Analysis of Alternatives and Socio-Economic Analysis

Legal name of applicant(s): AB Connectors Ltd

Submitted by: AB Connectors Ltd

Date: 30 March 2025

Substance: Chromium Trioxide

EC: 215-607-8
CAS: 1333-82-0

Use title: Industrial application of a mixture with hexavalent chromium compounds (chromium trioxide) for the surface treatment of mechanical parts, electrical connectors and associated components meeting the relevant standards and requirements for challenging environments and/or high safety applications.

Use number: 2

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TABLE 1 - LIST OF ABBREVIATIONS

Abbreviation	**Full Term**
ADCR	Aerospace and Defence Chromates Reauthorisation Consortium
Cr(III)	Trivalent Chromium
Cr(VI)	Hexavalent Chromium
CRS	Chemical Safety Report
CTAC	Chromium Trioxide Authorisation Consortium
EMI	Electromagnetic Interference
EU	European Union
HSE	Health & Safety Executive
MIL-DTL	Military Detail Specification
MoD	Ministry of Defence
OEM	Original Equipment Manufacturer
PCN	Product Change notification
RAC	Risk Assessment Committee
REACH	Registration, Evaluation, Authorisation, and Restriction of Chemicals
RFI	Radio Frequency Interference
SEA[1]	Socio-Economic Analysis
SEA[2]	Surface Engineering Association
SEAC	Socio-Economic Analysis Committee
SVHC	Substance of Very High Concern
UK	United Kingdom

Declaration

We, the Applicant, AB Connectors Ltd, are aware of the fact that further evidence might be requested by Health & Safety Executive (HSE) to support the 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 30 March 2025, the information is not publicly available, and, in accordance with the due measures of protection that we have implemented, a member of the public should not be able to obtain access to this information without our consent or that of the third party whose commercial interests are at stake.

Signature: AB Connectors Ltd

Date, Place: 30 March 2025, Abercynon, Mountain Ash, UK

1 Summary

AB Connectors Ltd. is a downstream user of #1 [redacted] and #2 [redacted] which contain Hexavalent Chromium. Through the process the substance name changes based on its situation. For clarity, as a raw material it may be referred to as Chromium Trioxide, if it is diluted in water, it may be referred to as Chromic Acid and if it is mixed with additional substances, it may be referred to as Hexavalent Chromium.

This report evaluates the continued use of hexavalent chromium (Cr(VI)) in surface treatments applied to electrical connectors used in harsh environments and markets. Due to its classification as a Substance of Very High Concern (SVHC) under Annex XIV of the UK REACH regulation, Cr(VI) use is highly restricted, necessitating a comprehensive assessment of alternative coatings.

Hexavalent chromium has been widely used for decades due to its unmatched combination of corrosion resistance, electrical conductivity, adhesion properties, and durability. These properties are essential for ensuring the long-term reliability of electrical connectors exposed to extreme conditions, including high humidity, fluctuating temperatures, vibration, and corrosive environments.

This report examines potential alternatives, including trivalent chromium (Cr(III)), electroless nickel with advanced sealers, zinc-nickel alloy coatings, and high-performance polymer coatings. Each alternative is evaluated for technical feasibility, economic viability, safety considerations, and overall suitability for use in the required markets.

The findings indicate that, while research into alternatives is ongoing, no fully compliant drop-in replacement exists that meet all performance and regulatory requirements. Therefore, the continued use of Cr(VI) remains necessary for harsh environment applications, and further efforts should focus on risk mitigation and long-term transition strategies.

Figure 1 - Example of products concerned by Use-2

2 Aims and Scope

2.1 Aims

The main markets which the business currently operate in would be the defence, industrial and rail. These markets rely heavily on electrical connectors that must withstand extreme environmental conditions, including high humidity, temperature fluctuations, corrosion, and mechanical wear. Hexavalent chromium (Cr(VI)) has long been used in surface treatments, such as chromate conversion coatings and anodising, due to its superior corrosion resistance, electrical conductivity, and adhesion properties.

However, due to health and environmental concerns, regulatory restrictions on Cr(VI), such as the UK REACH regulation, have increased, necessitating an analysis of alternative solutions to ensure compliance while maintaining performance standards. This report evaluates potential alternatives against the stringent requirements set by the design authority.

The primary objectives of this Analysis of alternatives AoA are:

- To assess the feasibility of replacing Cr(VI)-based surface treatments with alternative coatings.
- To evaluate the technical, economic, and safety aspects of potential alternatives in the context of their application in defence and rail industries.
- To provide a technical justification for the continued use of Cr(VI) where no viable alternatives currently exist.
- To outline risk mitigation strategies and long-term research efforts towards developing safer alternatives.

2.2 Scope

This analysis focuses on:

- Application: Surface treatments for electrical connectors used in extreme environments.
- Industries: Defence, industrial and rail sectors, where reliability and long-term durability are critical.
- Performance Requirements: Corrosion resistance, electrical conductivity, mechanical durability, and compliance with regulatory standards.
- Alternatives Assessed: Various coatings and surface treatment technologies that could potentially replace Cr(VI).
- Stakeholders Consulted: Manufacturers, suppliers, regulatory bodies, and end-users.
- Geography: The use in manufacturing at the AB Connectors facility in South Wales, UK

2.3 Performance Requirements

Electrical connectors used within harsh environments, must meet the following criteria:

- Corrosion Resistance: Minimum 500-hour salt spray resistance (per MIL-DTL-38999 or equivalent).
- Electrical Conductivity: Low contact resistance for EMI/RFI shielding.
- Adhesion Properties: Ensures long-term durability of coatings.
- Environmental Stability: Withstands extreme temperatures, moisture, and chemicals.
- Mechanical Durability: Maintains performance under vibration, impact, and wear.
- Regulatory Compliance: Adheres to REACH, RoHS, and other industry-specific regulations.

2.4 Key Facts

The following outlines key information regarding the use of hexavalent chromium at AB Connectors Ltd:

TABLE 2 – KEY FACTS AB CONNECTORS

Current workforce	<250 (projected to end of 2025: <250).
Turnover	[redacted]
Revenue Split (2025), specific to products that utilise Cr(VI)	
Gross Margin	
Markets	
Key Customers (not exhaustive)	
Applications	

3 Analysis of Alternatives

3.1 SVHC Use Applied For

Industrial application of a mixture with hexavalent chromium compounds (chromium trioxide) for the surface treatment of mechanical parts, electrical connectors and associated components meeting the relevant standards and requirements for challenging environments and/or high safety applications.

3.1.1 Description of the Functions of the Annex XIV Substance and Performance Requirements of Associated Products

Hexavalent chromium (Cr(VI)) is used in surface treatments such as chromate conversion coatings and anodising processes applied to aluminium and other metals. It plays a critical role in:

- Corrosion Protection: Provides superior resistance to oxidation, salt spray, and chemical exposure, ensuring long-term performance.
- Electrical Conductivity: Maintains low contact resistance (as per customer requirement or by connector specification/standard), ensuring effective EMI/RFI shielding and reliable electrical connections.
- Adhesion and Durability: Enhances adhesion of subsequent coatings, such as paints or adhesives, and withstands mechanical wear and abrasion.
- Environmental Resistance: Ensures functionality in extreme conditions, including high humidity, temperature fluctuations, vibration, and mechanical stress.

Harsh environment connectors must meet stringent design authority requirements, including:

- Salt Spray Resistance: Minimum 500-hour resistance as per MIL-DTL-38999 or equivalent.
- EMI/RFI Shielding: Critical for electronic systems requiring electromagnetic compatibility (EMC).
- Temperature and Mechanical Stability: Must withstand harsh operational conditions without degradation.

3.1.2 Market Analysis of Products Manufactured with Annex XIV Substance

- Defence Sector: We are significantly engrained in the support of the global defence market, especially across the UK and North America supporting global UK primes such as [redacted]. Electrical connectors are used in military vehicles, aircraft, naval systems. Reliability is mission-critical, and failures could compromise national security. Key uses include, but are not limited to, power distribution in military vehicles and tanks, as well as supporting secure communication networks.

- Rail Sector: Currently the UK leading supplier of circular connectors for the rail market. Critical for dependable power distribution, signalling, and communication systems, with components designed to withstand relentless weather exposure and mechanical strain. Markets globally are also supported.

- Aerospace & Industrial Uses: Employed in avionics, industrial automation, industrial measurement systems and high-performance electronics, where exceptional durability and reliability are non-negotiable. Sales into the aerospace market are expected to be c.[redacted] in 2025 although connector specific sales are forecast to be [redacted] in 2027, representing a market with high potential for the business.

The applications within these sectors have long life cycles (20+ years), making backward compatibility and long-term performance essential.

3.1.3 Annual Volume of the SVHC Used

The total annual usage of Cr(VI) for this specific use case is estimated to be 0.372 tons per year in total.

3.2 Efforts Made to Identify Alternatives

We have a close working relationship with our chemical suppliers, [redacted] and have engaged with them on identifying alternatives. In addition, we occasionally use third party suppliers that apply the plating for us to support capacity or downtime issues. More specifically, we use [redacted] and [redacted] so we can reference their AoA and SEA[1] documentation that they have provided as a consortium with other Plating companies (CTAC), and more recently ADCR and SEA[2] Reach consortiums.

3.2.1 Research and Development

We are aware that chemical and plating suppliers are actively looking for alternatives and we have engaged with them to support sample manufacture, which allows us to evaluate plating effects on different materials and different intricate features of the connector design.

In addition, we support with laboratory testing of alternative coatings, including:

- Corrosion resistance tests (salt spray, cyclic corrosion testing).
- Electrical performance tests (contact resistance, EMI shielding).
- Mechanical durability tests (wear resistance, adhesion).
- Collaboration with defence and aerospace organisations for joint research.

3.2.2 Consultations with Customers and Suppliers of Alternatives

Feedback from end-users reveals worries that alternative coatings may not meet required performance levels.

Additionally, customers face challenges with the capacity and resources needed to revise documentation, given the sheer number of updates involved and the fact that many foundational drawings and specifications are outdated. Many specifications call for specific colours, especially rail and the default here is black.

Many customers have a want and are contracted to maintain a minimum % of a UK supply chain.

Ultimately, the availability of appropriate chemicals dictates the feasibility of finding viable alternatives, prompting us to maintain close collaboration with our chemical and plating suppliers to stay informed on any progress in developing substitutes.

3.2.3 Data Searches

Essentially, the ability to source chemicals drives the availability of a suitable alternative and so we remain close to our chemical and plating suppliers regarding any development of alternatives.

Review of REACH-compliant coatings and regulatory exemption processes.

Analysis of patents, technical reports, and industry white papers.

3.2.4 Identification of Alternatives

The following alternatives have been identified with the main area of focus on Corrosion resistance and striking a balance versus Electrical conductivity.

- Trivalent Chromium (Cr(III)) Coatings
- Electroless Nickel with Advanced Sealers
- Zinc-Nickel Alloy Coatings
- High-Performance Polymer-Based Coatings

3.2.5 Shortlisted Alternatives

Based on feasibility studies, the following alternatives were shortlisted for detailed assessment:

TABLE 3 – SHORTLISTED ALTERNATIVES

Alternative Name	Corrosion Resistance	Electrical Conductivity	Durability	Regulatory Compliance	Suitability for Harsh Environments
Current - Cr(VI) Chromate Conversion	**Excellent**	**Excellent**	**Excellent**	**Restricted**	**Highly Suitable**
Trivalent Chromium (Cr(III)) Coatings	Moderate	Moderate	Moderate	Compliant	Limited Suitability
Electroless Nickel with Advanced Sealers	Good	Low	Good	Compliant	Moderate Suitability
Zinc-Nickel Alloy Coatings	Good	Low to Moderate	Moderate	Compliant	Moderate Suitability
High-Performance Polymer-Based Coatings	Good	Poor	Moderate	Compliant	Limited Suitability

3.3 Assessment of Shortlisted Alternatives

Each alternative is evaluated based on:

• Technical Feasibility

• Economic Viability

• Safety and Environmental Considerations

• Suitability for required Applications

3.3.1 Trivalent Chromium (Cr(III)) Coatings

3.3.1.1 General Description

Uses Cr(III) instead of Cr(VI) in conversion coatings and has a thick (black) passivate layer to protect from abrasion and add the desired colour.

3.3.1.2 Availability

Commercially available but lacks full military qualification.

3.3.1.2 Safety Considerations

Significantly lower toxicity than Cr(VI).

3.3.1.2 Technical Feasibility

Moderate corrosion resistance and electrical conductivity; In certain applications where lower corrosion resistance is needed the corrosion resistance performance would be acceptable, however the electrical performance suffers due to the non-conductive passivate layer and so remains unsuitable. In addition, there are some compatibility issues with legacy defence and rail applications.

3.3.1.3 Economic Feasibility

Moderate cost but requires process changes.

3.3.1.4 Suitability

Limited for extreme conditions.

3.3.2 Electroless Nickel with Advanced Sealers

3.3.2.1 General Description

Electroless nickel (EN) coatings with additional sealers (such as PTFE or nano-ceramic sealants) provide corrosion and wear resistance.

3.3.2.2 Availability

This was one of the first development for an alternative coating and whilst it is used in various industries, it is not optimised for EMI/RFI shielding.

3.3.2.3 Safety Considerations

Safer than Cr(VI), but nickel has some regulatory concerns.

3.3.2.4 Technical Feasibility

Whilst this plating provides good corrosion, there is again a compromise and gives high electrical resistance.

3.3.2.5 Economic Feasibility

Converting plating lines over would be highly expensive and would need post-processing to achieve necessary performance. Alternatively, this could be outsourced to a specialist contractor, with obvious additional costs.

3.3.2.6 Suitability

Limited for electrical connectors.

3.3.3 Zinc-Nickel Alloy Coatings

3.3.3.1 General Description

A sacrificial coating often used in aerospace and automotive industries, offering improved corrosion resistance compared to traditional zinc plating.

3.3.3.2 Availability

Used in aerospace and automotive but not widely adopted for connectors.

3.3.3.3 Safety Considerations

Environmentally safer than Cr(VI).

3.3.3.4 Technical Feasibility

Moderate corrosion protection; poor conductivity.

3.3.3.5 Economic Feasibility

Cost-effective but requires additional processing.

3.3.3.6 Suitability

Limited for high-reliability applications.

3.3.4 Conclusion on shortlisted alternatives

Based on the current state of alternative technologies:

- No identified alternative meets all performance criteria required for applicable markets for electrical connectors.
- While some alternatives show potential, they exhibit technical limitations in corrosion resistance, adhesion, and electrical conductivity.
- The continued use of Cr(VI) remains necessary until a viable substitute is fully developed and validated.

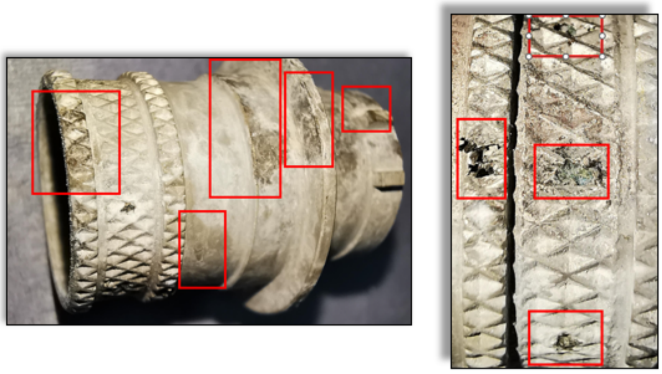

Figure 2 - Visual examination of poor corrosion resistance (plating finish penetrated to base material following 500-hour salt mist)

4 Socio-Economic Analysis

This Socio-Economic Analysis (SEA[1]) examines the implications of both the continued use and the non-use of hexavalent chromium (Cr(VI)) in surface treatment processes for electrical connectors used in harsh environments. The analysis assesses the economic, technical, regulatory, and social impacts associated with each scenario, considering the viability of alternatives, risks of continued use, and economic consequences of discontinuation.

The SEA[1] aims to inform policymakers and stakeholders in the defence and rail industries about the real-world effects of Cr(VI) restrictions and whether a review period is necessary to allow for further research and development (R&D) into viable substitutes.

4.1 Continued use scenario

4.1.1 Summary of Substitution Activities

Efforts to identify and qualify alternative surface treatments have been extensive and ongoing. Research has focused on coatings such as trivalent chromium (Cr(III)), electroless nickel, zinc-nickel alloys, and high-performance polymer coatings. However, no alternative has fully met the performance, reliability, and regulatory requirements necessary for defence and rail applications.

Key substitution activities include:

1. Research & Development (R&D)
   - Extensive laboratory testing of potential alternative coatings to evaluate corrosion resistance, electrical conductivity, adhesion, and durability.
   - Collaboration with chemical suppliers, plating suppliers, universities, and material science experts to improve Cr(III) formulations.

2. Consultation with Industry Stakeholders
   - Engaging with Original Equipment Manufacturers (OEMs), military authorities, railway operators, and suppliers to understand operational needs.
   - Participation in industry forums and regulatory discussions to assess feasibility of new solutions.

Despite these efforts, no alternative has demonstrated equivalent performance in all required parameters to date.

4.1.2 Conclusion on Suitability of Available Alternatives in General

None of the identified alternatives meet the stringent performance and reliability requirements for applicable harsh environments for electrical connectors. Continued use of Cr(VI) is essential until an equivalent substitute is developed.

4.1.3 Substitution Plan

As no suitable alternative currently exists, substitution is not possible or applicable at this time.

Despite extensive efforts to identify and qualify alternatives, all currently available substitutes fail to meet the critical technical, operational, and regulatory requirements necessary for defence and rail applications.

4.1.3.1 Factors affecting substitution.

n/a – see 4.1.3

4.1.3.2 List of actions and timetable with milestones

n/a – see 4.1.3

4.1.3.3 Monitoring of the implementation of the substitution plan

n/a – see 4.1.3

4.1.3.4 Conclusions

n/a – see 4.1.3

4.1.3.5 References

n/a – see 4.1.3

4.1.4 R&D Plan

A long-term R&D roadmap is required to bridge the gap between Cr(VI) performance and alternative solutions. Key initiatives include:

1. Advanced Trivalent Chromium Development
    - Investigating new formulations to improve corrosion resistance and adhesion properties.
    - Enhancing coating deposition methods to increase uniformity and durability.
2. Hybrid Coating Systems
    - Combining Cr(III) with nanoparticle-infused sealers to enhance performance.
    - Testing multi-layered approaches that mimic Cr(VI) characteristics.
3. Accelerated Field Testing & Qualification
    - Conducting real-world exposure tests in high-humidity, high-salt environments.
    - Monitoring long-term degradation rates.
4. Collaboration with Defence and Rail Authorities
    - Partnering with military and rail organisations to co-fund R&D and share test data.
    - Standardising testing protocols for alternative coatings.

Each of the above initiatives will involve close liaison and involvement with various stakeholders, not least many of the members of the Chromium Trioxide Authorisation Consortium. The consortium consists of not only specialist in the field, but also suppliers of the plating treatments. In addition, we maintain a close relationship with [redacted] for access to and development of the chemistry involved.

A review period of 12 years is recommended to continue R&D while maintaining Cr(VI) use in critical applications.

4.2 Risks Associated with Continued Use

Despite its technical superiority, the continued use of hexavalent chromium (Cr(VI)) presents several risks related to regulatory compliance, health and safety, environmental impact, and market reputation. These risks must be carefully managed to ensure that Cr(VI) use remains justifiable for mission-critical defence and rail applications. The current control measures within the business are already deemed to be sufficient to minimise exposure to environment and human health.

The worst-case assessment of worker health risks within the socio-economic analysis utilises the results of a study endorsed by ECHA identifying the reference dose response relationship for carcinogenicity of hexavalent chromium. The results are acknowledged to be the preferred approach of the RAC and SEAC and therefore have been used as a methodology for the calculation of work cancer risks in this socio-economic analysis.

The following steps are therefore necessary to complete the health impact assessment:

- 1 – Assessment of worker exposure (actual measurements)
- 2 – Estimation of additional cancer deaths relative to the baseline lifetime risk
- 3 – Estimation of additional non-fatal cancer based on survival rate statistics
- 4 – Monetary valuation of fatal and non-fatal cancer risks

Following the worst-case approach, the combined worker exposure values from the corresponding chemical safety report, section 10, are used to make the assessment of health impacts. Following the ECHA methodology where the applicant only provides data for the exposure to the inhalable particulate fraction, it will be assumed that all particles were in the respirable size range and only lung cancer need be considered.

For the lung cancer calculation, excess lifetime risk (ELR) is defined as the additional risk of dying from cancer due to exposure of toxic substances incurred over the lifetime of an individual. From the ECHA RAC the unit of occupational excess lifetime mortality risk is 4×10^{-3} per µg Cr(VI)/m^3.

TABLE 4 – EXCESS LUNG CANCER MORTALITY RISK TO WORKERS

A	Inhalation exposure weighted average	4.97
B	Excess risk unit coefficient	4×10^{-3} per µg/m^3
C	Excess risk for 40 years (A x B)	19.88×10^{-3}
D	Excess risk per year (C/40)	0.50×10^{-3}
E	Number of workers exposed	7
F	Total annual excess risk (number of cases)	0.003479

The individual development of cancer may be fatal or non-fatal whereas the dose response function considers only fatal cancer. If therefore follows that the excess risk of cancer is higher than the excess risk of fatal cancer.

According to Cancer Research UK the following table can be developed:

Table 5 - AGE-STANDARDISED, FIVE-YEAR SURVIVAL RATES FOR LUNG CANCER IN THE UK, 2013-2017

Relative cumulative survival	Non-fatal / fatal ratio
16.2	0.193

This means that for every fatal case of lung cancer, there is an additional 0.193 non-fatal cases in the UK. This equates to 0.0003 non-fatal cancer cases associated with this application.

Table 6 - VALUES FOR FATAL AND NON-FATAL CANCER TAKEN FROM ECHA GUIDANCE USING DECEMBER 2003 EXCHANGE RATE €1.42 / £1

	2003	GDP Factor	2024
Value of statistical life	£740,845	132.21	£979,471
Value of statistical life (sensitivity)	£1,590,141		£2,102,325
Value of cancer morbidity	£370,423		£489,736
Value of cancer morbidity (sensitivity)	£795,070		£1,051,162
Value of cancer fatality	£1,111,268		£1,469,207
Value of cancer fatality (sensitivity)	£2,385,211		£3,153,487

The GDP factor is the change in UK GDP between 2003 and 2024 as per the UK Office for National Statistics and allows for inflationary impacts to be included in the assessment.

Table 7 - ESTIMATED MONETRY VALUE OF ANNUAL RISK OF LUNG CANCER FROM CHROMIUM TRIOXIDE EXPOSURE FOR THIS APPLICATION

	All sites combined
Fatal cancer risk per year	0.003479
Annual cost of fatal cancer Per case £1,469,207 Sensitivity £3,153,487	 £5,111.37 £10,970.98
Non-fatal proportion Non-fatal cancer risk per year Annual cost of non-fatal cancer risk Per case £489,736 Sensitivity £1,051,162	0.193 0.000671 £328.83 £706
Total annual cost of cancer Sensitivity	£5,440.20 £11,676.78

These figures used the same methodology of those submitted by Grohe AG who were granted a 12-year review period for their authorisation.

Given that the results show no increased risk over that of the General Population and that emissions to atmosphere are very low and likely to be atmospherically reduced to chromium trioxide, the implications of a non-use scenario will only affect the applicants and their customers.

Similarly, the continued-use scenario does not give rise to any additional economic burden toward health or environment.

4.2.1 Impact on Humans

Cr(VI) is classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC) and is associated with several adverse human health effects. Exposure risks arise in manufacturing, application, maintenance, and disposal stages. The key human health impacts include:

Occupational Health Risks

- Inhalation Exposure: Workers involved in Cr(VI) plating and surface treatment may inhale airborne Cr(VI) particulates, increasing the risk of lung cancer, respiratory irritation, and chronic bronchitis.
- Dermal Exposure: Direct skin contact with Cr(VI) compounds can cause severe skin irritation, ulceration ("chrome ulcers"), and allergic dermatitis.
- Ingestion Risks: Accidental ingestion due to hand-to-mouth transfer can lead to gastrointestinal distress and potential kidney or liver toxicity.

Non-Occupational Exposure Risks

- End-User Contact: While Cr(VI) is primarily used in surface treatments and becomes embedded in a stable form, some degradation over time may release Cr(VI) particles. However, direct consumer exposure is minimal due to sealing and protective coatings.
- Community Exposure: Improper waste disposal or leaks from plating facilities can contaminate local water sources, potentially exposing nearby communities.

Mitigation Measures – Currently in Place

- Strict Occupational Safety Measures: Use of ventilation systems, protective clothing, and regular health monitoring to minimise worker exposure.
- Process Improvements: Implementation of closed-loop plating systems and automation to reduce human handling.
- Training and Compliance Programs: Regular worker training on handling protocols and emergency response to minimise risks.

4.2.2 Impact on Environmental Compartments

Cr(VI) can enter various environmental compartments through air emissions, wastewater discharge, and solid waste disposal. The environmental risks associated with its continued use include:

Air Pollution

- Industrial Emissions: Airborne Cr(VI) particulates may be released from plating facilities, posing a risk of atmospheric deposition.
- Risk Mitigation: Scrubbers, filtration systems, and stringent emission controls help minimise airborne release.

Water Contamination

- Plating Process Wastewater: Cr(VI) residues from surface treatment processes can leach into groundwater or be discharged into waterways if not properly managed.
- Bioaccumulation Risk: Cr(VI) is highly toxic to aquatic organisms, potentially leading to mutagenic effects in fish and disruption of aquatic ecosystems.
- Risk Mitigation: Industrial wastewater treatment, ion-exchange filters, and chemical reduction processes (converting Cr(VI) to the less toxic Cr(III)) before discharge.

Soil Contamination

- Industrial Waste Disposal: Improper disposal of Cr(VI)-contaminated sludge and byproducts may result in long-term soil contamination, affecting agriculture and local biodiversity.
- Risk Mitigation: Secure hazardous waste landfills, recycling of Cr(VI)-contaminated materials, and adherence to strict disposal regulations.

Long-Term Environmental Persistence

- Unlike organic pollutants, Cr(VI) does not degrade easily, meaning it can accumulate in the environment and remain hazardous for decades if not properly managed.

4.2.3 Compilation of Human Health and Environmental Impacts

The combined human health and environmental impacts associated with Cr(VI) can be summarised as follows:

TABLE 8 – COMPILATION OF HUMAN HEALTH AND ENVIRONMENTAL IMPACTS

Impact Category	Description	Mitigation Measures
Human Health - Occupational	Increased risk of lung cancer, skin ulceration, and dermatitis.	Strict PPE use, ventilation, automated processes.
Human Health - General Public	Potential exposure via contaminated water sources.	Industrial wastewater treatment, regulatory oversight.
Air Pollution	Industrial emissions may contribute to atmospheric deposition.	Scrubbers, air filtration, emission reduction systems.
Water Contamination	Toxic to aquatic life, potential bioaccumulation risk.	Chemical reduction of Cr(VI) to Cr(III) before discharge.
Soil Contamination	Improper disposal may lead to persistent environmental contamination.	Secure hazardous waste landfills, proper disposal protocols.

4.2.4 Conclusion

While the risks associated with Cr(VI) exposure and environmental contamination are significant, current risk mitigation strategies and strict regulatory controls have proven effective in reducing potential harm. Continued research into safer handling methods and process improvements will further minimise risks, ensuring that Cr(VI) use remains as safe and controlled as possible until a viable alternative is available.

4.3 Non-Use Scenario

4.3.1 Summary of Consequences of Non-Use

If Cr(VI) is phased out without a viable alternative, the consequences include:

- Severe performance degradation in defence and rail connectors.
- Supply chain disruptions, leading to long lead times for critical components.
- Regulatory non-compliance, preventing sales to military customers.
- Economic downturn due to plant closures and job losses.

4.3.2 Identification of Plausible Non-Use Scenarios

Scenario 1: Shutdown of Plating Process, Resulting in Company Closure

AB Connectors Ltd will no longer be able to meet the performance standards and will need to cease operations, resulting in loss of high-skill jobs within their South Wales facility.

In addition, there will be significant disruption in the associated defence, rail and industrial markets due to shortages of compliant connectors.

Scenario 2: Change to Inferior Performing Alternative

This approach is unlikely to gain acceptance from customers or end-users. Adopting a less effective alternative would result in more frequent failures and elevated maintenance expenses. Given that these connectors are integral to safety-critical systems, their use in mission-critical applications also introduces potential safety hazards. Consequently, end-users might turn to non-UK suppliers, causing economic disruption.

4.3.3 Conclusion on Most Likely Non-Use Scenario

The most likely outcome of non-use is the shutdown of Cr(VI) plating processes, leading to company closures, job losses, and negative economic impacts.

4.4 Societal Costs Associated with non-Use

4.4.1 Economic Impacts on Applicants

In a non-use scenario, AB Connectors would be unable to fund a relocation of it manufacturing outside of the UK an EU and so there would be a significant loss of contracts from defence and rail industries, which represents 75% of the companies' activities. With the addition of increased cost to develop alternative solutions, the company would be faced with significant job losses, and most likely complete closure due to being unable to recover overhead costs. The Senior Management Team the business not viable without the ability to service the key markets and preference is to remain in the UK.

TABLE 9 - ECONOMIC IMPACT ON APPLICANT - ANNUAL

Revenue Dependency	[redacted]
Profit	
Relocation outside of UK/EU	
Total Loss	
Growth Impact	
Jobs	<250

TABLE 10 - ECONOMIC IMPACT ON APPLICANT – 10 YEAR PERIOD

Revenue Dependency	[redacted]
Profit	
Total Loss	
Growth Impact	
Jobs	<250

4.4.2 Economic Impacts on the Supply Chain

- Procurement would need to be performed from outside the UK/EU
- Increased lead times for alternative coatings
- Higher procurement costs for end-users
- Loss of UK content. End customer contracts stipulate UK supply minimum content

4.4.3 Economic Impacts on Competitors

- Non-EU competitors may gain a market advantage if they continue using Cr(VI).

4.4.4 Wider Socio-Economic Impacts

Beyond the impacts already outlined, the wider effects include AB Connectors Ltd, as an SME, losing its capacity to support prime contractors and Tier 1 supply chains. This would undermine the UK market's agility and competitiveness, leading to the elimination of high-value engineering jobs across a diverse network of customers, suppliers, and service providers. AB Connectors is market leading in support and lead-time. This would be lost as a result and consequently, supply chain into UK critical markets would suffer. Rail delays and defence delays are likely.

Evidently, such job losses would drive up unemployment rates and reduce VAT and income tax revenue. Furthermore, a potential shift of production beyond the EU could inflict lasting harm on our economy, while granting a competitive advantage to entities outside the UK and EU.

4.4.5 Compilation

#12 [redacted] loss annually, <250 jobs, societal safety risks and delays.

4.5 Combined impact assessment

Considering the economic benefits and the low risk to exposure and subsequently health, the benefits far out way the risks.

4.6 Sensitivity Analysis

4.6.1 Key Assumptions of the Selected Methodology

The socio-economic analysis of the continued use of hexavalent chromium (Cr(VI)) is based on a structured approach that considers technical, economic, environmental, and social factors. The following key assumptions underpin the analysis:

4.6.1.1 Technical Feasibility of Alternatives

- The evaluation assumes that currently available alternative coatings do not meet the required performance standards for defence and rail applications.
- Future improvements in trivalent chromium (Cr(III)) and hybrid coatings are uncertain, and widespread adoption is unlikely within the next 5-7 years.

4.6.1.2 Regulatory Landscape

- It is assumed that regulatory authorities will continue to allow Cr(VI) use in critical applications where no feasible substitute exists, subject to strict exposure controls and environmental management measures.
- Future regulatory tightening may lead to higher compliance costs, but a total ban on Cr(VI) before a viable alternative is available is considered improbable in the short term.

4.6.1.3 Economic Impact Modelling

- The economic impact analysis assumes that:
    i. Job losses and facility closures would occur if Cr(VI) use were prematurely discontinued.
    ii. The transition to inferior alternatives would result in increased maintenance costs, shorter component lifespans, and reduced system reliability.

iii. Supply chain disruptions would increase costs and lead times for the mentioned markets.

4.6.1.4 Environmental and Health Risk Management

- It is assumed that current mitigation measures (e.g., exposure controls, wastewater treatment, and waste management) will continue to minimise occupational and environmental risks.

- The quantification of health impacts is based on current worker exposure limits, and no significant increase in health risks is anticipated under existing regulatory frameworks.

4.6.2 Certainty and Confidence in Impact Quantification and Valuation

The confidence levels in the analysis vary depending on the availability of quantitative data, regulatory clarity, and the maturity of alternative technologies.

Economic Impacts: High Confidence

- The direct costs of switching to alternatives and potential business closures can be reasonably estimated based on historical data, industry reports, and stakeholder input.
- Labour market impacts (job losses, retraining needs, and supply chain disruptions) can be modelled with moderate-to-high certainty.

Technical Feasibility of Alternatives: High Confidence in Short Term, Lower Confidence in Long Term

- The short-term infeasibility of alternatives is well-documented through field testing, expert consultations, and R&D reports.
- The long-term outlook depends on future material science breakthroughs, making it more uncertain.

Health and Environmental Impacts: Moderate Confidence

- The occupational health risks of Cr(VI) are well-studied, but long-term exposure effects at low concentrations remain subject to scientific uncertainty.
- Environmental impacts depend on site-specific conditions, regulatory enforcement, and mitigation effectiveness, introducing some variability.

Regulatory Outlook: Moderate Confidence

- While Cr(VI) use in critical applications is currently permitted, future regulatory tightening or phase-out pressures introduce uncertainty.
- Engagement with policymakers and alignment with industry standards will be key to ensuring continued authorisation.

4.6.3 Summary of Sensitivity Considerations

TABLE 11 – SUMMARY OF SENSITIVITY CONSIDERATIONS

Key Variable	Confidence Level	Sensitivity Factors
Economic impact of non-use (job losses, supply chain disruptions, maintenance costs)	High	Business closure risk, transition costs, defence/rail sector reliance on Cr(VI).
Technical feasibility of alternatives	High (Short Term), Moderate (Long Term)	Ongoing R&D, material science advancements, qualification timeline.
Health and environmental risks	Moderate	Workplace exposure controls, environmental contamination risks, regulatory updates.
Regulatory changes	Moderate	Policy shifts, industry engagement, risk-based authorisation extensions.

4.6.4 Conclusion on Sensitivity Analysis

The overall conclusions of this socio-economic analysis remain robust, as they are based on strong evidence from industry testing, economic modelling, and regulatory precedents. However, long-term uncertainties remain regarding regulatory changes and the future development of alternative coatings. Continued engagement with research initiatives, policymakers, and industry stakeholders will be critical to refining these assumptions over time.

A review period of 10-12 years is recommended to reassess the technical feasibility of alternatives, economic conditions, and regulatory outlook, ensuring that any future transition is both practical and sustainable.

4.7 Information to Support the Review Period

Given the technical necessity of hexavalent chromium (Cr(VI)) in the surface treatment of harsh environment electrical connectors for the defence and rail industries, a review period of 10–12 years is proposed. This period is based on a combination of R&D timelines, regulatory considerations, and industry adaptation cycles. The following factors justify the proposed review period:

4.7.1 Current State of Alternative Development

Ongoing R&D efforts indicate that no viable substitute currently exists that meets the necessary corrosion resistance, conductivity, and durability requirements. Industry trials of Cr(III)-based coatings and alternative surface treatments have demonstrated limited success, but further material science advancements are needed. The review period therefore aligns with industry-standard R&D cycles, allowing sufficient time for alternative coatings to be tested, validated, and qualified for use in mission-critical applications.

4.7.2 Expected Technological Progress in the Next 10–12 Years

Material qualification processes in the markets typically take years, given the stringent reliability and safety standards. In addition, the review period allows for collaboration between industry, regulatory bodies, and research institutions to accelerate innovation and ensure any alternative is both technically feasible and economically viable.

4.7.3 Economic and Supply Chain Implications

A premature ban or phase-out without a viable alternative would result in severe economic consequences, including facility closures, job losses, disruptions especially to the defence and rail supply chains, impacting equipment reliability and operational safety.

In addition, there will be increased costs for customers due to requalification and redesign of components if an alternative were prematurely forced into production.

A 10–12-year review period provides stability for businesses, ensuring that any transition to alternatives is planned, cost-effective, and does not compromise operational performance.

4.7.4 Conclusion on Review Period

The proposed 10–12-year review period provides a balanced approach, allowing time for:

- Further research and testing of alternative technologies.
- Regulatory alignment and compliance adaptations.
- Industry transition planning to avoid economic and operational disruption.

During this period, continuous monitoring of technological advancements and risk mitigation measures will be maintained to ensure that any future transition away from Cr(VI) is scientifically sound, economically sustainable, and technically viable.

5 Conclusion

The socio-economic analysis of the continued use of hexavalent chromium (Cr(VI)) in the surface treatment of electrical connectors for harsh environment connectors demonstrates that no viable alternative currently exists that meets the stringent performance, reliability, and regulatory requirements of these industries. The assessment of both the continued use scenario and the non-use scenario highlights that Cr(VI) remains critical for ensuring the durability, corrosion resistance, and electrical conductivity of mission-critical components.

5.1 Key Findings

- Research and development efforts have failed to identify a substitute that provides equivalent performance in harsh environments.
- The occupational and environmental risks associated with Cr(VI) use are well understood and are being effectively managed through strict safety protocols, process improvements, and regulatory compliance measures.
- A premature ban or discontinuation of Cr(VI) without a suitable alternative would lead to severe economic and operational consequences, including:
    - The shutdown of plating processes, resulting in plant closures and job losses.
    - The use of inferior alternatives, leading to increased failure rates, higher maintenance costs, and reduced safety in defence and rail systems.
    - Supply chain disruptions, impacting national security and transportation infrastructure reliability.

5.2 Socio-Economic Justification for Continued Use

Given that Cr(VI) remains the only feasible option for ensuring the long-term reliability of critical electrical connectors, continued use is essential until a technically and economically viable alternative is available. The industry has demonstrated a commitment to reducing risks through enhanced occupational safety measures, environmental controls, and ongoing research into alternatives.

5.3 Recommendation & Review Period

A review period of 10-12 years is recommended to allow further R&D into alternative coatings and application methods, to continue risk mitigation strategies to ensure safe Cr(VI) use.

Maintain close engagement with regulatory bodies to balance technical necessity with environmental and human health concerns.

Until a truly equivalent alternative is developed, Cr(VI) must remain authorised for use in essential applications, ensuring the continued operational integrity of the rail, industrial, Aerospace and defence markets.