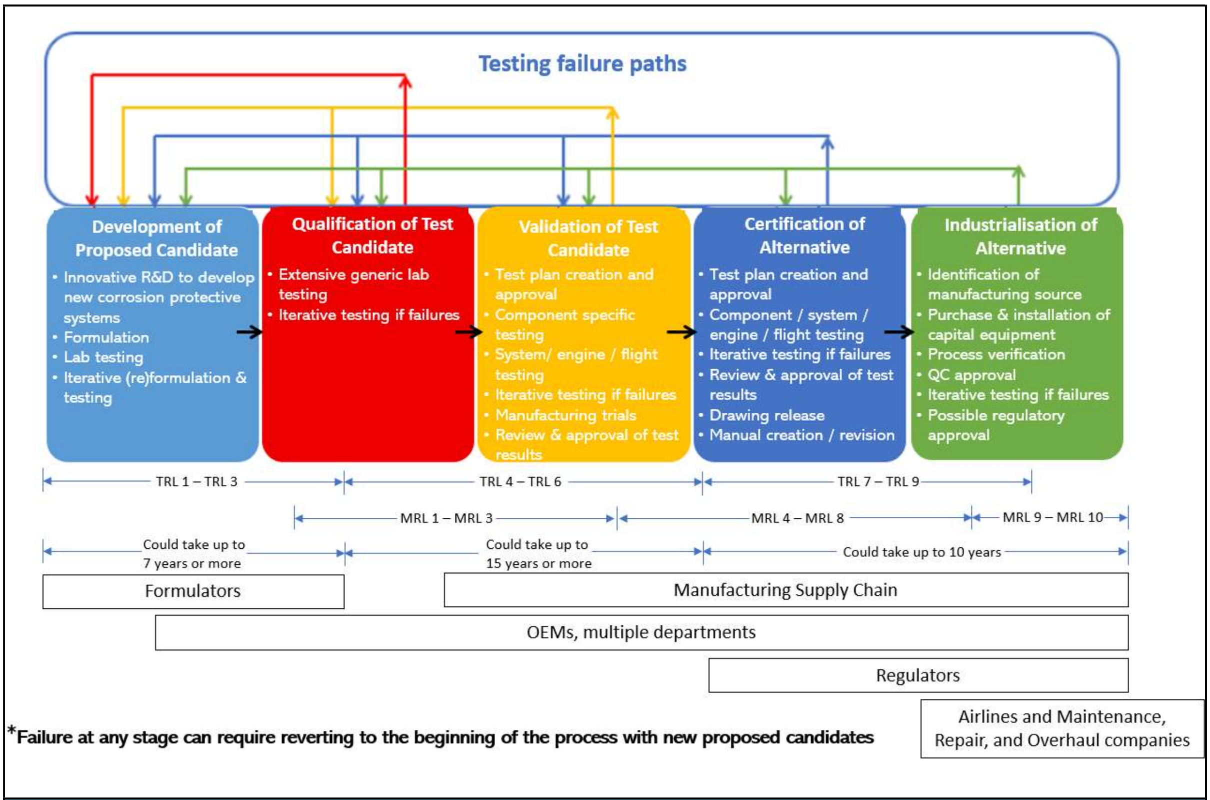

Figure 6-1: Schematic showing the key phases of the substitution process.

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

Activities undertaken include:

- Development of test alternatives in laboratory environments up to TRL 6;
- Qualification of test alternatives and suppliers including:
    - Modification of drawings;
    - Updating specifications;
    - Introduction of new processes to suppliers;
    - Negotiation of supplier(s) contracts.
- Demonstration of compliance followed by industrialisation; and
- Certification or approval.

6.2 The substitution plan

ADCR member companies have ongoing substitution plans in place to develop test candidates with the intent of replacing Cr(VI) in slurry coating. Individual members often have multiple substitution plans within slurry coatings, reflecting the complexity of different components to be treated, the various substrates, and the different performance resulting from test candidates in these different situations. While there have been successes, with some members having been able to implement alternatives to Cr(VI) in certain limited situations and for certain substrates, thereby reducing their Cr(VI) usage, many technical challenges remain.

As discussed in Section 3.10.3 and shown in **Figure 6-2** below of the 24 distinct substitution plans for slurry coating assessed in this combined AoA-SEA none of them are expected to have achieved MRL 10 by September 2024. MRL 10 is the stage at which manufacturing is in full rate production/deployment and is therefore where it is expected that Cr(VI) will be fully substituted under the relevant plan.

The proportion of substitution plans that are expected to achieve MRL 10 is then expected to progressively increase to 13% in 2028, 71% in 2031, and 88% in 2036. The potential need for more than 12 years has been identified by some OEMs due to their inability to identify any technically feasible alternatives to date, or due to the need by MROs and MoDs for continued use in the maintenance and repair of in-service (legacy) final A&D products.

In 2031 (equivalent to seven years beyond the expiry date for the existing applications), while many substitution plans are expected to have successfully progressed to industrialisation phase or MRL 10 and the consortium is expected to have reduced its Cr(VI) use, a proportion are not expected to have achieved MRL 10. For these substitution plans (which are from several member companies), there is still expected to be a need for the use of Cr(VI).

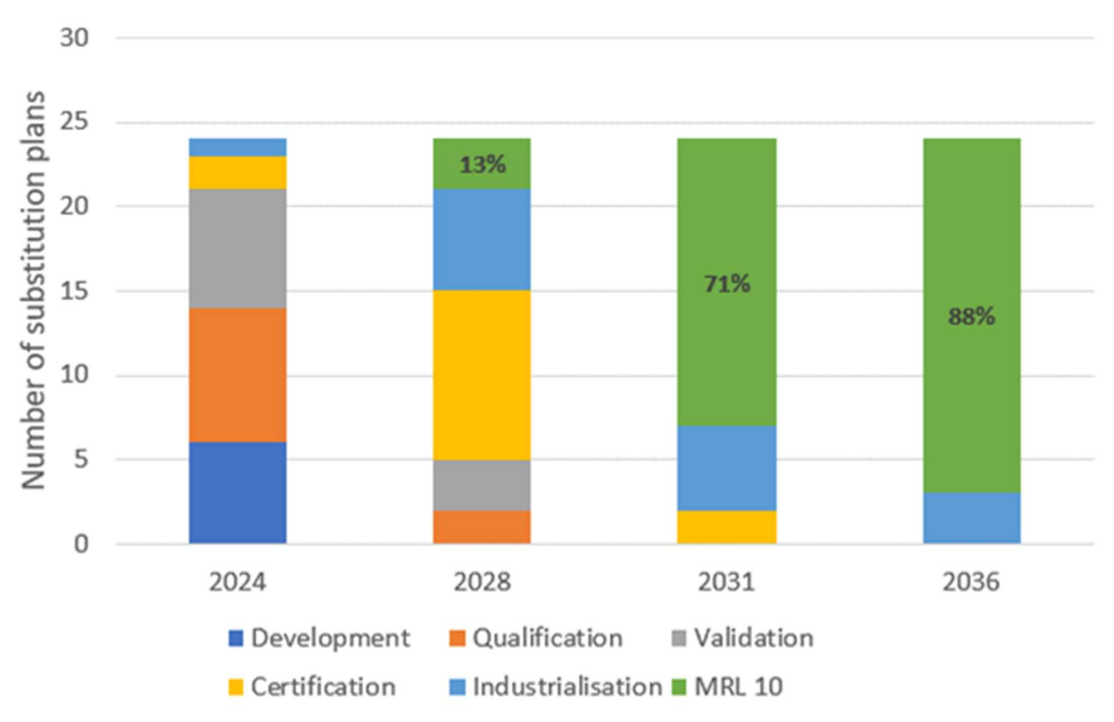

Figure 6-2: Expected progression of substitution plans for the use of Cr(VI) in slurry coating, by year.

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

Source: RPA analysis, ADCR members

As a result of individual members' substitution plans summarised above, **the ADCR request a review period of 12 years for the use of Cr(VI) in slurry coating**.

6.3 Comparison of the benefits and risk

Table 6-1 summarises the socio-economic benefits of continued use of the chromates in slurry coatings by companies in the A&D sector. Overall, net benefits of between ca. €1.6 to €3.8 billion for the EEA and €690 million to €1.9 billion for the UK (Net Present Value social costs over 2 years/risks over 12 years, @4%) can be estimated for the Continued Use scenario. These figures capture continued profits to the applicants and the A&D companies and the social costs of unemployment.

As can be seen from Table 6-1, the ratio of the benefits of continued use to the monetised value of the residual health risks is around 25,179 on the lower bound assumptions for the EEA and 15,582 on the lower bound assumptions for the UK.

Table 6-1: Summary of societal costs and residual risks (NPV costs over 2 years/risks 12 years, 4%)

Societal costs of non-use		Risks of continued use
Monetised profit losses to applicants	Losses in profits from reduced sales of the chromate substances and associated formulations. Losses quantified in the	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.

Table 6-1: Summary of societal costs and residual risks (NPV costs over 2 years/risks 12 years, 4%)

Societal costs of non-use		Risks of continued use	
	Formulation SEA	These risks are quantified and monetised in the Formulation SEA	
Monetised profit losses to A&D companies	EEA: €520 –2,800 million (£440 – 2, 400 million) UK: €240 – 1,400 million (£200 – 1,200 million)	Monetised excess risks to directly and indirectly exposed workers (€ per year over 12 years)	EEA: €120k (£103,200) UK: €76k (£65, 360)
Social costs of unemployment	EEA: €1,100 million (£910 million) UK: €460 million (£390 million)	Monetised excess risks to the general population (€ per year over 12 years)	EEA: €20k (£17,200) UK: €20k (£17,200)
Qualitatively assessed impacts	Wider economic impacts on civil aviation, impacts on cargo and passengers. Impacts on armed forces including military mission readiness. Impacts on R&D and technical innovation. Impacts from increased CO_2 emissions due to MRO activities moving out of the EEA/UK; premature redundancy of equipment leading to increased materials use.		
Summary of societal costs of non-use versus risks of continued use	- NPV (2 years societal costs/12 years excess health risks): ○ EEA: €1,600 – 3,900 million (£1,400 – 3,300 million) ○ UK: €690 – 1,900 million (£600 - 1,600 million) - Ratio of societal costs to risks: ○ EEA: 11,400 :1 to 27,640 :1 ○ UK: 7,050 :1 to 19,136 :1		

It should be appreciated that the social costs of non-Authorisation could be much greater than the monetised values reported above, due to the likely 'knock-on' effects for other sectors of the economy:

If the Applicants are not granted an Authorisation that would allow continued sales of the chromates, critical substances and formulations would be lost to A&D downstream users in the EU and UK

⬇

EEA/UK formulators would relocate to ensure that they could continue to supply their downstream customers until alternatives are certified across products; this could result in the temporary loss of key slurry coated formulations to downstream users as relocation of manufacturing would require re-certification of the formulations

⬇

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

⬇

OEMs would shift most of their manufacturing activities outside the EEA/UK as it would not be technically feasible in some cases, as well as inefficient and costly, to transport parts in and out of the EEA/UK

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

↓

Build-to-Print suppliers in the EEA would be forced to cease treatments reliant upon slurry coatings as a follow-on process treatment; as a result, BtP suppliers in the EEA/UK would be replaced by suppliers outside the EEA/UK

↓

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

↓

The relocation of MRO activities outside the EEA will cause significant disruption to civil aviation. This will impact on both passenger flights and cargo transport. It will also impact other aviation such as helicopters used for medical emergencies

↓

Ministries of Defence will face logistic difficulties with respect to the maintenance of aircraft and other equipment, with this impacting on mission readiness or the need to retire equipment prematurely. This will include the need to reach servicing agreements with non-EEA countries

↓

Passengers and freight shippers will face reduced flight availability and routes, as well as increased costs

Overall, it is clear that the benefits of the continued use of the chromates in slurry coatings activities significantly outweigh the residual risks from continued use.

Three further points are relevant. **Firstly, the use of CT is required (and may be required beyond 12 years) to ensure the operational capabilities of the military and the ability to comply with international obligations as partner nations at the EU level and in a wider field, e.g., with NATO.**

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

Finally, the non-use scenario would involve the relocation of economically and strategically important manufacturing processes. This would be in contradiction to the EU policy on “Strategic dependencies and capacities”, which highlights the need to minimise such dependencies where they could have a significant impact on the EU’s core interests, including the access to goods, services and technologies.[80] The need to support the A&D industry (as one of the 14 priority industrial ecosystems) is explicitly recognised within the update to the 2020 New Industrial Strategy.[81]

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*

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[80] https://ec.europa.eu/info/sites/default/files/swd-strategic-dependencies-capacities_en.pdf

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

measures and operational conditions should clearly demonstrate that risks are adequately controlled, and that the risk characterisation ratio is below the value of one. For applications for non-threshold substances, the applied risk management measures and operational conditions should be appropriate and effective in limiting the risks and it should be clearly demonstrated that the level of excess lifetime cancer risk is below $1x10^{-5}$ *for workers and* $1x10^{-6}$ *for the general population. For substances for which the risk cannot be quantified, a review period longer than 12 years should normally not be considered, due to the uncertainties relating to the assessment of the risk.*

7. *As evaluated by the SEAC, the analysis of alternatives and the third party consultation on alternatives should demonstrate without any significant uncertainties that there are no suitable alternatives for any of the utilisations under the scope of the use applied for and that it is highly unlikely that suitable alternatives will be available and can be implemented for the use concerned within a given period (that is longer than 12 years)"* (CARACAL, 2017).

As far as the second criterion above is concerned, the same document provides some relevant examples, one of which (Example (d)) reads as follows:

> "(…) *the use of the substance has been authorised in accordance with other EU legislation (e.g., marketing authorisation, certification, type-approval), the substance being specifically referred to in the authorisation/certification granted and substitution, including the time needed for modification of the authorisation/certification/type-approval, would not be feasible within 12 years and would involve costs that would jeopardise the operations with regard to the use of the substance*".

6.4.2 Criterion 1: Demonstrably Long Investment Cycle

The aerospace and defence industry is driven by long design and investment cycles, as well as very long in-service time of their products, which are always required to meet the highest possible safety standards. As noted in Section 4.4, the average life of a civil aircraft is typically 20-35 years, while military products typically last from 40 to >90 years. Furthermore, the production of one type of aircraft or piece of equipment may span more than 50 years.

These long investment cycles and long product lives have been recognised in the FWC Sector 26 study on the Competitiveness of the EU aerospace industry[82]. They are a key driver underlying the difficulties facing the sector in substituting the use of the chromates in slurry coatings across all components within final products. The long service life of aircraft and other products makes it difficult to undertake all of the tests required to qualify and certify a component with the substitute, due to the level of investment and costs that would be involved in such an activity for out of production A&D products; as it would require testing at multiple levels (components, sub-assemblies, assemblies, final aircraft/defence equipment).

The ADCR would like to emphasise the crucial role every single component within an A&D product play with respect to its safety. For example, an aircraft is a complex system involving not only design of the aircraft itself, but also its use and maintenance history in varied climates and service. An aircraft engine is exposed to massive forces and extremely high stress levels due to high velocities and

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[82] 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.

environmental impacts. Therefore, every single component needs to be designed and manufactured with serious attention and care.

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

Even where such a small change is considered feasible in principle, the implications are significant and highly complex; 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 7 years to implement the use of a substitute across the value chain due to the scale of investment required and the need for OEMs to undertake their own qualification of different suppliers.

In addition, MoDs rarely revise specifications for older equipment, which must nevertheless be maintained and repaired. MROs servicing military equipment therefore have to undertake any maintenance or repairs in line with the OEMs' original requirements. Similarly, MROs in the civil aviation field are only legally allowed to carry out maintenance and repairs in line with OEMs' requirements as set out in Maintenance Manuals. Long service lives therefore translate to on-going requirements for the use of the chromates in the production of spare parts and in the maintenance of those spare components and the final products and aircraft/equipment they are used in.

As such, a review period of at least 12 years is warranted and requested for the highly complex systems the ADCR is addressing in this Combined AoA/SEA. A 12-year review period in itself may not be sufficient for the aerospace and defence industry to fully replace the chromates across all uses of slurry coatings however, the industry is committed to the goal of substitution. A 12-year review period will enable the implementation of the significant (additional) investment in R&D, qualification and certification of design/drawing changes and industrialisation required across the various OEMs.

6.4.3 Criterion 2: Cost of moving to substitutes

Cr(VI) coatings were validated/certified in the 1950s and 60s and extensive in-service performance has demonstrated the performance of chromated materials. This includes modifications to design practice and material selection based upon resolution of issues noted in service. Chromate-based slurry coatings, due to its extensive performance history, represent the baseline that alternatives must match to demonstrate equivalence.

For example, modern commercial aircraft (including helicopters) in their entirety consist of between 500,000 to 6 million components, depending on the model. Depending on the materials of construction, 15-70% of the entire structure of an aircraft requires treatment using Cr(VI) at some point during the manufacturing process. Older models generally require a larger percentage of Cr(VI) surface treatments as the aerospace industry has worked diligently to incorporate new base materials and Cr(VI)-free protective coatings in newer models wherever it is safe to do so.

There are literally billions of flight hours' experience with components protected from corrosion by chromate-based slurry coatings. Conversely, there is still limited experience with Cr(VI)-free alternatives on components. It is mandatory that components coated using a Cr(VI)-free alternative are demonstrably every bit as safe as they had been when coated using a Cr(VI) product. The performance of Cr(VI)-free products can sometimes be demonstrated at the laboratory step but then fails at industrial scale, as it is impossible to replicate all in-service conditions in a laboratory. As a result, the time taken to progress through the TRL process may be increased until it is possible for the performance of the alternative to be demonstrated as per safety requirements at the aircraft level when operating under real life conditions.

Flight safety is paramount and cannot be diminished in any way. Take, for example, a compressor blade that is located in the middle of an engine. If that blade can only survive for a portion of the life of an engine due to service life (and hence maintenance requirement) limitations on a new coating, the engine would need to be disassembled to be able to access the blades. That means taking the engine off the wing, sending it to a Repair Center, disassembling the engine and replacing the components at much shorter intervals than previously needed for the remainder of the engine. This would add inherent maintenance time and costs to the manufacturers; operators; and eventually end-use customers.

Where possible, and for specific components and final products, some new designs have been able to utilize newly developed alloys that do not require a Cr(VI)-based coating (as typically used to provide corrosion protection on metallic legacy components). However, even in newer designs there may still be a need for the use of chromate-based slurry coatings which cannot be replaced at present due to safety considerations.

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

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

Research into the substitution of the chromates has been on-going for several decades. Although use continues, it should be recognised that significant achievements have been made over this period in the substitution of the use of the chromates by alternative substances or technologies. This is illustrated by the achievements of one of the OEMs in reducing by 75% (reduction by weight) of their level of dependency on use of CT across all processes. (See Figure 6-3).

This 75% reduction in the use of CT by weight reflects the massive efforts and investment in R&D aimed specifically at substitution of the chromates. Although these efforts have enabled substitution across a large range of components and products, this OEM will not be able to move to substitutes for chromate-based slurry coatings (its single most important on-going use of the chromates) across all components and products for at least 12 years, and perhaps longer for those parts and products which have to meet military requirements (including those pertaining to UK, EEA and US equipment).

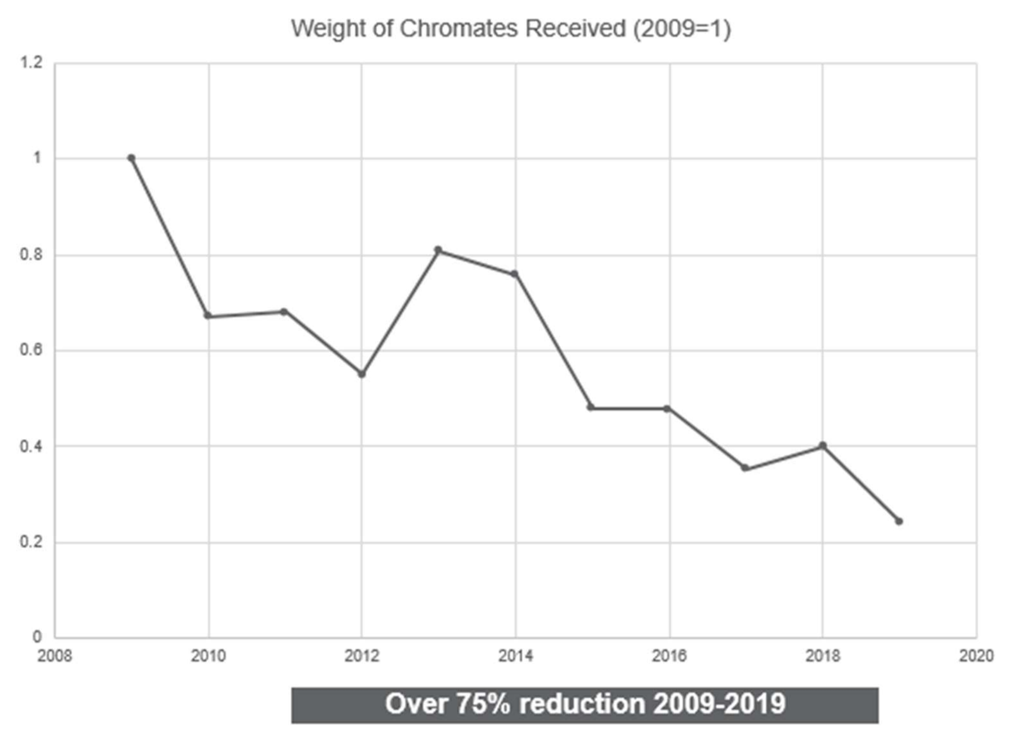

Figure 6-3: Reductions in chromate dependency over the period 2009 -2019

The European aerospace and defence industry is heavily regulated to ensure passenger/operator safety. The consequence are that there are very long lead times and testing cycles before technologies developed from a research project can be implemented into real products. Technologies which are available on the market today are the result of extensive research, including research funded by grants and conducted over the last 25+ years. In 2020, the European A&D industry spent an estimated €18 billion in Research & Development (with an approximate 40:60 split between civil and military activities, and investment in R&D in the US roughly four times higher)[83].

A PricewaterhouseCoopers (PwC) study[84] refers to the high risks of investments in the aerospace industry: "Historically, step changes have been the norm in aircraft R&D. But recent development efforts have been so expensive that it is unclear whether the companies will earn the anticipated return on their investments. Furthermore, slips in the programme schedule have worsened the economics".

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 slurry coatings, it requires testing of changes in a process of corrosion protection, which includes changes in the primers (another step in the process) applied to a slurry coating treated component or product.

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

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

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

If such performance is not achieved, then the alternatives cannot be used. The implications for repair, replacement and overhaul must also be understood before moving to an alternative. In particular, it must be recognised that the performance delivered by one component is dependent upon the performance of other components; thus, the performance delivered by a final product is dependent upon the components used. The number of configurations of components and final products is immense, and each configuration may differ from the next in terms of its behaviour with a Cr(VI) alternative.

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

6.4.5 Criterion 4: Legislative measures for alternatives

As discussed in detail in section 3.1.2, the identification of a technically feasible Cr(VI)-free formulation is only the first stage of an extensive multi-phase substitution process leading to implementation of the alternative. This process, illustrated below, requires that all components, materials and processes incorporated into an A&D system must be qualified, validated, certified and industrialised before production can commence. Each phase must be undertaken to acquire the necessary certification to comply with airworthiness and other safety-driven requirements.

From start to finish, significantly more than 12 years is required to move from Phase 1 to Phase 5 (i.e., to identify, qualify, validate, certify and industrialise alternatives) for all critical A&D applications. The ADCR OEMs and DtBs as design owners are currently working through this process with the aim of implementing chromate-free conversion coatings by 2036; their current substitution plans are designed to ensure they achieve TRL9 and MRL10 within the next 12 years or sooner. This includes gaining airworthiness certification or military safety approvals, both of which can take up to several years to ensure safety.

In addition, several of the ADCR members note that military procurement agencies prefer key components of defence equipment to be produced in the EEA, although there are also international agreements enabling manufacture in partner countries. In contrast to other industry sectors, shifting production to a non-EU territory and import of finished surface treated parts or products into the EU is more complex, as it could create a dependence on a non-EU 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 slurry coatings 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 slurry coatings by several actors in several EU member states (i.e., it often relies on a transnational supply chain). In contrast, defence exemptions are valid at a national level and only for the issuing member state. Furthermore, the defence exemption process cannot be used as an alternative to the normal authorisation process unless this is necessary for confidentiality reasons and in the interest of defence. Thus, defence applications also need to be covered by the normal authorisation process.

Finally, the EU defence sector requires only small quantities of chromates in slurry coatings. On the basis of a defence exemption alone, the quantities demanded would not be sufficient for manufacturers, formulators and surface treatment companies to continue to offer their services and products. As a result, coatings components for use in for military aircraft and equipment would not continue in the EEA or UK if other civilian applications were not also possible. This can only be ensured by the granting of an authorisation.

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

As demonstrated by the information collected by the SEA questionnaire, A&D companies have invested in monitoring and the installation of additional risk management measures in response to the conditions placed on the continued use of the chromates under the initial (parent) authorisations. This has resulted in reduced exposures for both workers and reduced emissions to the environment. As substitution progresses across components and assemblies and the associated value chains, consumption of the chromates will decrease, and exposures and emissions will reduce further over the requested 12-year review period. As a result, the excess lifetime risks derived in the CSR for both workers and humans via the environment will decrease over the review period. These risks will also be controlled through introduction in 2017 of the binding occupational exposure limit value on worker exposures to Cr(VI) at the EU level under the Carcinogens and Mutagens Directive[85].

The European aerospace and defence industry is a world-class leader in technology and innovation. They are an essential part of the European economy contributing to job creation (880,000 workers were employed in 2020[86]) and Europe's trade balance (55% of products developed and built in the EEA are exported).

Civil aeronautics alone accounted for around €99.3 billion in revenues, with military aeronautics accounting for a further €47.4 billion in turnover; overall taking into account other defence and space turnover, the sector had revenues of around €230 billion. Of the €99.3 billion in civil aeronautics turnover, €88.3 billion represented exports from the EU.

Both acknowledged market reports of Airbus and Boeing find a growing trend in the aerospace industry. Passenger air traffic is predicted to grow at 3.6% CAGR for 2022-2041 and freight traffic to grow at 3.2% CAGR globally, according to Airbus' Global Market Forecast. By 2041, there will be some 46,900 aircraft in service, with this including an estimated 39,500 new passenger and freighter aircraft (and the retirement of some of the older aircraft. This includes delivery of new aircraft for the European market, as well as the Asian and Chinese markets in particular.[87]

Boeing's 2022 Commercial Market Outlook[88] indicates a similar level of increase, noting that the global fleet will increase by around 80% through to 2041 with the forecast value of new airplane deliveries at around US $7.2 trillion (based on a slightly higher growth in traffic at around 3.8% CAGR.

The socio-economic benefits of retaining the key manufacturing base of the EEA and UK A&D industries are clearly significant, given that they will be major beneficiaries of this growth in demand. As demonstrated in the socio-economic analysis presented here, even without accounting for such growth in demand under the Continued Use Scenario, the socio-economic benefits clearly outweigh

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[85] 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

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

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

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

the associated risks to human health at social costs to risk ratios of over 3,560 to one for the EEA and 1,426 to one for the UK.

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

As the AoA shows, where alternatives have been proven as technically feasible – on a component-by-component basis – they have been, or are in the process of, being implemented. However, there are still many cases where components do not have technically feasible alternatives available. Figure 6-1 highlights the actions that are being taken by A&D design owners to develop, qualify, validate, certify and industrialise alternatives for individual components.

This work will continue over the requested review period with the aim of phasing out all uses of chromate-based slurry coatings. All illustrated in Section 4.4, on-going substitution is expected to result in significant decreases in the volumes of the two chromates used in slurry coatings within the next 7 years. However, technically feasible alternatives are still at the development phase (Phase 1 out of the 5 phases) for some components and final products, where alternatives have not been found to meet performance requirements.

6.6 Links to other Authorisation activities under REACH

This Combined AoA/SEA is one of a series of applications for the re-authorisation of the use of chromium trioxide in surface treatments carried out by the A&D industry. This series of Combined AoA/SEAs has adopted a narrower definition of uses original Authorised under the CTAC, CCST and GCCA parent applications for authorisation. Please see the Explanatory Note for further details.

In total, the ADCR will be submitting 11 combined AoA/SEAs covering the following uses and the continued use of chromium trioxide, sodium dichromate, potassium dichromate, sodium chromate and dichromium tris(chromate):

1) Formulation
2) Pre-treatments
3) Electroplating (hard chrome plating)
4) Passivation of stainless steel
5) Anodising
6) Chemical conversion coating
7) Anodise sealing
8) Passivation of non-aluminium metallic coatings
9) Inorganic finish stripping
10) Chromate rinsing after phosphating
11) Slurry coatings

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8 Annex 1: Standards applicable to slurry coating

Table 8-1 lists examples of standards and specifications reported by ADCR members applicable to the use slurry coating. The specifications/standards listed here are test methods and do not define success criteria for alternatives validation.

Table 8-1: Examples of standards applicable to slurry coating

Standard Reference	Standard Description	Key function/Standard type
ASTM B117	Standard Practice for Operating Salt Spray (Fog) Apparatus	Corrosion resistance
ISO 9227	Corrosion tests in artificial atmospheres - Salt spray tests	Corrosion resistance
EN ISO 2409	Paints and varnishes - Cross-cut test	Adhesion promotion
ISO 2812	Paints and varnishes - Determination of resistance to liquids	Chemical resistance
BS 3900-G5:1993	Sacrificial coatings: Paints and varnishes. Determination of resistance to liquids.	Chemical resistance

Source: ADCR members
"Standard description" obtained from https://standards.globalspec.com

9 Annex 2: European Aerospace Cluster Partnerships

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
International Aviation Services Centre (IASC)Ireland	Ireland	Shannon	60	46000	3.6bn GVA

Cluster Name	Country	City	Number of Companies	Employees	Sales/turnover
Invest Northern Ireland	Northern Ireland	Belfast	100	10000	£6.7 billion
LR BW Forum Luft- und Raumfahrt Baden-Württemberg e.V.	Germany	Baden-Wuerttemberg	93	15000	4.8 billion Euros
LRT Kompetenzzentrum Luft- und Raumfahrttechnik Sachsen/Thüringen e.V.	Germany	Dresden	160	12000	1.5 billion Euros
Madrid Cluster Aeroespacial	Spain	Madrid		32000	8 billion Euros
Midlands Aerospace Alliance	UK	Midlands	400	45000	
Netherlands Aerospace Group	Netherlands		89	17000	4.3 billion Euros
Niedercachsen Aviation	Germany	Hanover	250	30000	
Normandie AeroEspace	France	Normandy	100	20000	3 billion Euros
Northwest Aerospace Alliance	UK	Preston	220	14000	£7 billion
OPAIR	Romania			5000	150 million Euros
Portuguese Cluster for Aeronautics, Space and Defence Industries	Portugal	Évora	61	18500	172 million Euros
Safe Cluster	France		450		
Silesian Aviation Cluster	Poland	Silesian	83	20000	
Skywinn - Aerospace Cluster of Wallonia	Belgium	Wallonia	118	7000	1.65 billion euros
Swiss Aerospace Cluster	Switzerland	Zurich	150	190000	16.6 billion CHF 2.5 % of GDP
Torino Piemonte Aerospace	Italy	Turin	85	47274	14 billion euros

10 Annex 3: UK Aerospace sector

10.1 Aerospace

The annual ADS Industry Facts and Figures guide provides an indication of the UK aerospace, defence, security and space sectors' contribution to the economy in 2021, as shown in Figure 10-1. The Aerospace, Defence, Security and Space Group (ADS) notes that it has over 1,100+ member companies (including over 1,000 SMEs), supporting around 1,000,000 jobs (direct and indirect) across the country.

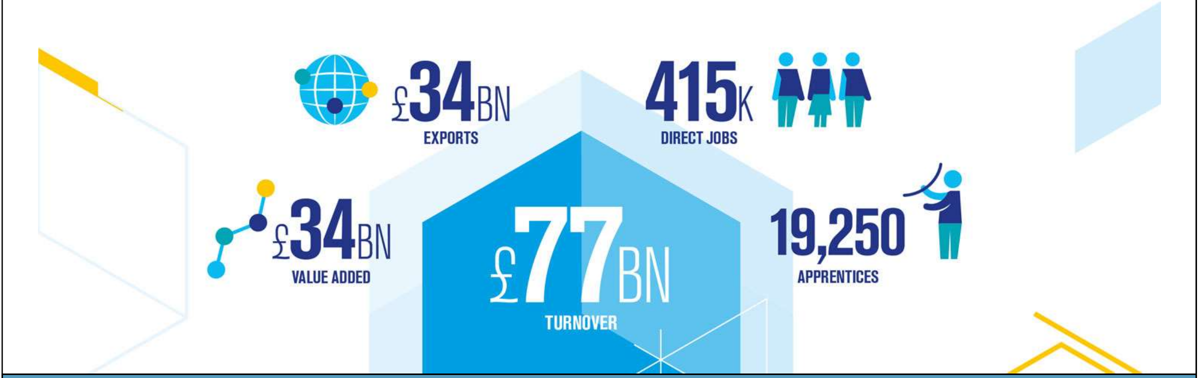

Figure 10-1: Contribution of UK aerospace, defence, security and space sectors to the economy in 2021[89]

The UK aerospace sector is considered by the government to be "hugely important to the UK economy"[90], providing direct employment of over 120,000 highly skilled jobs that pay about 40% above the national average. The sector has an annual turnover of around £77bn, half of which comes from exports to the rest of the world. It is a driver of economic growth and prosperity across the UK, given that most of the jobs (92%) are located outside London and the Southeast.

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)[91]. To date, this co-funded programme has invested £2.6 billion, across all parts of the UK. It is anticipated that the UK aerospace sector will continue to grow into the future, due to the global demand for large passenger aircraft, as discussed further below.

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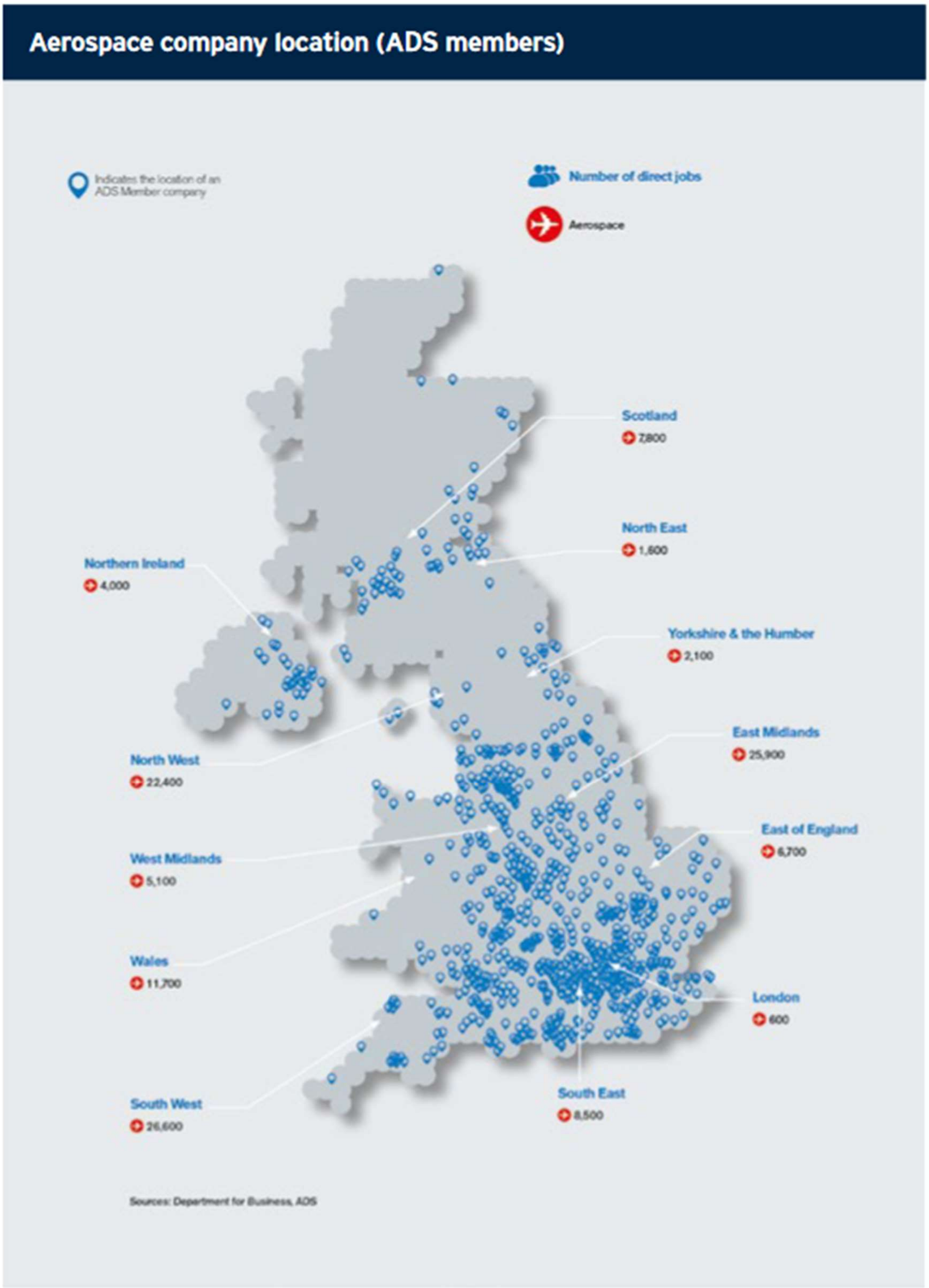
[89] https://www.adsgroup.org.uk/wp-content/uploads/sites/21/2022/06/ADS-FF2022-Twit-header-72.jpg

[90] BEIS, Aerospace Sector Report, undated.

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



Sources: Department for Business, ADS

Figure 10-2: Location of aerospace manufacturing sites and associated jobs in the UK[92]

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

The National Aerospace Technology Exploitation Programme was created in 2017 to provide research and technology (R&T) funding with the aim of improving the competitiveness of the UK aerospace industry, as well as other supporting measures under the Industrial Strategy. The Government's investment in R&T is through the Aerospace Technologies Institute and is programmed at £1.95 billion in expenditure between 2013-2026.

This will help in maintaining the current expected market development in the UK, which would see a 2.3% per year growth in real terms, leading to direct added value of just over £14 billion in 2035 (compared to £9 billion in 2016). In 2016, the UK aerospace sector employed around 112,500 people, with each direct job in the aerospace industry creating at least one additional job within the aerospace supply chain. This gives around 225,000 people directly and indirectly employed by the aerospace sector in high-value design and high value manufacturing jobs. By maintaining its current direction of growth, the sector is expected to create up to a further 45,000 positions by 2035.

The value of the sectors is also significant in wider economic terms. Investment in aerospace research and technology leads to wider impacts beyond the sector. Every £100 million spent on R&T by the government crowds-in around £300 million of additional private sector investment. Furthermore, every £100 million invested benefits not only UK aerospace GVA by £20 million per year, but also the wider economy by £60 million per year through technology spillovers. These include automotive, marine, oil and gas, nuclear, electronics, composites, metals and other UK industrial sectors. In total, the return on government investment in the sector is estimated as delivering an additional £57 billion of gross value added for the UK aerospace sector and a further £57 billion to the wider UK economy between 2015 and 2035.

10.2 Defence

With respect to defence, the UK is the second largest defence exporter in the world, with its contribution to employment, turnover, and exports illustrated in Figure 10-3[93]. Again, the importance of the sector to UK exports and value added, as well as employment is clear from the figure below.

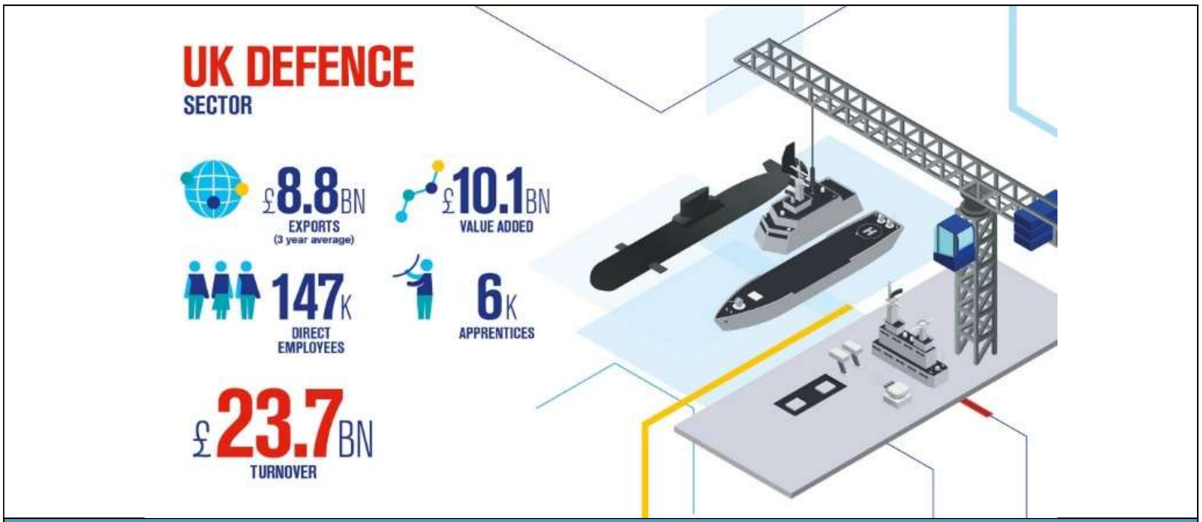

Figure 10-3: UK defence sector contribution to the economy in 2021

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[93] Sources: https://www.adsgroup.org.uk/industry-issues/facts-figures/facts-figures-2022/