ANALYSIS OF ALTERNATIVES

and

SOCIO-ECONOMIC ANALYSIS

Public version

Legal name of applicant(s):	Linde AMT UK Ltd.
Submitted by:	Linde AMT UK Ltd.
Date:	November 2023
Substance:	Chromium trioxide, EC 215-607-8 and CAS 1333-82-0
Use title:	Industrial spraying or brush application of chromium trioxide mixtures for the coating of metallic articles subject to harsh environment, to ensure a high temperature corrosion & oxidation resistance, as well as anti-fouling properties or lubricity at high temperature, for automotive, aviation, power generation machinery, Oil and Gas and marine applications
Use number:	Use-1

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LIST OF ABBREVIATIONS

AfA	Application for Authorisation
AoA	Analysis of Alternatives
B	Billion (€)
CPI	Consumer Price Index
Cr(III)	Trivalent chromium
Cr(VI)	Hexavalent chromium
CrO_3	Chromium Trioxide
CSR	Chemical Safety report
CTAC	Chromium Trioxide Authorisation Consortium
EU	European Union
GB	Great Britain
HSE	Health and Safety Executive
ILO	International Labour Organisation
IMF	International Monetary Fund
INSEE	Institut national de la statistique et des études économiques *National Institute for Statistic and Economics Studies*
k	Thousand
M	Million
NPV	Net Present Value
NSCLC	Non-Small-Cell Lung cancer
NUS	Non-Use Scenario
OECD	Organisation for Economic Co-operation and Development
PV	Present Value
R&D	Research & Development
RR	Review Report
SEA	Socio-Economic Analysis
UK	United Kingdom
UNECE	United Nations Economic Commission for Europe

1 SUMMARY

CONTEXT

Linde Advanced Material Technologies Inc. (hereinafter "Linde AMT" or the "Applicant"), a US-based company, is recognised as a worldwide specialist in the formulation and application of surface treatment solutions.

Linde AMT, via its EU Only Representative, Linde AMT GmbH, holds an authorization for two continued uses of chromium trioxide in anti-corrosion coating mixtures since European Commission Decision C(2017)5880 dated 31st August 2017[1].

With this Application for Authorisation (AfA), Linde AMT via its UK Only Representative is seeking an authorisation for its UK Lincoln plating shop, to continue to use chromium trioxide after 21st September 2024 in continuity of the EU upstream authorized Use "REACH/17/X/0: Industrial spraying or brush application of chromium trioxide mixtures for the coating of metallic articles subject to harsh environment, to ensure a high temperature corrosion and oxidation resistance, as well as deposit-resistant properties of the surface or lubricity at high temperature, for automotive, aviation, power generation machinery, oil and gas and marine applications" which currently covers the Linde AMT Lincoln plating shop activities in the UK.

The current AfA covers only the use made by Linde AMT's own coating shop in Lincoln (see below).

The impacted mixtures are based on the coating ability to sacrificially protect substrates from corrosion. This sacrificial behavior is provided by the coating conductive aluminium structure, made possible by a dense dispersion of aluminium particles within a matrix (binder) of chromate-phosphate ceramic. These solutions are part of proprietary coating systems (basecoat and/or top coat). The most commonly used basecoat in different industries is the SermeTel W.

Only the Lincoln UK coating shop owned by Linde AMT still applies Linde AMT's coating systems for parts subject to harsh environments in the automotive, aviation, power generation machinery, Oil and Gas and marine sectors covered by Use-1 in the UK.

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[1] REACH/17/X/0: Industrial spraying or brush application of chromium trioxide mixtures for the coating of metallic articles subject to harsh environment, to ensure a high temperature corrosion and oxidation resistance, as well as deposit-resistant properties of the surface or lubricity at high temperature, for automotive, aviation, power generation machinery, oil and gas and marine applications

REACH/17/X/1: Industrial spraying of chromium trioxide mixtures for the coating of metallic articles subject to harsh environment to ensure either a low temperature-cured coating for corrosion protection, or a high temperature corrosion and oxidation resistance with reduction of surface roughness or a high temperature adhesive, for aviation, power generation machinery, oil and gas and marine applications

SUBSTANCE FUNCTIONS

Chromium trioxide is used in an aqueous solution with phosphoric acid to form a chromate-phosphate compound. The chromate-phosphate product serves as the binder component of the coating. The binder provides adhesion to the substrate, as well as cohesion of the metallic particle component.

Parts coated with the hexavalent chromium-containing slurries serve in many different industries which require corrosion resistance and high temperature resistance. Metallic components in turbomachinery, aerospace parts, automotive parts, and oil & gas industry parts all make use of these slurry derived coatings. The metals are often composed of steel, but may also be composed of other metals such as magnesium and aluminium.

The hexavalent chromium containing binders, as well as any non-chromium containing alternatives, would need to provide these key properties:

- **Sprayability** (as the liquid slurry form): This includes **solubility in a carrier solvent**, such as water, as well as **suitable viscosity** to be applied in a uniform stable film on complex part geometries.
- **Processability** of Slurry in industrial environments: to enable economical adoption by customers and production plants.
- **Convertibility to insoluble form (curing)**: To provide irreversible adhesion and cohesion of coating in service.
- **Mechanical properties** of cured film form: To provide final mechanical properties, and to enable successful burnishing of cured coatings.
- **Chemical resistance** of cured film form: To provide necessary robustness of coating in in-service chemical environments.
- **Thermal resistance** of cured film form: To provide necessary robustness of coating in in-service thermal environments.

More specifically some performances in the following areas are expected:

- Sacrificial Corrosion Protection
- Inhibitive Sealant
- High Temperature Corrosion
- Anti-Fouling
- High Temperature Oxidation & Hot Corrosion
- Lubricity at high temperature

IDENTIFICATION OF ALTERNATIVES

Linde AMT is fully aware of Cr(VI) toxicity and has engaged efforts to substitute chromium trioxide where possible. As a result, three different alternatives have originally been developed by Linde AMT to replace hexavalent chromium mixtures for the performances described under Use-1 in the initial EU AfA submitted in 2015.

Each alternative being specific to a certain set of performances (i.e. without competing solutions), their study was made separately in the previous EU AfA. The aim was therefore not to compare them, but rather to describe how they can be deemed technically feasible while not being available at the time. The main argument to support the original AfA was indeed the time needed by Linde AMT customers to validate/qualify these alternatives.

Unfortunately, the previously presented alternatives did not allow complete substitution of Cr(VI) for Linde AMT spraying applications. Chrome-free coatings and coating systems (specific combinations of multiple coatings applied in a multi-layer manner) have been developed and tested in R&D to replace about 85% of the coatings currently used. Linde AMT has therefore been evaluating a number of other alternatives which might be suitable for completing the substitution of Cr(VI) in their process.

Multiple customer trials are underway for both performance and processability validation for the purpose of qualification of these alternative systems. Product ionization trials have been performed in several of Linde AMT coating plants for two-way suitability study of chrome-free alternatives.

One of these trials has been completed with successful trials of three new chrome-free coating systems. This includes demonstration of plant capability to spray each of the new CF systems on both test panels, and real 3-dimensional trial parts.

As of today, the main challenges for Linde AMT regarding these newly selected alternatives is scale-up to production, including raw material sourcing, process development, quality control set up, labelling and shipping documents development. Customer approvals and qualifications are also important factors to consider to finalize the complete substitution of Cr(VI) at Linde AMT.

Moving forward with new alternatives to Cr(VI) (which was not possible with previously selected alternatives in the initial EU AfA) slowed down the process to achieve complete substitution in the originally agreed timeline.

"APPLIED FOR USE" AND "NON-USE" SCENARIO

Under the "applied for use" scenario, Linde AMT will pursue the use of chromium trioxide for the coating of metallic articles subject to harsh environment, to ensure a high temperature corrosion and oxidation resistance, as well as deposit-resistant properties of the surface or lubricity at high temperature, for automotive, aviation, power generation machinery, oil and gas and marine applications while pursuing and finalizing the substitution of chromium trioxide.

Given the strategic targets of the Applicant, which is to accompany its customers in the move to Cr(VI) free slurries to become global leader in the development, manufacture and application of Cr(VI) free slurries, the most likely Non-Use Scenario (NUS) will be the discontinuation of its plating operations under Use-1 and as a consequence the loss of its key OEM customers that Linde AMT would not be able to get back once substitution is finalized.

The most important factor which seriously impedes the continuity of business contemplated under Use-1 is indeed the time needed by users (OEM = customer of Linde AMT) to validate/qualify the new products.

The non-use scenario therefore presents the costs associated with the possible cease of Cr(VI) coating activities in the UK since customers will not accept downgraded alternatives during the qualification/certification process. Assessment is made for the UK Lincoln site specifically and compared to the costs avoided for keeping the substance and exposing 29 workers.

IMPACTS OF GRANTING AUTHORISATION

There is a maximum of 29 operators dedicated to the chromium-based surface treatment activities at the Lincoln plating shop for a total of [redacted]kg [100-400] (#2) per year of chromium trioxide ([redacted]kg [52-208] (#2) per year as Cr(VI)). Stringent standardised risk management measures are put in place on site with a consolidated reporting and follow up to the US.

The risk associated with the substance use is described in the associated CSR and is limited to the Linde AMT workers and the general population at the local level.

Monetised impacts of the "applied for use" scenario include costs related to medical treatment, morbidity and mortality associated with the number of statistical cancer cases of lung and small intestine cancer arising from the exposure to chromium trioxide of workers and the general population over the review period.

The total annualised monetised impacts of the "applied for use" scenario amount to £227 707.

Monetised impacts of the NUS include loss of profit and loss of employment.

The total annualised monetised impacts of the NUS amount to [redacted] £[1M-5M] (#1).

Based on this assessment, the socio-economic benefits outweigh the risks arising from the use of the substance by a factor of approximately [redacted] [5-15] (#1).

REVIEW PERIOD

Given the argument put forward, and in order to finalize the substitution of chromium trioxide under Use-1, Linde AMT applies for an additional two years review period, i.e. until the end of 2026.

2 AIMS AND SCOPE

2.1 Aim

Linde Advanced Material Technologies (Linde AMT) is a worldwide company specialised in the formulation and application of surface treatment solutions. From the point of view of the UK REACh regulation, the Applicant is to be considered as a downstream user of chromic acids generated from chromium trioxide for the coating of metallic articles.

Considering that substitution works are well advanced, this AfA's objective is to allow Linde AMT customers to validate and qualify the alternatives developed.

Chromium trioxide was included in the list of substances subject to authorisation in the EU in the course of the third recommendation of ECHA for the inclusion of substances in Annex XIV from 20th December 2011. By Commission Regulation (EU) No 348/2013 chromium trioxide was added to Annex XIV to EU REACH. The latest application date was fixed to 21 March 2016 and the Sunset date to 21st September 2017. When EU REACH was brought into UK law on 1 January 2021 as UK REACH, the EU REACH Annex XIV list was taken over, and notably the latest application and sunset dates for the use of chromium trioxide.

In this regard, Linde AMT filed an EU Upstream AfA via its EU Only representative in November 2015 for two uses of chromium trioxide. By Commission Decision C(2017)5880 dated 31st August 2017, Linde AMT was granted an EU authorization for two uses, one related to the "*Industrial spraying or brush application of chromium trioxide mixtures for the coating of metallic articles subject to harsh environment, to ensure a high temperature corrosion and oxidation resistance, as well as deposit-resistant properties of the surface or lubricity at high temperature, for automotive, aviation, power generation machinery, oil and gas and marine applications*", which will expire on 21 September 2024 and another use related to the "*: Industrial spraying of chromium trioxide mixtures for the coating of metallic articles subject to harsh environment to ensure either a low temperature-cured coating for corrosion protection, or a high temperature corrosion and oxidation resistance with reduction of surface roughness or a high temperature adhesive, for aviation, power generation machinery, oil and gas and marine applications*" which will expire on 21 September 2029.

The present Application for Authorisation under UK REACH is mirroring the review report submitted under EU REACH regarding the authorization granted in 2017 for the use which expires on 21 September 2024, i.e. "*Industrial spraying or brush application of chromium trioxide mixtures for the coating of metallic articles subject to harsh environment, to ensure a high temperature corrosion and oxidation resistance, as well as deposit-resistant properties of the surface or lubricity at high temperature, for automotive, aviation, power generation machinery, oil and gas and marine applications.*"

Considering that substitution works have well advanced, the length of the review period requested is very short.

Together with the Chemical Safety Report (CSR) provided separately, the AoA/SEA document constitutes the single use AfA dossier submitted by Linde AMT for a continued Use-1 in the UK for a period of 2 years, i.e. until the end of 2026.

The aim of the present document is to provide a comprehensive analysis of both the Analysis of Alternatives (AoA) and the Socio-Economic Analysis (SEA) parts of Linde AMT's AfA, i.e.:

- To provide a comprehensive understanding of the context of the AfA;
- To describe the initiatives of research for alternatives, potential alternatives and substitution strategy;
- To provide a comparative assessment of the impacts of the pursued use of chromium trioxide (also hereafter "the Substance") ("applied use scenario") and the impacts of the refusal of an authorisation ("non-use" scenario) via a cost-benefits assessment of the application.

2.2 Scope

Key elements of the scope of the AfA are provided in the table below:

SCOPE	COMMENT
Temporal boundary	2-years review period
Geographical boundaries	Direct impacts concern the UK Indirect impacts concern Linde AMT supply chain and customers covering a worldwide scope
Economic boundaries	Monetised damage of the impacts on human health of the "applied for use" scenario includes: - Medical treatment - Mortality and morbidity Main impacts of the "non-use" scenario include: - Economic impacts on the activity of Linde AMT with loss of profits - Social impacts are related to the loss of employment at the plating shop
Volumes	Quantities of chromium trioxide used: [redacted] kg [100-400] (#2) CrO3, (equivalent to [redacted] kg [52-208] (#2) per year as hexavalent chromium) Quantities on the final product: None

Table 1. Scope of Use-1

The temporal boundaries and the impact period considered are as follows:

SCENARIO	IMPACT	IMPACT PERIOD
"Applied for use" scenario	Medical treatment	2 years: 2025 – 2026
	Mortality and morbidity	2 years: 2025 – 2026
"Non-use" scenario	Loss of profit due to the cease of the activity	2 years: 2025 - 2026
	Loss of employment	7 years: 2025 – 2031

Table 2. Impact period of Use-1.

Present value is set in 2022, at the date of drafting of this document.

Considering that Linde AMT's use of chromium trioxide is currently covered by Authorisation C(2017)5880 until 21st September 2024, a realistic approach assumption is made that the Applicant will only be unable to use the Substance as of 2025 only.

In order to ensure consistency of analysis between impacts of both scenarios, and as recommended by ECHA's guidance, it was chosen to consider a common discounting period for both the "applied for use" and "non-use" scenarios corresponding to the review period. Thus, the discounting period for the "non-use" scenario is set to begin in 2022.

2.3 Information on the Applicant

Linde Advanced Material Technologies (Linde AMT) is a worldwide company specialised in the formulation and application of surface treatment solutions.

Linde AMT is a subsidiary of Linde plc, the worldwide present largest industrial gas company in the world. Linde AMT represents 2.300 employees and a global turnover of $ [redacted]M [500-1000] (#1), the European market representing [redacted] [500-1000] (#1) employees and a turnover of $ [redacted]M [100-500] (#1).

Linde AMT's engineers, technologists and coating experts are present across 34 sites in 12 countries, including 2 in the UK, of which 1 site with [redacted] (50-100) (#1) employees in total is impacted by Use-1. Linde AMT which dates back to 1904, has its global headquarters located in Indianapolis, Indiana, Unites States.

The Applicant high-performance anti-corrosion slurries activity started in the 21st century. But Linde AMT has committed to constant improvement and is always striving for innovation, as the company experiments with environmentally sustainable coatings and other products, and innovative new processes, such as rapid prototyping technologies and advanced application methods.

The business related to chrome containing materials represents an overall turnover of $[redacted]M [10-50] (#1), the UK market representing $[redacted]M [1-10] (#1).

As mentioned before, the present AfA is submitted by Linde AMT UK Ltd. in its capacity as Only Representative of Linde Advanced Material Technologies Inc..

2.3.1 Products

The products which contain chromium trioxide are liquid mixtures, commonly referred to as “slurries”. These slurries form a coating layer when sprayed onto a metal substrate, dried and cured. These coatings, also called “metallic-ceramic coatings” are widely utilised for their corrosion resistance, high temperature oxidation protection, their anti-fouling / non-stick behaviour, and their ability to lower the surface roughness of certain components making them aerodynamically favourable in applications such as gas turbine engines.

Linde AMT’s coatings are used principally in:

- The aircraft sector (both in the gas turbine engines and on certain airframe components)
- The power generation industry (to extend the life of turbomachinery and provide enhanced efficiency imparted by the smooth surfaces).

But also in other less significant markets:

- The Oil and Gas market (to protect offshore components such as fasteners from severe corrosion)
- The automotive market (to provide corrosion resistance to engine fasteners, exhaust components and hangers)

Many important actors of those mentioned sectors like Rolls Royce, Safran, GE, Siemens, Airbus, Baker Hughes, Piaggio, Ansaldo, Fokker, Collins and Polaris rely on the slurries subject of Use-1.

While the primary use of these products is to protect ferrous-based alloys, they have also been successfully employed to protect aluminium and some magnesium-based alloys. For example, the “lipskin” nacelles of selected commercial and military jet aircraft are coated with these materials to protect the leading edge from the damaging effects of corrosion and rain erosion.

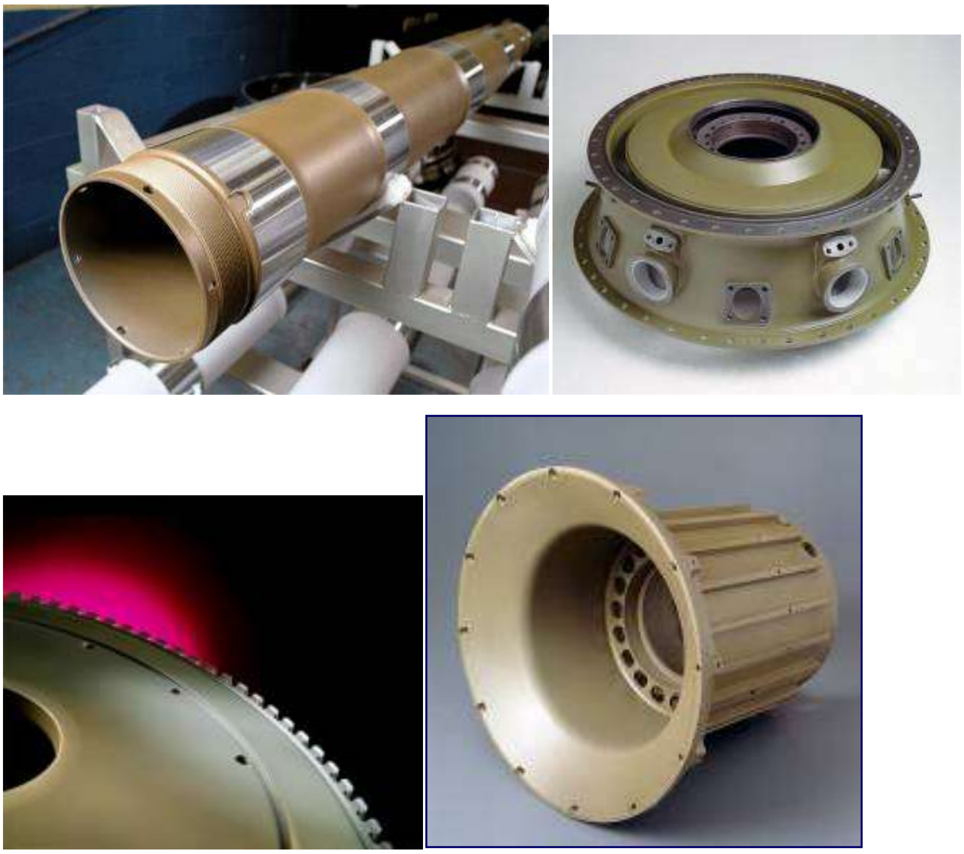


Figure 1. SermeTel 725/2F-1 – sealed sacrificial aluminium/ceramic composite, landing gear, engine cases, IGT disks

The different Linde AMT's hexavalent chromium slurries subtype processes, regarding the Use-1, are listed below:

- "SermeTel process 2F1" is a multi-layer coating system including a basecoat (SermeTel W) with aluminium sacrificial activity and a chromate/phosphate topcoat with sealant activity;
- "SermeTel process 5380 DP", consists of a closely packed aluminium-filled chromate/phosphate basecoat, sealed with a chromate/phosphate topcoat;
- "SermaLoy J" diffuses slurry alumnide coating as a unique silicon-enriched outer layer.

These slurries are manufactured by PRAXAIR group in the US before being shipped to the UK.

One of the core products being addressed in this application is the SermeTel W, which was developed and patented by Charlotte Allen in the 1960's. The basic invention is summarized in US Patent 3,248,251.

2.3.2 The UK located Linde AMT coating shop

The Lincoln site is the sole site among the three UK sites, which is using chromium trioxide under Use-1.

For quality and safety reasons, processes are standardised by Linde AMT corporate for all the sites around the world, and hence also the Lincoln site.

The table below presents the current business of Linde AMT's UK Lincoln coating shop.

Linde AMT SHOP	NUMBER OF WORKERS ON SITE	NUMBER OF WORKERS EXPOSED TO CR(VI)	GLOBAL TURNOVER (2022)	USE-1 RELATED TURNOVER (2022)
Lincoln (UK)	[redacted] [50-100] (#1)	29	£[redacted] [5M-15M] #1	£[redacted] [1M-5M] #1

Table 3. Lincoln Linde AMT shop activities and turnover globally and for Use-1 (#1)

2.3.3 Overview of the revenues of Use-1 by market

The main market sector impacted by the Use-1 mixtures is the aviation sector and more specifically the gas turbines of aircraft which represents the major market of Linde AMT hexavalent chromium coating. If applicant adds the Industrial Gas turbines sector and the Oil & Gas sector, which are subject to the same type of testing and qualification constraints (being themselves, frequently, aeroderivative turbines or elements), these 3 sectors of activities represent more than 90% of the Use-1 business. Constraints applicable to these sectors are moreover deemed representative since other Linde AMT customers will also need to go through the same 3 steps before using Linde AMT's proposed alternatives:

- A qualification step
- A certification step
- An industrialization step

The most important issue for this sector is indeed to maintain the airworthiness of the material. Even if alternative substances are available, the companies will need to go through different steps before being ready & authorised to use them (described in the paragraph 4.3.4).

The Applicant and therefore its customers are constrained by numerous normative rules that do not allow them to use anti-corrosion coating alternatives before having gone through compulsory steps.

These rules are controlled by the European Aviation Safety Agency (EASA), which validates at the end the right to use the alternatives.

From the point of view of safety requirements, the SermeTel™ process (which is the most representative of the Use-1 mixtures) is of the utmost importance for many applications since it bonds inorganic coatings with metal substrates to form a ceramic-metallic composite layer that provides unparalleled protection against aqueous corrosion, heat scaling, erosion, abrasion and wear. These performances are essential for aviation companies to ensure the airworthiness of their materials, particularly the engines.

Moreover, these SermeTel systems are certified by several important aviation companies, such as SNECMA, Airbus or Boeing.

Specific parts are coated for each sector of activity, though some parts can be common to several sectors. In the figure below, the Applicant presents two examples of parts coated by Chromium trioxide containing SermeTel slurries in the Linde AMT UK shop.

	
Compressor blades	Flight turbine stator vanes

Table 4. Example of parts coated by Linde AMT Lincoln shop

It is to be stressed that due to the chemical reaction during the chrome-curing process, Cr(VI) is reduced into Cr(III), there is no substance left in the final product, and consequently no substance in the chains manufactured. The Applicant is therefore the last downstream user in the supply chain for chromium trioxide.

2.3.4 Overview of sales projections for chromium trioxide mixtures

Regarding the Use-1, the sales projection will be stable. If the authorisation is granted, the use of mixtures covered by the Use-1 should also be stable until Linde AMT customers "qualify/certify" the developed alternatives. For the main business concerning this Use (Aerospace gas turbines), the customers will need the time described in the following assessment to implement the use of alternatives.

2.3.5 Concluding remarks on supply chain and markets considered in the applied for use scenario

Two comments can be made:

- Though each coating shop is a separate legal entity, industrial processes (as well as risk management measures from another prospective) are the same. The fundamental reason is that the quality and reliability of Linde AMT's coating systems are both chemistry and process driven. This is made compulsory by the high level of sustained performances required by Linde AMT's customers. Consequently, stoichiometry and handling of the spraying must be mastered and replicable. This is also a matter of efficiency as having different processes would hamper the good monitoring of performances, the dissemination of information and the mutual benefits of problem solving. To allow this organisation, all information is centralised at Linde AMT headquarter in the US and all management decisions are taken in the US and dispatched to the EU and UK coating shops to standardise as far as possible the Linde AMT coating activities.
- The location of shops is the result of an industrial strategy whose result is the capacity of Linde AMT in the EU and the UK to serve adequately its customers in terms of needs and geographic proximity.

2.3.6 Competitors

Main competitors of the Applicant on the market of anti-corrosion slurries for the same sectors covered by Linde AMT are based outside in the USA (Ceral USA and Coatings for Industry) and the UK (Indestructible Paints).

2.3.7 Strategic targets / investment plans of the Applicant

Linde AMT strategy is to be a global leader in the development, manufacture and application of chrome VI free slurries with a shift to chrome VI free slurries on a global basis by end 2026. The markets targeted for that shift include aviation, industrial gas turbines, oil & gas, automotive & marine. The slurry manufacture would continue to be based in the USA and 4 manufacturing sites would be retained in EU/UK, 3 sites in USA & 1 in Asia for the application of the new Cr(VI) free coatings.

The present AfA is submitted to be able to finalize that shift and achieve the strategic target.

2.4 General methodology

Under the European Union (Withdrawal) Act 2018, the EU REACH Regulation was brought into UK law on 1 January 2021 and is known as UK REACH. UK REACH regulates chemicals placed on the market in GB. The key principles of the EU REACH Regulation were retained in UK REACH.

Pursuant to HSE indication, the process for applying for an authorisation under UK REACH is very similar to the EU process and much of the ECHA guidance and templates can be used.

As a consequence, the present document refers where useful to the relevant ECHA guidance and notes.

Chromium trioxide is categorised as a non-threshold substance and therefore the so-called "socio-economic route" applies for the present AfA[2]. The socio-economic route applies where it can be demonstrated that the risk to human health or the environment from the use of the substance is outweighed by the socio-economic benefits and there are no suitable alternative substances or techniques (Art. 60(4) REACH).

As per ECHA's guidance, the assessment of the socioeconomic component of the present AfA will be based upon a Cost-Benefit Analysis approach. A comparative assessment will therefore be carried out, between the monetised impacts related to the "applied for use" and the "non-use" scenarios.

In order to best reflect the consequences of both these scenarios, an effort has been undertaken to place this RR in the context of the realistic worst-case scenario. Whenever possible:

[2] ECHA, "Guidance on Authorisation Applications" January 2021

- Over-estimating hypothesis have been used to assess the impacts of the "applied for use" scenario and, conversely, under-estimating hypothesis have been used to assess the impacts of the "non-use" scenario;
- Representative examples have been provided and structuring hypothesis or assertions have been justified either based on literature or institutional sources.

Furthermore, and so as to provide a comprehensive understanding of the limits of the proposed assessment, an uncertainty analysis was carried out for both the results of the "applied for use" and "non-use" scenarios. This analysis, carried out both quantitatively and qualitatively, is provided in Section 4.6.

2.4.1 Exchange rate

Many of the studies used as reference being EU based studies, costs and financial elements are primarily expressed in Euro (€). In order to convert such monetary amounts to British Pound Sterling (£), an exchange rate € to £ was used. Regarding the heterogeneity of the data, it was chosen in the following document to convert all the values from € to £ by using: 1€ = 0.84£ (mean annual value of 2012-2022 exchanges rates, data provided by the French statistical Institute, Insee, extract European Central Bank_Eurostat dated 13th January 2023). This exchange rate value is considered as representative of the mid-term exchange rate between these two currencies.

2.4.2 Actualisation

All final monetised results of this document are expressed in present value (PV). In this context, the following factors are used for the actualisation of past values (correction for inflation) or future values (discounting).

2.4.3 Inflation

Given the type of values considered (health expenditures, social benefits), it was chosen to rely on the Consumer Price Index to carry out actualisation according to inflation. The choice of this statistical estimate is in line with ILO/IMF/OECD/UNECE/Eurostat/The World Bank recommendations, stating[3]: "CPIs are widely used for the index linking of social benefits such as pensions, unemployment benefits and other government payments, and also as escalators for adjusting prices in long-term contracts."

The following values will be used in the present document:

	UK	EU-27
2012-2022	25,52%	19,50%
2018-2022	13,68%	Not used

Table 5. Inflation values considered in this AfA[4].

[3] ILO/IMF/OECD/UNECE/Eurostat/The World Bank, "Consumer price index manual: Theory and practice Geneva", International Labour Office, 2004.

[4] OECD, "Main economic indicators, Consumer Price Index – data and methods", UK.

2.4.4 Discounting

Comparing costs and benefits during different periods of time to present values requires the use of discounting techniques to translate future costs and benefits into present-day values to account for the time value of money.

The choice of discount rate is important since it can affect the cost-benefit results of the analysis. The higher the discount rate is, the lower the future benefits and costs values will be, as compared to present values.

As per ECHA's guidelines, the calculation of discounted values is performed on an annualised basis, with the following formula:

$$PV = \sum_{n=1}^{n=t} F_n(1+r)^{-n} = \frac{F_1}{(1+r)} + \frac{F_2}{(1+r)^2} + \cdots + \frac{F_t}{(1+r)^t}$$

Considering:

PV = present value.
F_n= future costs at year n.
r =annual discount rate.
t = last annuity of the discount period.

Based on ECHA's recommendation[5], a 4% discounting rate is used to assess the future cost/benefits values for all impacts.

2.4.5 Confidentiality

In order to preserve the confidentiality of strategic data of the present AfA, confidential business information has been blanked out in the public version of the AoA-SEA document.

3 ANALYSIS OF ALTERNATIVES

3.1 SVHC use applied for

3.1.1 Description of the function(s) of the Annex XIV substance and performance requirements of associated products

Exact function of the substance and use

Chromium trioxide is used in an aqueous solution with phosphoric acid to form a chromate-phosphate compound. The reaction requires elevated temperatures to ensure the reaction goes to completion. The final chromate-phosphate product formed from this reaction is insoluble in water, and does not extract hexavalent chromium in water.

[5] ECHA, "Guidance on the preparation of socio-economic analysis as part of an application for Authorisation", 2011.

The chromate-phosphate product serves as the binder component of the coating. The binder provides adhesion to the substrate, as well as cohesion of the metallic particle component.

The chromium trioxide (as chromic acid) is soluble in water as a small molecule, providing a low viscosity that enables the slurry to be sprayed with standard paint equipment. Physical drying of the applied slurry leaves a film comprised of the metallic particles dispersed in the chromate-phosphate binder solids. High temperature curing of this film results in an insoluble, porous, film adhered to the substrate. This coating is then burnished with media to condense the discrete metallic particles to form an electrically conductive metallic phase.

There is also potentially an anti-corrosive effect gained from the interaction of the hexavalent chromium component with the metallic substrate. This is the mechanism employed by Chromium-containing conversion coatings.

The products which contain chromium trioxide are liquid mixtures, commonly referred to as “slurries”. These slurries form a coating layer when sprayed onto a metal substrate, dried and cured. These coatings, also called “metallic-ceramic coatings” are widely utilised for their corrosion resistance, high temperature oxidation protection, their anti-fouling / non-stick behaviour, and their ability to lower the surface roughness of certain components making them aerodynamically favourable in applications such as gas turbine engines.

Linde AMT’s coatings are used principally in:

- The aircraft sector (both in the gas turbine engines and on certain airframe components)
- The power generation industry (to extend the life of turbomachinery and provide enhanced efficiency imparted by the smooth surfaces).

But also, in other less significant markets:

- The Oil and Gas market (to protect offshore components such as fasteners from severe corrosion)
- The automotive market (to provide corrosion resistance to engine fasteners, exhaust components and hangers)

While the primary use of these products is to protect ferrous-based alloys, they have also been successfully employed to protect aluminium and some magnesium-based alloys. For example, the “lipskin” nacelles of selected commercial and military jet aircraft are coated with these materials to protect the leading edge from the damaging effects of corrosion and rain erosion.

Function of the sub-product and/or final product (coated part) and quality criteria

Parts coated with the hexavalent chromium-containing slurries serve in many different industries which require corrosion resistance and high temperature resistance. Metallic components in turbomachinery, aerospace parts, automotive parts, and oil & gas industry parts all make use of these slurry derived coatings. The metals are often composed of steel, but may also be composed of other metals such as magnesium and aluminium.

Other properties which may be attributed to these parts include chemical resistance and barrier effects, erosion resistance, fouling resistance (resistance to the build-up of contaminants on surfaces), surface lubricity, and humidity and atmospheric contaminant resistance.

Short reminder of the application process

In a nutshell, the coating is deposited onto a surface using air-atomized spray guns, which are commonly used to deposit conventional paints. The coating is then typically dried at an elevated temperature, such as 175 °F (80°C), and then cured at a higher temperature between 350 °F (176.67°C) and 650 °F (343.33°C).

Chemistry of the process

From the point of view of the main steps of the chemical reaction, it should be reminded that the curing process causes the coating to undergo a polymerization process, forming a water-insoluble film.

A conversion takes place in which the Chromium (VI) compounds are converted to Chromium (III) compounds.

The chromium compounds along with other substances form a ceramic binder matrix which surrounds and holds the aluminium particles and other pigments in place, and ensures adhesion of the film to the substrate.

This coating cannot be re-wetted by water or solvents, and forms a corrosion resistant material that enables the coated component to be exposed to over 1,000 hours in severe salt fog testing (ASTM B117 used as the Standard Practice for Operating Salt Spray Apparatus) without any appearance of red rusting (on ferrous substrates such as 1010 steel). The coating is effective at temperatures up to approximately 593 °C and can be exposed to a wide range of chemicals and solvents, including various engine fluids, without degradation.

3.1.2 Market analysis of products manufactured with the Annex XIV substance

Linde AMT is currently engaged in the UK marketplace in the following ways:

- Wholly-owned coating service facility located in Lincoln with the plating shop falling under this AfA.
- Export of powders and slurries to customers in the UK from the manufacturing facilities in Indianapolis USA.

It should be reminded that Linde AMT has had facilities located in the EU and UK for over 35 years. As part of its strategy to best serve its EU and UK clients, Linde AMT acquired SermaTech International and its slurry coating business in 2010.

Prior to its acquisition, Sermatech had been serving the EU and UK market for over 25 years and had therefore created very strong local links with several major EU and UK industries (aerospace for instance).

From this point of view, it should be stressed again that Linde AMT does not manufacture any parts, but provides coating services. This logically entails that the parts must be shipped, processed and shipped back to the customer. Linde AMT therefore strategically located its facilities close to its customers in order to reduce the timing required for shipping and processing.

For a better understanding of Linde AMT's market, the three following figures present:

- The actors of the supply chain;
- The supply chain of the substance;
- The supply chain of the articles treated by Linde AMT coating shops.

Linde AMT corporate is the formulator and the supplier of the Chromium trioxide containing mixtures. Moreover, regarding their UK coating shop, Linde AMT headquarter designs and specifies the standardised processes to be used in the UK shop.
Original Equipment Manufacturers (OEM) are manufacturers engaged in different sectors of activities (automotive, aviation, power generation machinery, Oil and Gas and marine). They use the mixtures either directly (downstream users) or contract out certain activities of surface treatment.
OEM part subcontractors manufacture certain parts of the final OEM articles and need the services of the Linde AMT UK shop to apply surface treatment and therefore provide the required performances.
The Linde AMT UK shop is the contractor covered by this AfA. Based on the processes defined by Linde AMT headquarter, it carries out the coating activities (as downstream users) on parts sent to it by OEM subcontractors.

Figure 2. Supply chain actor description

As a consequence, the Linde AMT UK shop is very often a third- or fourth-tier contractor for all transactions (vis-à-vis the OEM):

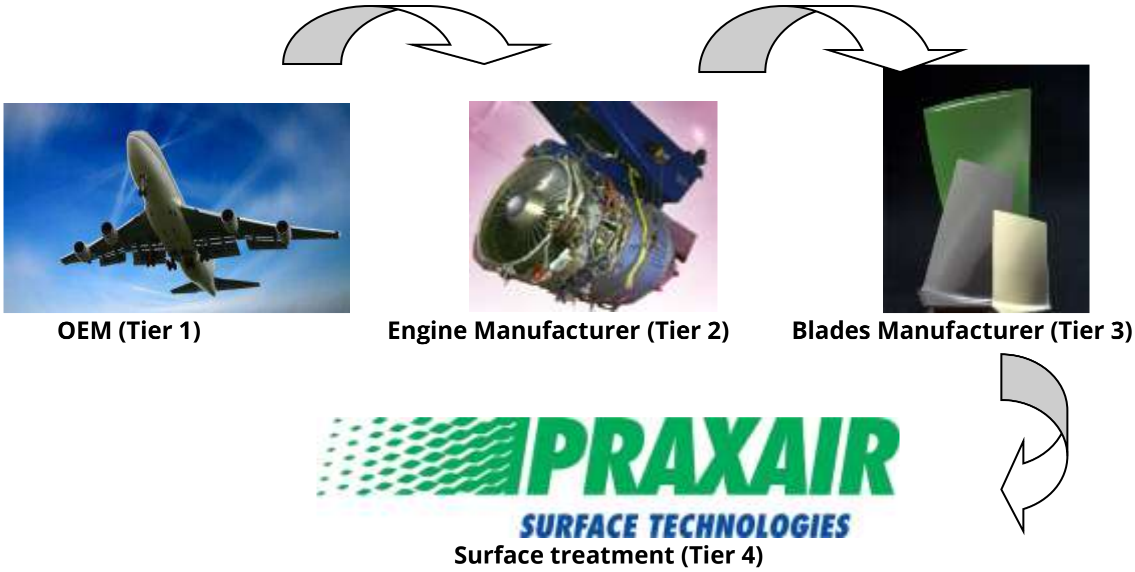


Figure 3. Typical position of Linde AMT in the aerospace industry supply chain

3.1.3 Annual volume of the SVHC used

Under the use applied for, a maximum of [redacted] kg [100-400] (#2) CrO_3 per year, (equivalent to [redacted] kg [52-208] (#2) per year as hexavalent chromium) are expected to be used by the UK site as total amount of the substance.

3.2 Efforts made to identify alternatives

3.2.1 Research and development

It should also be noted that Linde AMT is in a particular situation regarding an application for authorisation: on the one hand, as a non-UK formulator, Linde AMT is not subject to the same type of regulatory pressure than its UK competitors, therefore leading to possibly different R&D strategies and maturity of alternatives. Moreover, Linde AMT does not need to apply for the formulation step but rather, as a downstream user, for the work performed by its entity in the UK. On the other hand, Linde AMT supplies its coating shop in the UK with its own mixtures. Linde AMT coating shops are members of Linde AMT corporate. Given the fact that Linde AMT corporate is a formulator of coating mixtures, the Linde AMT coating shop in the UK has no other choice but using the alternatives developed by the head office. This could not be the case for many of Linde AMT competitors (competitors for both the suppliers of slurry coatings, and separate competitors for the application processes) who can use the mixtures of different suppliers to improve the research of alternatives and satisfy customers' requests. Any proposal of alternative outside the portfolio of Linde AMT (present and future) is therefore irrelevant and would defeat the very purpose of having one's own coating shops.

It should however be stressed that, in response to the identification of hexavalent chromium Cr(VI) as a hazardous substance for health, significant efforts were made to develop viable Cr-free replacement coatings. However, its elimination proved to be very challenging because of the unique Cr(VI) passivating and corrosion control properties,.

Historically, extensive R&D and substitution works were initiated by SermaTech Co. (later acquired by Linde AMT), as well as its competitors, some 15 years ago.

For instance, one alternative Cr-free coating that was considered was an aluminium ceramic basecoat layer with a phosphate-based binder. The coating, when employed in conjunction with Cr(VI) free top coating, presented properties and performances (e.g., salt spray corrosion resistance, high temperature heat oxidation resistance, erosion resistance, mechanical properties) comparable to the benchmark coating systems with SermeTel W® basecoat. However, when used alone without the top coat / sealer, these basecoats exhibited insufficient corrosion resistance: the coatings developed red rust in the scribe and the field when subject to prolonged testing of up to 1000 hrs in the Salt Spray test per ASTM B117.

Another major drawback of this iteration of Cr-free basecoat stemmed from a significant interaction of aluminium particles with the phosphate binder in a water-based slurry in the absence of Cr(VI) species (the latter having a passivating effect on aluminium metal). As a result of this adverse interaction of the aluminium particles with the phosphate binder, the basecoat slurry could not be maintained as a “one-part” composition, in which all constituents could be mixed together into a single formulation, without one or more of the constituents adversely affecting other constituents of the composition.

Rather, the slurry had to be maintained in storage as a two-part slurry, in which the aluminium powder was kept separate from the aqueous binder, until the point of use when the binder and Al could be mixed. However, the pot life of the mixed slurry was only about 8 hours, a duration beyond which a rapid deterioration of the mixture could be observed and that manifested itself in agglomeration of Al particles leading to a significant increase in the particle size. These undesirable properties created significant complications in scaling –up and deterred anyone from employing this Cr-free slurry in any large-scale coating applications.

When Linde AMT acquired SermaTech in 2011, efforts on developing viable Cr-free were of course continued. However, another technical direction was taken: the present development focused on alkali silicate-based binders. Indeed, after testing multiple alkali silicates, individual and mixed ones, with different SiO2:Me2O ratios (where “Me” is an alkali metal cation), it was discovered that utilizing lithium-doped potassium silicate as a binder, in combination with atomized aluminium powder, produced a ceramic coating with outstanding adhesion to various metal substrates and very advantageous functional properties, in particular high resistance to corrosion and cyclic heat oxidation – corrosion exposure. US Patent has been granted to Linde AMT for this invention.

During the next stage of this development, the goal became to develop Cr(VI)-free top coating formulations, thus allowing REACH compliant replacements of the major Cr (VI) containing legacy SermeTel™ coating systems. As a result of extensive formulation and testing studies, the applicant developed top coat slurries that are based on Cr-free acidic, metal phosphate-based binders and employ different metal oxide functional pigments, thus also providing coating systems of different colours (green, white, grey, etc.). Then, coating systems composed of the developed basecoat + top coat were extensively tested internally and demonstrated excellent performance, with application of the top coat significantly enhancing functional properties of the basecoat.

As discussed above and to summarise, Linde AMT was able to develop since mid-2014 alternatives covering performances currently obtained by hexavalent chromium metallic-ceramic coating mixtures.

Since mid-2014, Linde AMT corporate has developed 3 alternatives to cover different performances which were selected in the initial AfA:

- SermeTel CF (Chrome Free) overlay coating systems
- Sermaloy J CF (Chrome Free) diffusion coating
- 1758 lubricating coating

The Applicant mentioned in the initial AfA that they were not comparing the different alternatives because each one of them was covering specific performances addressed by the Use-1. Consequently, the 3 alternatives together were meant to allow the covering of previous mixtures performances.

Unfortunately, the previously presented alternatives did not allow complete substitution of Cr(VI) for Linde AMT spraying applications. Chrome-free coatings and coating systems (specific combinations of multiple coatings applied in a multi-layer manner) have been developed and tested in R&D to replace about 85% of the coatings currently used. Linde AMT has therefore been evaluating a number of other alternatives which might be suitable for completing the substitution of Cr(VI) in their process.

Performance data for several trials were initiated, demonstrating the performance of the chrome-free alternatives in comparison with the legacy hexavalent chromium-containing products has shown in the table below:

Coating Classes	Legacy Cr(VI) containing products Examples	Alternative Chrome-free solutions (developed and proposed)	Description of Alternatives
Basecoats	SermeTel W, Sermetel 962, SermaGard 1105, SermaGard 902, SermeTel 853	SermeTel CF W SermeTel CF 962 SermeTel CF 7800	Silicate-based binder with Aluminum powder in slurry form.
Lower Temperature-cure Basecoats	SermeTel 1460, SermeTel 984	SermeTel CF W LC SermeTel CF 962 LC	Silicate-based binder with Aluminum powder in slurry form and added

		SermeTel CF 984	material to encourage low temperature cure.
Sealers/ Topcoats	SermeTel 565 (TCS), SermeTel 570A, SermeTel 134, SermeTel 985, SermeTel 842, SermeTel Blue 95	SermeTel CF Gray LT SermeTel CF Green LT SermeTel CF Gray HT SermeTel CF Green HT SermeTel CF TCS SermeTel CF 842 SermeTel CF Blue	Phosphate-based binders with variety of optional additives and pigments to supply additional properties (color, erosion resistance, surface finish, surface properties, etc.)
Basecoat for special environment applications	SermeTel 622	SermeTel CF 622	Silicate-based binder with Aluminum and other alloy powders in slurry form.
Hot Corrosion resistant Basecoat	SermeTel 1740	SermeTel CF HCB	Silicate-based or phosphate-based binder with ceramic and or metallic pigments.
Coatings for Diffusion	SermaLoy J, SermaLoy 963, SermaLoy 1245, SermaLoy 1515, SermaLoy 1595	SermaLoy CF J	Phosphate-based binder with ceramic and metallic pigments to enable the formation of diffusion layers similar to that of legacy products.
Dry film lubricants	SermaLube 20, SermaLube 72, etc.	SermaLube 1758	Phosphate based binders with additives and pigments to supply low friction surfaces.

Table 6. List and description of alternative solutions (substance or technology) that could eventually be used by Linde AMT.

Multiple customer trials are underway for both performance and processability validation for the purpose of qualification of these alternative systems. Product ionization trials have been performed in several of Linde AMT coating plants for two-way suitability study of chrome-free alternatives.

One of these trials has been completed with successful trials of three new chrome-free coating systems. This includes demonstration of plant capability to spray each of the new CF systems on both test panels, and real 3-dimensional trial parts.

The most promising (and newly selected) Linde AMT's hexavalent chromium slurries subtype processes, regarding the Use-1, are listed below:

- "SermeTel W process 2F1" is a multi-layer coating system including a basecoat (SermeTel W) with aluminium sacrificial activity and a chromate/phosphate topcoat with sealant activity;
- "SermeTel process 5380 DP", consists of a closely packed aluminium-filled chromate/phosphate basecoat, sealed with a chromate/phosphate topcoat;
- "SermaLoy J" diffuses slurry aluminide coating as a unique silicon-enriched outer layer.

These slurries are manufactured by Linde AMT group in the US before being shipped to the UK.

As of today, the main challenges for Linde AMT regarding these newly selected alternatives is scale-up to production, including raw material sourcing, process development, quality control set up, labelling and shipping documents development. Customer approvals and qualifications are also important factors to consider to finalize the complete substitution of Cr(VI) at Linde AMT.

Moving forward with new alternatives to Cr(VI) (which was not possible with previously selected alternatives in the initial AfA) slowed down the process to achieve complete substitution in the originally agreed timeline.

3.2.2 Consultations with customers and suppliers of alternatives

Linde AMT coating shops are members of Linde AMT corporate. Given the fact that Linde AMT corporate is a formulator of coating mixtures, the Linde AMT coating shop in the UK has no other choice but using the alternatives developed by the head office. This could not be the case for many of Linde AMT competitors who can use the mixtures of different suppliers to improve the research of alternatives and satisfy customers' requests.

Since Linde AMT is the formulator of such slurries they rely on their own R&D department come formulate new Cr(VI)-free (CF) coating mixtures.

3.2.3 Data searches

Linde AMT conduct their own data search as part of their own R&D programs aiming at substituting Cr(VI) from their coating mixtures and finding alternatives.

3.2.4 Identification of alternatives

The Applicant is aware that some alternative solutions are available, they are summarised in the table below:

Coating Classes	Legacy Cr(VI) containing products Examples	Alternative Chrome-free solutions (developed and proposed)
Basecoats	SermeTel W, Sermetel 962, SermaGard 1105, SermaGard 902, SermeTel 853	SermeTel CF W SermeTel CF 962 SermeTel CF 7800
Lower Temperature-cure Basecoats	SermeTel 1460, SermeTel 984	SermeTel CF W LC SermeTel CF 962 LC SermeTel CF 984
Sealers/ Topcoats	SermeTel 565 (TCS), SermeTel 570A, SermeTel 134, SermeTel 985, SermeTel 842, SermeTel Blue 95	SermeTel CF Gray LT SermeTel CF Green LT SermeTel CF Gray HT SermeTel CF Green HT SermeTel CF TCS SermeTel CF 842 SermeTel CF Blue
Basecoat for special environment applications	SermeTel 622	SermeTel CF 622
Hot Corrosion resistant Basecoat	SermeTel 1740	SermeTel CF HCB
Coatings for Diffusion	SermaLoy J, SermaLoy 963, SermaLoy 1245, SermaLoy 1515, SermaLoy 1595	SermaLoy CF J
Dry film lubricants	SermaLube 20, SermaLube 72, etc.	SermaLube 1758

Table 7. List and description of potential alternative solutions

Considering the time remaining for the alternative investigation, the Applicant has made some choices and already dismissed potential alternatives and decided to focus all R&D and industrial efforts on most promising candidates.

At this time, Linde AMT has shortlisted five suitable and viable alternatives which are described in the following section.

3.2.5 Shortlist of alternatives

To date, Linde AMT has shortlisted five potential Cr(VI)-free candidates based on the results obtained from early Research and Development campaigns and consultations (as successors of the previously 3 alternatives chosen in the original AfA).

ALTERNATIVE	COATING CLASSES	ALTERNATIVE CHROME-FREE SOLUTIONS
Alternative 1	**Overlay coating systems Multi-layer coating system**	**SermeTel W process 2F1**
		SermeTel process 5380 DP
		SermeTel 1740
		SermeTel Blue (Sealer Top coat)
Alternative 2	**Coatings for Diffusion**	**Sermaloy J**

Table 8. List and description of shortlisted alternatives

The Applicant would like to emphasise that they are not comparing the different alternatives because each one of them was covering specific performances addressed by the Use-1. Consequently, the 2 alternatives together (including all the various above mentioned solutions) are meant to allow the covering of previous mixtures performances and an almost complete substitution of the remaining Cr(VI)-containing formulation and applications.

3.3 Assessment of shortlisted alternatives

3.3.1 Alternative 1: Overlay coating systems

3.3.1.1 General description of Alternative 1

Cr(VI)-free overlay coating systems (Alternative 1) consists in a combination of several chrome-free technology developed by Linde AMT to cover all their applications including:

- "SermeTel W process 2F1" which is a multi-layer coating system including a basecoat; (SermeTel W) with aluminium sacrificial activity and a chromate/phosphate topcoat with sealant activity;
- "SermeTel process 5380 DP", consists of a closely packed aluminium-filled chromate/phosphate basecoat, sealed with a chromate/phosphate topcoat;
- SermeTel 1740;

- SermeTel Blue.

The Applicant would like to emphasise that they are not comparing the different alternatives because each one of them was covering specific performances addressed by the Use-1. Consequently, the 4 above mentioned solutions together are meant to allow the substitution of the remaining Cr(VI)-containing formulation and applications.

3.3.1.2 Availability of Alternative 1

Linde AMT is Alternative 1 formulator; therefore, should the industrialisation and customer approval phases should be successful then Alternative 1 should not entail supply disrupts. However, most of Alternative 1 solutions remains to date in the "Internal Lab testing" or "Customer Lab testing" phase and are therefore not yet readily commercially available.

3.3.1.3 Safety considerations related to using Alternative 1

Based on the available information, the classification and labelling of the classified substance in Alternative 1 slurries can be reviewed for comparison of the hazard profile:

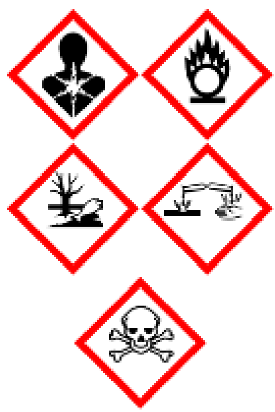
CHARACTERISTICS	Aluminium nitrate nonahydrate	Orthophosphoric acid	Silicic acid, lithium salt	Chromium trioxide
CAS number	7784-27-2	7664-38-2	12627-14-4	1333-82-0
EC number	616-523-8	231-633-2	235-730-0	215-607-8
Hazard Class and Category Code(s) Hazard Statement Code(s)	No harmonised classification	H314 Skin Corr. 1B	No harmonised classification	H314 Skin Corr. 1A H400 Aquatic Acute 1 H271 Ox. Sol. 1 H311 Acute Tox. 3 H317 Skin Sens. 1 H330 Acute Tox. 2 H334 Resp. Sens. 1 H340 Muta. 1B H350 Carc. 1A H361f Repr. 2 H372 STOT RE 1 H410 Aquatic Chronic 1
Pictograms				

Table 9. Comparison of the toxicological profiles between Alternative 1 classified substance and Chromium trioxide.

The intrinsic properties of Chromium trioxide are of greater concern than the ones of the Alternative 1 substance (with the above-table only depicting the classified substances in the slurry mixtures). As such, transition from chromium trioxide-based process to Alternative 1 would constitute a shift to a less hazardous substance.

3.3.1.4 Technical feasibility of Alternative 1

Information on technical feasibility and obstacles for the alternative solutions

- Alternative materials have been developed and tested in laboratory environments.
- Many of the newly developed alternative materials still require scale-up to production, including raw material sourcing, process development, quality control set up, labelling and shipping documents development, etc.
- Scale-up and training in industrial environments has begun but needs to be further continued to allow all operators at each plant to have mastery of the new materials application characteristics.
- Development of application processes for real customer parts, including both spraying, burnishing, and quality control processes must be performed.

Finally, the Customer approval of the materials must be completed in order to switch from current materials to chrome-free alternative materials without interruption of capability to provide service.

The hexavalent chromium containing binders, as well as any non-chromium containing alternatives, would need to provide these key properties:

- **Sprayability** (as the liquid slurry form): This includes **solubility in a carrier solvent**, such as water, as well as **suitable viscosity** to be applied in a uniform stable film on complex part geometries.
- **Processability** of Slurry in industrial environments: to enable economical adoption by customers and production plants.
- **Convertibility to insoluble form (curing):** To provide irreversible adhesion and cohesion of coating in service.
- **Mechanical properties** of cured film form: To provide final mechanical properties, and to enable successful burnishing of cured coatings.
- **Chemical resistance** of cured film form: To provide necessary robustness of coating in in-service chemical environments.
- **Thermal resistance** of cured film form: To provide necessary robustness of coating in in-service thermal environments.

More specifically some performances in the following areas may be expected:

- Sacrificial Corrosion Protection
- Inhibitive Sealant
- High Temperature Corrosion

- Anti-Fouling
- High Temperature Oxidation & Hot Corrosion
- Lubricity at high temperature

Description of the impacts of the alternative for process changes and impact on the technical feasibility of the alternative

- Process changes which may result from the transfer of newly developed alternative materials include:
- New Spray equipment (spray guns, etc.)
- New humidity control equipment (spray booths, meters, etc.)
- Modified fire extinguishment systems (if necessary)
- Modified process times and application rates for current systems, such as different times to coat same parts with alternative materials.
- Modified processes for certain part geometries. These may be discovered during the transfer to plants.

3.3.1.5 Economic feasibility of Alternative 1

As of today, the assessment of Alternative 1 and its economic feasibility and impacts are still limited but on-going. Some investments as well as extra production costs calculations have been initiated but not all the information are readily available at the time and some enquiries remain in progress.

Linde AMT performed some preliminary economic assessment of Alternative 1 which suggests that, while the material costs are comparable to the current chromium containing solutions, the application costs are higher.

Moreover, direct and indirect costs in order to assess the viability of the alternative and any information to support efforts to achieve it may be required, including:

- **Capital costs such as:**
    - Spray Equipment
    - Humidity control in spray booths
    - Fire Extinguishment systems
- **Cost associated with Customer Approval:**
    - Engineering time
    - Development time
    - Coated panels and parts for customers
- **Costs associated with Scale-up to plants, customer parts:**
    - Time to learn proficiency with new alternative materials
    - Time to develop processes on customer parts (application, post treatment processing, etc.)

In conclusion, the implementation and operation of Alternative 1 is most likely to be more expensive than the conventional Cr(VI)-based method.

3.3.2 Alternative 2: Coatings for Diffusion

3.3.2.1 General description of Alternative 2

"SermaLoy J" diffuses slurry aluminide coating as a unique silicon-enriched outer layer.

The Applicant would like to emphasise that they are not comparing the different alternatives (Alternative 1 and 2) because each one of them was covering specific performances addressed by the Use-1.

3.3.2.2 Availability of Alternative 2

Linde AMT is Alternative 2 formulator; therefore, should the industrialisation and customer approval phases should be successful then Alternative 2 should not entail supply disrupts. However, Alternative 2 remains to date in the "Industrial testing" phase and is therefore not yet readily commercially available.

3.3.2.3 Safety considerations related to using Alternative 2

The intrinsic properties of Chromium trioxide are of greater concern than the ones of the Alternative 2 substances. As such, transition from chromium trioxide-based process to Alternative 2 would constitute a shift to a less hazardous substance.

3.3.2.4 Technical feasibility of Alternative 2

Information on technical feasibility and obstacles for the alternative solutions

- Alternative materials have been developed and tested in laboratory environments.
- Many of the newly developed alternative materials still require scale-up to production, including raw material sourcing, process development, quality control set up, labelling and shipping documents development, etc.
- Scale-up and training in industrial environments has begun but needs to be further continued to allow all operators at each plant to have mastery of the new materials application characteristics.
- Development of application processes for real customer parts, including both spraying, burnishing, and quality control processes must be performed.

Finally, the Customer approval of the materials must be completed in order to switch from current materials to chrome-free alternative materials without interruption of capability to provide service.

The hexavalent chromium containing binders, as well as any non-chromium containing alternatives, would need to provide these key properties:

- **Sprayability** (as the liquid slurry form): This includes **solubility in a carrier solvent**, such as water, as well as **suitable viscosity** to be applied in a uniform stable film on complex part geometries.
- **Processability** of Slurry in industrial environments: to enable economical adoption by customers and production plants.
- **Convertibility to insoluble form (curing):** To provide irreversible adhesion and cohesion of coating in service.
- **Mechanical properties** of cured film form: To provide final mechanical properties, and to enable successful burnishing of cured coatings.
- **Chemical resistance** of cured film form: To provide necessary robustness of coating in in-service chemical environments.
- **Thermal resistance** of cured film form: To provide necessary robustness of coating in in-service thermal environments.

More specifically some performances in the following areas may be expected:

- Sacrificial Corrosion Protection
- Inhibitive Sealant
- High Temperature Corrosion
- Anti-Fouling
- High Temperature Oxidation & Hot Corrosion
- Lubricity at high temperature

Description of the impacts of the alternative for process changes and impact on the technical feasibility of the alternative

- Process changes which may result from the transfer of newly developed alternative materials include:
- New Spray equipment (spray guns, etc.)
- New humidity control equipment (spray booths, meters, etc.)
- Modified fire extinguishment systems (if necessary)
- Modified process times and application rates for current systems, such as different times to coat same parts with alternative materials.
- Modified processes for certain part geometries. These may be discovered during the transfer to plants.

3.3.2.5 Economic feasibility of Alternative 2

As of today, the assessment of Alternative 2 and its economic feasibility and impacts are still limited but on-going. Some investments as well as extra production costs calculations have been initiated but not all the information are readily available at the time and some enquiries remain in progress.

Linde AMT performed some preliminary economic assessment of Alternative 2 which suggests that, while the material costs are comparable to the current chromium containing solutions, the application costs are higher.

Moreover, direct and indirect costs in order to assess the viability of the alternative and any information to support efforts to achieve it may be required, including:

- **Capital costs such as:**
  - Spray Equipment
  - Humidity control in spray booths
  - Fire Extinguishment systems
- **Cost associated with Customer Approval:**
  - Engineering time
  - Development time
  - Coated panels and parts for customers
- **Costs associated with Scale-up to plants, customer parts:**
  - Time to learn proficiency with new alternative materials
  - Time to develop processes on customer parts (application, post treatment processing, etc.)

In conclusion, the implementation and operation of Alternative 2 is most likely to be more expensive than the conventional Cr(VI)-based method.

3.4 Conclusion on shortlisted alternatives

The shortlisted Chromium-free alternatives have proved to cover several "classical" properties of metallic-ceramic coating (not necessarily all at once depending on Linde AMT applications and the alternatives themselves), during in-house Linde AMT testing processes:

- Sacrificial corrosion protection property
- High temperature corrosion resistance
- Inhibitive sealant property
- Anti-fouling protection
- High temperature oxidation and corrosion resistance
- Lubricity at high temperature

Regarding these alternatives, Linde AMT's customers will need further time to validate/qualify before being ready to use these new chromium-free mixtures, since the parts coated are critical to ensure the security and the service life of their engines. Considering these problematics, Linde AMT requests a review period of 2 additional years from the end date of the original Authorisation granted (2024) to implement the two above-described alternatives and make sure the OEMs have reached the compulsory level of safety for the new materials.

It is important to note that the Applicant is not comparing the different alternatives between themselves in this review report because each one of them is covering specific performances addressed by the Use-1. **Consequently, the two alternatives together are meant to allow the covering of previous mixtures performances and lead towards complete substitution of Cr(VI) from Linde AMT's slurries and processes.**

As of today, the main challenges for Linde AMT regarding these newly selected alternatives is scale-up to production, including raw material sourcing, process development, quality control set up, labelling and shipping documents development. Customer approvals and qualifications are also important factors to consider to finalize the complete substitution of Cr(VI) at Linde AMT.

Moving forward with new alternatives to Cr(VI) (which was not possible with previously selected alternatives in the initial AfA) slowed down the process to achieve complete substitution in the originally agreed timeline.

4 SOCIO-ECONOMIC ANALYSIS

4.1 Continued use scenario

4.1.1 Summary of substitution activities

Linde AMT has continued their Cr(VI) substitution work as intended since the original AfA. Unfortunately, the previously presented alternatives did not allow complete substitution of Cr(VI) for Linde AMT spraying applications. Chrome-free coatings and coating systems (specific combinations of multiple coatings applied in a multi-layer manner) have been developed and tested in R&D to replace about 85% of the coatings currently used. Linde AMT has therefore been evaluating a number of other alternatives which might be suitable for completing the substitution of Cr(VI) in their process.

Multiple customer trials are underway for both performance and processability validation for the purpose of qualification of the 2 new selected alternative systems. Productionization trials have been performed in several of Linde AMT coating plants for two-way suitability study of chrome-free alternatives.

As of today, the main challenges for Linde AMT regarding these newly selected alternatives is scale-up to production, including raw material sourcing, process development, quality control set up, labelling and shipping documents development. Customer approvals and qualifications are also important factors to consider to finalize the complete substitution of Cr(VI) at Linde AMT.

4.1.2 Conclusion on suitability of available alternatives in general

It is important to note that the Applicant is not comparing the different alternatives between themselves in this review report because each one of them is covering specific performances addressed by the Use-1.

Consequently, the two alternatives together are meant to allow the covering of previous mixtures performances and lead towards complete substitution of Cr(VI) from Linde AMT's slurries and processes.

4.1.3 Substitution plan

4.1.3.1 Factors affecting substitution

The following table gives a coarse comparison on suitability and availability of the shortlisted alternatives:

	Alternative 1	Alternative 2
Variant	-	-
Technical feasibility	***P***	***P***
Economic feasibility*	***OK***	***OK***
Availability	***N.D.***	***N.D.***
Health & Safety Risk	***OK***	***OK***

Table 10. Comparison of the most promising potential alternatives ***OK = compliant; NOK = non-compliant; P = perfectible, N.D = Not-Determined***

Linde AMT is following a qualification process derived from the aerospace industry which means that to describe the general validation / qualification / certification process, the Applicant used the aviation industry, which represents the major market of Linde AMT hexavalent chromium coating in the UK. Moreover, and as indicated in the introduction, the industrial Gas Turbines (which are composed mainly of aeroderivative turbines) and the Oil & Gas sector (for inherent safety reasons), are subject to comparable testing and qualification constraints in terms of length and stringency. The following descriptions are therefore deemed representative of Linde AMT customers problematic to substitute a new corrosion coating mixture.

As described in the ECHA/EASA document, airworthiness requirements are the set of measures which allow the aircraft's safe flight. To this end, extreme caution must be exercised and risks understood before replacing a material which has proven experience. To validate the replacement of a material (or substances), the OEMs need to go through different steps consecutively:

1. Qualification;
2. Certification;
3. Industrialisation.

The qualification step is a process by which a company validates that a substance meets the performance requirements as described in the performance specifications. As stressed in the ECHA/EASA document,

'When new materials or design changes are introduced, the original compliance demonstration will have to be reviewed for applicability and validity, in addition to a review of potential new aspects of the new material or design change that could affect the airworthiness of the aircraft. Depending on the change, this review could be restricted to coupon or component tests, but for

other changes this could involve rather extensive testing. E.g. changes in protective coatings could affect not only the corrosion resistance but could also affect the friction characteristics of moving components in actuators in the different environmental conditions, changing the dynamic behaviour of the system, which in the end affects the dynamic response of the airplane'.

The changing of engine parts corrosion coating involves therefore the necessity to perform an engine test in addition to anti-corrosion resistance on parts.

This qualification step (in the case of Linde AMT customer) includes 2 major sub-steps:

1. OEM substances screening/testing
2. OEM engine testing (in ground or in flight)

This step, depending on the company, can take up to several years. Since the modification is important (new anti-corrosion coating) in the case of Linde AMT, tests are expected to be lengthy.

The certification is realized by a competent aviation authority such as the European Aviation Safety Agency (EASA) in the EU. If the modification is considered as an important modification (for example, new coating mixture), the whole engine and not only the part directly impacted will need to be certified. The certification duration can take 6 months to 1 year (1 year approximately in the case of Linde AMT).

After the qualification/certification process, an industrial implementation of the process is realized. The estimated duration could be different depending on the type of process.

4.1.3.2 List of actions and timetable with milestones

A provisional timeline as well as an outlook for the future have been drawn for the substitution of industrial spraying of chromium trioxide mixtures for the coating of metallic articles subject to harsh environment based on using Alternatives 1 and 2 for various applications and on the Applicant companies' current situation. Spraying of chromium trioxide mixtures is expected to continue until its complete phase-out at the end of the review period after the qualification/certification process, and once the industrial implementation of the process is realized.

The list of different phases and milestones for Alternative 1 transition plan is described below:

Alternative	Phase as per program	2023				2024				2025				2026			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Lab Testing at Customer																
	Industrial testing																
	Customer Documentation & Approval																

	Industrialisation																
2	Industrial testing																
	Industrialisation																

Table 11. Linde AMT Substitution Plan for the two selected Alternatives to Cr(VI) for Use-1

<u>Lab testing at Customer</u>

- Performance testing of alternative chrome-free materials vs defined materials specifications.
- Typically performed on metal test panels in model scenarios.

<u>Industrial Testing</u>

- Application of alternative chrome-free materials in industrial environments, with real production parts.
- Performance testing of industrially-produced parts (in laboratory or in-service environments).
- Defining acceptable ranges of application parameters for quality assurance.

<u>Customer Documentation & approval</u>

- Customer approval to material specifications.
- Customer purchasing documentation.
- Potential audits of manufacturing sites/ quality departments.
- Updating of engineering documents, specifications and drawings to reflect new materials.

<u>Industrialization</u>

- First Article testing procedure.
- Transfer of application procedures and customer part requirements to application plants.
- Standardization of processes in multiple plants, if necessary.

Finally, hexavalent chromium will still be necessary almost until the end of the review period (end of 2026) as the Applicant will need time to adapt to these new processes and gradually ramp up customer program transfers and production. Indeed, the review period required along this AfA would correspond to gradual shift of the conventional spraying to the substitutive solutions. Chromium trioxide-free plating alternatives are foreseen to be fully developed, industrially implemented and qualified in 2026.

Regarding these alternatives, Linde AMT's customers will need further time to validate/qualify before being ready to use these new chromium-free mixtures, since the parts coated are critical to ensure the security and the service life of their engines. Considering these problematics, Linde AMT requests a review period of 2 years additional years from the end date of the original Authorisation granted (2024) to implement the two above-described alternatives and make sure the customers have reached the compulsory level of safety for the new materials.

Given the argument put forward, and in order to develop, implement and validate the most suitable alternatives for the Use applied for, Linde AMT apply for 2 additional years compared to the previously obtained review period.

4.1.3.3 Monitoring of the implementation of the substitution plan

If the review report is granted, the Applicant will pursue the substitution plan previously described.

To this end, the Applicant will set up annual substitution reports to follow-up the progress made. Technical follow-up meetings will eventually be held, but their frequency will have to be specified.

The Applicant will also regularly request feedbacks (quarterly update) from suppliers, customers and partners to ensure that the gradual production shift to Alternative 1 and complete phase-out of Cr(VI) spraying stays on tracks.

4.1.3.4 Conclusions

Given the argument put forward, and in order to develop, implement and validate the most suitable alternatives for the Use applied for, Linde AMT apply for two additional years in the UK compared to the previously obtained review period in the EU, granting authorisation extension up to end of 2026.

4.1.4 R&D plan

Alternative 1 and 2 have been identified as suitable substitutions to Cr(VI) usage. A Substitution Plan as well as a list of actions and timetable with milestones have been described in Sections 4.1.3 and 4.1.3.2.

4.2 Risks associated with continued use

The individual excess risk of cancer that can be estimated for the review period are confirmed and specified by occupational air monitoring data and modelling for the workers exposure, and ambient air, and water- monitoring data as well as modelling for the general population exposure ("man via environment"), as detailed in the CSR.

These calculations are based on RAC's opinion on excess risks of several chromium compounds[6] and will be used to estimate the possible impacts on human health, should an Authorisation be granted to Linde AMT. As described in the CSR, the « applied for use

[6] Application for authorisation: establishing a reference dose response relationship for carcinogenicity of hexavalent chromium, RAC/27/2013/06 Rev.1 (Agreed at RAC-27).

» scenario presents a risk for operators, maintenance workers (external) and preparation coating workers, as well as for the general population.

Considering the transformation of hexavalent chromium, on water and soil, into trivalent chromium via redox reaction, it can however be stated that the risk for the general population is low. As regards the workers exposure, the handling of the mixture containing the substance is well managed with general and personal protection equipment and safety procedures.

As mentioned in Section 2.4, the assessment of the socioeconomic component of the present AfA will be based upon a Cost-Benefit Analysis for which a comparative assessment will therefore be carried out, between the monetised impacts related to the "applied for use" and the "non-use" scenarios.

The dominating health effect for workers resulting from the intrinsic hazardous properties of chromium trioxide is lung cancer due to inhalation of dust and/or aerosols.

In accordance with the RAC document on the dose-response relationship (RAC/27/2013/06 Rev.1), it has to be assumed that all particles are in the respirable size range. Hence, the oral route (mucociliary clearance and swallowing of the non-respirable fractions) is not considered for workers.

The risk assessment for humans exposed via the environment includes the inhalation of airborne residues of chromium trioxide, as well as the oral exposure via food (fish) and drinking water.

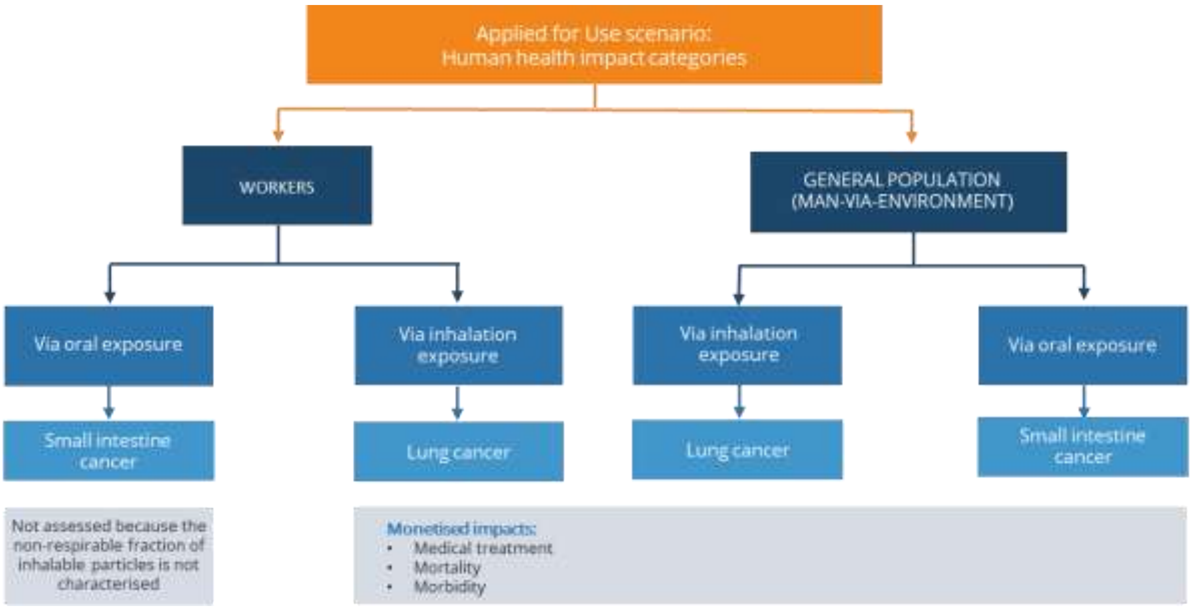


Figure 4 Scheme of risk assessment.

4.2.1 Impacts on humans

Monetised damage of the impacts on human health of the "applied for use" scenario include medical treatment, mortality and morbidity based on the individual excess risks figures as calculated in the CSR.

Where relevant, and in order to offer a comprehensive understanding of the amounts at stake, it was chosen to supplement values considering the number of statistical cancer cases with values based on the individual excess risk of cancer.

In what follows:

- **Individual values** refer to values based on the individual excess risk of cancer, thereby related to **one worker**, or **one person of the general population**;
- **The number of statistical cancer cases**, thereby related to **all workers**, **all general population**, or **workers and general population together as specified**.

The impacts presented are specific to the Lincoln plating shop.

4.2.1.1 Workers

	WORKERS -INHALATION - FATAL LUNG CANCER					
	Chrome sprayers	Cell leaders	Operators	Inspectors	Maintenance workers	External workers
Number of exposed persons	**6**	**1**	**12**	**2**	**5**	**3**
Individual Excess lifetime fatal cancer risk_40 years	**8,53E-02**	**1,86E-05**	**7,04E-04**	**3,73E-05**	**4,38E-06**	**4,38E-06**
Individual Excess risk_2 years	**4,27E-03**	**9,31E-07**	**3,52E-05**	**1,86E-06**	**2,19E-07**	**2,19E-07**
Number of statistical fatal lung cancer cases per type of workers_over 2 years	**2,56E-02**	**9,31E-07**	**4,22E-04**	**3,73E-06**	**1,09E-06**	**6,57E-07**
Number of statistical fatal lung cancer cases for workers_2 years	**2,60E-02**					

Table 12. Summary of fatal excess risk parameters for workers-40 years and 2 years, Lincoln (UK)

4.2.1.2 General population (man-via-environment)

ECHA in its note establishing a reference dose response relationship for the carcinogenicity of hexavalent chromium[7], provides also an excess lifetime fatal lung cancer risk via inhalation exposure and an excess lifetime intestinal cancer risk via oral exposure for the general population.

[7] Application for authorisation: establishing a reference dose response relationship for carcinogenicity of hexavalent chromium, RAC/27/2013/06 Rev.1 (Agreed at RAC-27).

Experts considered in different official reports on possible exposure to hexavalent chromium[8,9], that the most probable risk would be in the local air compartment. Indeed, on water and soil, the hexavalent chromium is transformed into trivalent chromium via redox reaction[10].

Moreover, in the EU RAR about release of hexavalent chromium compounds from use in metal treatment, no air release was considered (except during formulation of products).

As a consequence, as detailed in the CSR, the PEC regional derived were found to be very low. As a result, no further quantification relating to potential exposures at the regional level has been undertaken in the SEA.

The excess risk rates for respectively mortality by lung cancer and intestinal cancer for the general population at local level are as follows:

GENERAL POPULATION - INHALATION - FATAL LUNG CANCER	
PECair (µg/m3)	2,12E-03
Excess risk of lung cancer, per µg/m³ of Cr(VI) based on 70 years, 365 days per year, 24h per day (RAC 2013)	2,90E-02
Individual Excess lifetime cancer risk_70 years	6,15E-05
Individual Excess risk_2 years	1,76E-06
Number of people considered	103 000
Number of statistical fatal lung cancer cases in the general population_over 2 years	**1,81E-01**

GENERAL POPULATION - ORAL - INTESTINAL CANCER	
Total daily intake (µg/kg/d)	2,52E-04
Excess risk of intestinal cancer, per µg/kg/day of Cr(VI) based on 70 years, 365 days per year, 24h per day (RAC 2013)	8,00E-04
Individual Excess lifetime cancer risk_70 years	2,02E-07
Individual Excess risk_2 years	5,76E-09

8 European Union Risk Assessment Report on hexavalent chromium substances (Volume 53 3rd priority list).

9 INERIS - Fiche de données toxicologiques et environnementales du chrome et de ses dérivés.

10 EPA Ground Water Issue, "Natural Attenuation of Hexavalent Chromium in Groundwater and Soils", EPA154015-941505, 1994.

Number of people considered	103 000
Number of statistical intestinal cancer cases in the general population_over 2 years	**5,93E-04**

Table 13 Excess risk parameters of fatal lung cancer – Inhalation and intestinal cancer – Oral, for general population at local level, Lincoln.

4.2.2 Impacts on environmental compartments

As described in the CSR, the assessment of environmental impacts as such does not appear relevant for this AfA regarding the SVHC properties stated in column 2 of entry 16 in annex XIV of UK REACH.

The impact on man-via-environment is assessed as part of the human health impacts, as per CSR.

4.2.3 Compilation of human health and environmental impacts

The monetised damage of the impacts on human health of the "applied for use" scenario includes medical treatment, mortality and morbidity for workers and the general population.

As presented above, the assessment of environmental impacts as such not appearing relevant for this AfA, no monetisation of environmental impacts was performed, other than man-via-environment impacts.

A summary of the information is presented in the table below.

	Individual Excess lifetime cancer risk[1]	Number of exposed people	Estimated statistical cancer cases over 2 years	Monetised excess risk ([per year[4]] [over 2 years])[5]
Workers				
Directly exposed workers[2]	8,88E-02	26	2,69E-02	27 750£ (per year) 52 340£ (over 2 years)
Indirectly exposed workers[3]	5,77E-05	3		
Sub-total	8,88E-02	29	2,69E-02	27 750£ (per year) 52 340£ (over 2 years)
General population				
Local	6,37E-05	103 000	1,87E-01	199 957£ (per year) 377 138£(over 2 years)
Regional	PEC regional derived in the CSR were found to be very low. As a result, no further quantification relating to potential exposures at the regional level has been undertaken in the SEA.			

Sub-total	6,37E-05	103 000	1,87E-01	199 957£ (per year) 377 138£ (over 2 years)
Total	8,89E-02	103 029	2,14E-01	227 707£ (per year) 429 477£ (over 2 years)
Latency (years)	The values were not adjusted for any latency effects in the relationship between exposure and cancer cases. It is therefore considered that figures provided represent a worst-case scenario.			

Table 14. Summary of additional statistical cancer cases for human health, Lincoln site.

Notes:

[1]Excess risk is estimated over a typical lifetime working exposure (40 years) and via the environment over a typical lifetime exposure (70 years). As excess risks are likely to be different depending on the task, report the overall minimum and maximum excess risk among all the tasks carried out by the workers.
[2]Directly exposed workers perform tasks described in the worker contributing scenarios, typically characterised by an 8-hour Time Weighted Average (TWA) exposure of a representative worker.
[3]Indirectly exposed workers (bystanders) do not use the substance.
[4]Annualised value is derived from the present value of the monetised impact using the appropriate annuity factor over the review period.
[5]Derived from the lifetime risk of 40 or 70 years.

4.2.3.1 Methodology foreword

The RAC reference dose response gives an excess lifetime mortality risk and not an excess lifetime cancer risk (incidence) of lung cancer.

In order to take into consideration, the impacts of non-fatal cancer cases, the number of statistical non-fatal cancer cases was derived from the number of statistical fatal cancer cases considering the survival rate and the case fatality rate associated with lung cancer in the UK:

$$Number\ of\ statistical\ non\ fatal\ cancer\ cases = Number\ of\ statistical\ fatal\ cancer\ cases * \frac{Survival\ rate}{Mortality\ rate}$$

The number of statistical cancer cases of incidence can therefore be calculated as follows:

$$Number\ of\ statistical\ cancer\ cases\ (fatal + non\ fatal) = Number\ of\ statistical\ non\ fatal\ cancer\ cases + Number\ of\ statistical\ fatal\ cancer\ cases$$

On this basis, and considering a case fatality rate of 96,89% and a survival rate of 3,11% for inhalation route of exposure and a case fatality rate of 82,88% and a survival rate of 17,12% for oral route cancers[11], the following numbers of statistical cancer cases have been considered in the assessment of the impacts of the "applied for use" scenario on human health:

[11] Calculations based on data extracted from Eurocare 5 Survival Analysis 2000 - 2007 Database.

	NUMBER OF STATISTICAL CANCER CASES OVER REVIEW PERIOD		
Population	**Workers**	**General population**	
Endpoint	**Lung cancer**	**Lung cancer**	**Intestinal cancer**
Number of statistical fatal cancer cases	2,60E-02	1,81E-01	5,93E-04
Number of statistical non-fatal cancer cases	8,36E-04	5,81E-03	
Number of statistical cancer cases (fatal +non-fatal) over review period (2 years)	**2,69E-02**	**1,87E-01**	**5,93E-04**

Table 15. Number of statistical (fatal and non-fatal) cancer cases for workers and in the general population, Lincoln.

4.2.3.2 Medical treatment

- **Costs of lung cancer treatment and net survival rate**

As regards to the global cost of lung cancer treatment, different studies can be used that consider: hospitalisation cost, medicine cost but also various associated costs (e.g. in-house care etc…).

For the following analysis, the Applicant decided to use the data provided in a study analysing the treatment cost of non-small cell lung cancer in three European countries: comparisons across France, Germany, and England[12].

The study only deals with NSCLC as it accounts for approximately 87% of lung cancers[13].

As regards the Lincoln site, considering that the study figures relate to 2012, the values were adjusted to present 2022 values (by considering a 25,52% inflation over the period 2012-2022 in the UK):

	2012 values	Adjusted to 2022 values
Average patient costs at 1st year follow-up	£13 261	**£16 645**
Average patient costs at 2nd year follow-up.	£1 672	**£2 098**

Table 16. Total lung cancer costs in the UK, 2012 and adjusted to 2022 values.

As regards the relative survival rate, the Applicant considered rates at 1 and 3 years.

Relative survival rates for lung cancer, calculated at 1 and 3 years from diagnosis, were extracted from Eurocare 5 Survival Analysis 2000 - 2007 Database.

YEARS AFTER DIAGNOSIS	SURVIVAL RATES LUNG CANCER

[12] McGuire A, Martin M, Lenz C, Sollano JA. Treatment cost of non-small cell lung cancer in three European countries: comparisons across France, Germany, and England using administrative databases. J Med Econ. 2015;18(7):525-32. doi: 10.3111/13696998.2015.1032974. Epub 2015 May 20. PMID: 25802950.
[13] Morgensztern D, Ng SH, Gao F, Govindan R. Trends in stage distribution for patients with non-small cell lung cancer: A National Cancer Database survey. J Thorac Oncol 2010; 5 (1): 29–33.

1 year	27,9%
3 years	10,5%

Table 17. Survival rates after lung cancer diagnosis in the UK.

- ### Costs of intestinal cancer treatment and net survival rate

As regards the global costs of small intestine cancer treatment, failing more specific data, the Applicant decided to use the data provided in a study[14] on the cost of cancer in Europe, which provides total direct cancer costs for the UK. A study from 2013 on the economic burden of cancer across the European Union highlighted that colorectal cancer represented 10% of the total costs of cancer in Europe[15].

Colon cancer and rectal cancer are grouped together under the name of colorectal cancer. Colorectal cancer, or also called bowel cancer, represents the cancer of the large intestine. Together with the small intestine, they form the lower part of the digestive tract. Knowing that colorectal cancer treatment cost is higher than the one for small intestine cancer[16] , this consideration led the Applicant to consider a worst-case scenario, by using costs related to colorectal cancer, adjusted to 2022 values by considering a 13,68% inflation over the period 2018-2022 for the UK, as reference for calculating the impact related to small intestine cancer treatment medical costs.

	2018 values	Adjusted values to 2022
Total annual costs of cancer treatment	£9 820 440 000	-
Colorectal cancer costs in % of overall cancer costs	10%	-
Colorectal cancer costs	£982 044 000	-
5-year prevalence cases of colorectal cancer[17]	155800	-
Annual cost of colorectal cancer per patient	**£6 303**	**£7 166**

Table 18. Total annual colorectal cancer costs per patient in the UK, adjusted to 2022 values

As regards the relative survival rate, the Applicant considered rates at 1 and 3 years.

Relative survival rates for small intestine cancer, calculated at 1 and 3 years from diagnosis, were extracted from Eurocare 5 Survival Analysis 2000 - 2007 Database.

[14] Hofmarcher T, Lindgren P, Wilking N, Jönsson B. The cost of cancer in Europe 2018. Eur J Cancer. 2020 Apr;129:41-49. doi: 10.1016/j.ejca.2020.01.011. Epub 2020 Feb 28. PMID: 32120274.

[15] Luengo-Fernandez R, Leal J, Gray A, et al. 2013. Economic burden of cancer across the European Union: a population based cost analysis. Lancet Oncol 14(12): 1165-74

[16] Bowel Cancer UK, “Bowel cancer costs the UK £1.74 billion a year”, October 2020.

[17] Globocan 2020 France, World Health Organization.

YEARS AFTER DIAGNOSIS	SURVIVAL RATES SMALL INTESTINE CANCER, UK
1 year	56,1%
3 years	40,7%

Table 19.Survival rates after small intestine cancer diagnosis in the UK

➢ Monetisation

To monetise the damage on human health, the Applicant has considered the probability to observe the different cancer types on workers and the general population. The probability, in this case, corresponds to the number of statistical cancer cases of each specific cancer.

The individual cancer costs are listed in the table below, considering:

- The cost of cancer treatment by year after diagnosis (it is considered that the cost per year after year 1 is the same as for year 1),
- The survival rates at 1 year and 3 years,
- But also, for the requested review period of 2 years but without considering the excess risk, and without applying the discount rate.

In order to conform to the realistic worst-case scenario, it was chosen to use the survival rate of the upper bound of each duration range.

YEARS AFTER DIAGNOSIS	COSTS LUNG CANCER	COSTS SMALL INTESTINE CANCER
0 to 1 year	£16 645	£7 166
1 to 2 years	£584	£4 018
Total	**£17 230**	**£11 184**

Table 20.Individual cancer costs until the end of the review period, not applying a discount rate, UK.

In order to consider the excess risk of non-fatal lung and small intestine cancer cases, it was considered in the assessment of the costs associated with medical treatment **the number of statistical cancer cases (fatal and non-fatal).**

A 4% discount rate, as per ECHA provisions, was applied to the costs in order to consider time preference and adjust the costs to present value.

▪ Workers

A synthesis of the results is provided below:

YEARS AFTER DIAGNOSIS	COSTS LUNG CANCER LINCOLN
0 to 1 year	£447,51
1 to 2 years	£15,71
Total	£463,22
Total, discounted	**£411,26**

Table 21. Total lung cancer medical costs for workers until the end of the review period, considering the number of statistical cancer cases and a 4% discount rate, Lincoln.

General population

A synthesis of the results is provided below:

YEARS AFTER DIAGNOSIS	COSTS LUNG CANCER - LOCAL	COSTS SMALL INTESTINE CANCER - LOCAL
0 to 1 year	£3 108	£4,25
1 to 2 years	£109	£2,38
Total	£3 217	£6,64
Total, discounted	£2 856	£5,82
Total, all cancers, discounted	**£2 862**	

Table 22. Total cancer medical costs until the end of the review period, considering the number of statistical cancer cases in the general population and a 4% discount rate, Lincoln.

Total costs: workers and general population

The overall costs for medical treatment for workers and the general population is synthesized below:

	Total medical costs discounted, Lincoln
Workers	£411
General population	£2 862
Total	£3 274

Table 23. Total costs of medical treatment of the AfA.

4.2.3.3 Mortality and morbidity

The costs associated with mortality and morbidity represent the main monetised damage of the "applied for use" scenario. The following estimate methodology has been used, based on the value of a statistical life and the willingness to pay to avoid a cancer case as provided in ECHA's SEA guidance and ECHA's note on Willingness-to-pay values for various health endpoints associated with chemicals exposure[18].

The figures provided in ECHA's note on Willingness-to-pay values for various health endpoints associated with chemicals exposure[19] have been adjusted to present values as follows (considering a 19,5% inflation over the period 2012-2022 for the European Union):

[18] SEAC/32/2016/05.2 Rev.1†, Helsinki, 12 April 2017.

[19] SEAC/32/2016/05.2 Rev.1†, Helsinki, 12 April 2017.

		2012 VALUE	ADJUSTED TO 2022 VALUE
Mortality	**Higher value of statistical life – *Base Analysis***	£4 200 000	£4 215 960
	Lower value of statistical life – *Uncertainty Analysis*	£2 940 000	£2 951 172
Morbidity	**Willingness to pay**	£344 400	£345 709

Table 24. Reference value for 2012 and adjusted to 2022 values for the health endpoints assessed.

On this basis, and considering mortality, and morbidity for fatal and non-fatal cases, the following costs associated with mortality and morbidity are provided:

	WORKERS	GENERAL POPULATION	
	Lung cancer	Lung cancer - local	Small intestine Cancer - Local
Cost of mortality, discounted	£47 876	£332 534	£904
Cost for morbidity, fatal + non-fatal cases, discounted	£4 052	£40 748	£89
Total	£51 928	£373 282	£993
Total cost for mortality and morbidity, discounted		**£426 204**	

Table 25 . Total cost of mortality and morbidity, applying a 4% discount rate, Lincoln.

4.2.3.4 Synthesis of the monetised damage of the "applied for use" scenario

The overall monetised impacts of the "applied for use" scenario can be summarised as follows:

	COSTS	
IMPACTS	Workers	General population
Medical treatment	£411	£2 862
Mortality and morbidity	£51 928	£374 275
Sub-total	£52 340	£377 138
Total monetised damage	£429 477	

Table 26. Overall monetised impacts of the "Applied for Use" Scenario.

4.3 Non-use scenario

4.3.1 Summary of the consequences of non-use

As presented previously, the limits to use the alternatives in an industrial process is the time for the user (OEM = direct or indirect customer of Linde AMT) to validate/qualify these new products. As soon as these alternatives will be qualified, customers will use them. Linde AMT therefore only needs time to definitely replace hexavalent chromium for this use.

From the standpoint of the customers, any change of a material or process can only be towards an improved solution (rarely for an equivalent solution). Because of this need of an upgraded product, especially to ensure the airworthiness of their final products but also the safety & efficiency, Linde AMT customers will not use a non-validated/certified alternative. As discussed previously, the changing in coating substance is a major modification and necessitates a long and complete qualification/certification process.

The impact assessment is made for the Lincoln site specifically and compared to the costs avoided for keeping the substance and exposing 29 workers.

In the end, it is contended by the Applicant that the most likely non-use scenario for the Lincoln plating shop, would be the discontinuation of the hexavalent chromium coating activities.

4.3.2 Identification of plausible non-use scenarios

Three generic potential “non-use” scenarios can further be foreseen for any industrial activity:

- Downgrade of performances[20] ;
- Relocation or subcontracting of production outside the UK;
- Cease of production.

4.3.2.1 The downgrade of performances hypothesis

The limits to use the alternatives in an industrial process is the time for the user (OEM = direct or indirect customer of Linde AMT) to validate/qualify these new products. As soon as these alternatives will be qualified, customers will use them. Linde AMT therefore only needs time to definitely replace hexavalent chromium for this use.

From the standpoint of the customers, any change of a material or process can only be towards an improved solution (rarely for an equivalent solution). Because of this need of an upgraded product, especially to ensure the airworthiness of their final products but also the safety & efficiency, Linde AMT customers will not use a non-validated/certified alternative. As discussed previously, the changing in coating substance is a major modification and necessitates a long and complete qualification/certification process.

The downgrading of performance as such is therefore not an option as it would mean that Linde AMT would not be able to provide its customers a chrome plating service in line with their requirements. The company would therefore have no position anymore on this market at all and its customers would directly go to other suppliers (competitors of Linde AMT outside the UK) capable of chrome plating their products.

The consequences linked to the downgrading of performances mean that this is not an option for the Applicant.

[20] Withdrawal of the Substance in the production process, which translates in downgraded performances of the final product.

4.3.2.2 The relocation or subcontracting of the production outside the EU hypothesis

The possibility of a relocation of the plating shops outside of the UK is rather unlikely, even though there is a Linde AMT facility in the United Arab Emirates. Indeed, such a relocation would mean additional logistic costs for customers to be supported by Linde AMT.

Furthermore, all the processes are frozen and qualified by the customer for each production parts. Any outside production, as would be in the case of a relocation or subcontracting, would need the customers approval. As this is a lengthy process, possibly requiring re-certification/qualification it is not something which could be performed in less than two years.

As a consequence, the relocation non-use scenario is not considered very likely.

These potential "non-use" scenarios, and their applicability are summarised in the table below:

POTENTIAL "NON-USE" SCENARIO	USE-1
Downgrade of performances	✗
Relocation outside the UK	✗
Subcontracting outside the UK	✗
Cease of production	✓

Table 27. Potential "Non-Use" Scenarios for products impacted by Use-1.

✗ = not applicable; ✓ = potential

4.3.3 Conclusion on the most likely non-use scenario

The main arguments put forward in the previous Sections can be summarised as follows:

(a) parts concerned by Use-1 are key for Linde AMT's major customers,

(b) there is no available alternative to the use of chromium trioxide for the requirements of Use-1,

(c) a downgrade of parts performances is not acceptable by the customers

(d) and relocation or subcontracting of production outside of the UK are not envisageable.

Based on these arguments, the most likely "non-use" scenario is the following: with the prohibition of the use of chromium trioxide, Linde AMT will have **to cease the plating of the parts concerned by Use-1**.

4.4 Societal costs associated with non-use

Impacts of the denial of an authorisation would mainly have economic and social dimensions:

- **Economic impacts** on Linde AMTs activity include loss of profits;

- **Social impacts** mainly consist of loss of employment in the UK.

4.4.1 Economic impacts on applicants

As explained under Section 4.3.3, the NUS considered would be the cease of the plating activity of the Applicant.

As mentioned in Section 2.2 considering a realistic approach, it has been considered that the Applicant's NUS would start as of 2025.

4.4.1.1 Loss of revenues and profits

In this assessment, solely the impacts in terms of benefits due to chromium trioxide mixtures coating activities will be quantified.

Nevertheless, please note that an estimate 10% of the Cr(VI) coating activities are linked to other non-Cr(VI) coating activities. Because the precise costing of the knock-on effect would be subject to too many uncertainties (though being real), it was chosen not to take it into account in the following assessment.

Lincoln site	2019	2020	2021	2022	2023	2024	2025	2026
Overall Turnover	[redacted]							
Overall Profit	[redacted]							
Use-1 related Turnover	[redacted]							
Use-1 related Profit	[redacted]							

Table 28. Annual business and gross operating amount for Lincoln site (#1)

The assessment of the share of revenues and profits impacted by Use-1, i.e. the revenues that Linde AMT could lose in case of NUS, was carried out on the basis of the forecasts over the review period provided by the Lincoln coating shop.

SEAC's note[21] proposes a default value to be used for assessing producer surplus losses of **2 years of profit loss**.

Applying an annual discount rate of 4%, the discounted value of lost revenues and profits over the review period is as follows:

SHOP	IMPACT PERIOD	NOMINAL VALUE OF PROFIT LOSS	DISCOUNTED VALUE OF PROFIT LOSS	PROFIT LOSS TO BE TAKEN INTO ACCOUNT AS A PROXY OF THE CHANGES IN PRODUCER SURPLUS OVER THE REVIEW PERIOD[22]	ANNUALSED PROFIT LOSS
Lincoln	2 years: 2025-2026	[redacted]	[redacted]	[redacted]	[redacted]

Table 29. Total loss of profit considering the 2-year review period and a 4% actualisation rate (#1)

[21] ECHA, SEAC/52/2021/03.

[22] ECHA, SEAC/52/2021/03.

The total present value of the 2-year profit loss[23] for Lincoln would be of **£** [redacted] [1M-5M] (#1).

The annual value of profit loss is derived from the present value of the 2-year figure using the appropriate annuity factor, and is equal to £[redacted] [1M-3M] (#1).

4.4.2 Economic impacts on the supply chain

Affected group	Economic impact
Direct suppliers	Linde AMT is the supplier of the CR(VI) containing slurries for the UK Linde AMT plating shop, hence no significant impact is expected on Linde AMT.
Suppliers of alternatives in and outside the UK	No impact is expected in the short-term as Linde AMT plating shop customers will under the NUS first look for other plating shops being able to continue to plate their parts with CR(VI) containing coatings. In the medium-term, cooperation with alternative suppliers would probably be sought.
EU customers	Linde AMT is a Global Leader in this technology and is relied upon by customers such as GE, Safran, Rolls Royce, Siemens Energy amongst others. These key OEM's are unable to shift to the chrome VI free formulations until extensive testing is complete. Linde AMT would expect to lose the relevant market share in the region if these customers switched to alternative products. Due to the cycle time for approvals it is likely that once customers move, Linde AMT will be unable to regain market share. Linde AMT Sermetel products are critical element feature of high technology items such as gas turbines. Elimination of the chrome VI containing slurries would result in increased maintenance costs, safety risks and significant downtime. Manufacturing is frequently on a just in time basis with long delivery times for high value items. If customers are forced to move coating processes outside EU or UK, this may result in part manufacturing also being transferred to other global regions. As regards more specifically SMEs, Linde AMT currently has several Long Term Agreements (LTA) with companies which are themselves subcontractors of OEMs. The consequences in terms of business of a discontinuation of Linde AMT coating activities for these companies are difficult to estimate. Nevertheless, should they have to send their parts for coating outside the UK, this would very likely result into an increase of the price of the final products. This, in turn, could affect agreements between the SMEs and their customers (the OEMs) and result in: • At least a decrease of their gross operating rate • A possible unemployment increase for these small companies In the worst-case, if these companies cannot absorb the overcost, it could lead to a shut-down of their activities

Table 30. Economic impacts on the supply chain.

[23] ECHA, SEAC/52/2021/03.

4.4.3 Economic impacts on competitors

Affected group	Economic impact
Competitors in the UK	Linde AMT's competitor in the UK could possibly be positively impacted if they have the necessary authorisation to continue to use CrVI.
Competitors outside the UK	A positive impact is expected for non-UK competitors who are not subject to REACH regulation: they will gain UK customers who were providing from the companies forced to discontinue their plating activities.

Table 31. Economic impacts on competitors.

Concerning the competitors outside the UK, they are not subject to the same regulations and are therefore not obliged to substitute their chrome plating activity.

4.4.4 Wider socio-economic impacts

Different social impacts are expected in the context of the NUS:

- Impact on direct employment
- Impacts on indirect employment

4.4.4.1 Impact on direct employment

Number of jobs concerned

SHOP	Number of jobs lost under the NUS
Lincoln	25

Table 32. Number of jobs lost under the NUS.

In order to place this assessment of the impacts on employment on realistic (and under-estimated) assumptions, minimising on purpose the impacted employments, only workers which cannot be reassigned, have been considered as potentially lost in the context of the "non-use" scenario.

It is reminded that this value can be considered as very conservative as it only accounts for direct jobs and does not consider any indirect job loss that would be generated in the context of the "non-use" scenario, notably in terms of other productive functions (packaging, storage), logistics, sales and marketing.

Assessment via default value

SEAC's note[24] proposes a default welfare cost factor value of 2.7 for the assessment of costs associated with unemployment.

Following this method, the social value of jobs lost in the context of the "non-use" scenario for Use-1 can be estimated as follows:

[24] ECHA, SEAC/32/2016/04 - 32nd meeting of the committee for socio-economic analysis, 6-15 September 2016, Helsinki, Finland.

Welfare cost factor	2.7
Gross wage of workers	£ 28 000
Number of jobs lost	25
Social value of jobs lost	£ 1 890 000

Table 33. Calculation of the social value of jobs lost via the default value methodology for Use-1.

Detailed assessment

A complementary assessment is performed in what follows in view of providing a more specific characterization of the cost related to unemployment in the context of Use-1. This assessment is based on the framework drafted by R. Dubourg[25].

The following impact categories will be explored:

- Value of output/wages lost during the period of unemployment;
- Cost of searching for a new job;
- Leisure time;
- Recruitment costs;
- Impact of being made unemployed on future earnings and employment possibilities ('scarring' effect).

For each impact category, it was attempted to rely as much as possible on data specific to the situation of Linde AMT. Generic data, however, have had to be used where specific data was unavailable.

▪ Value of output/wages lost during the period of unemployment

The value of output (wages) lost during the period of unemployment was calculated using the gross wages of workers concerned and the average duration of unemployment in the UK:

Gross wage of workers	£ 28 000
Average duration of unemployment (months)	8,87
Nominal value of lost output due to the initial unemployment spell	£ 20 697
Discounted value of lost output due to the initial unemployment spell	£ 18 399

Table 34. Calculation of the value of output/wages lost during the period of unemployment for one job, Use-1.

[25] R. Dubourg, Valuing the social costs of job losses in applications for authorisation, The Economics Interface Limited, September 2016.

- ## Cost of searching for a new job

The value for unemployed persons of time spent searching for a new job can be roughly estimated via data proposed by Dubourg (it is considered an average of 2.5 hours spent per week searching for a job) and hourly reservation wage derived from the post-tax expected wage. Please note that the figure of time spent searching for a new job is a rough estimate whose main purpose is to provide an order of magnitude of this cost.

Weekly time spend looking for a new job	2.5 hours
Reservation wage per hour(*)	£ 8
Duration of unemployment (weeks)	38
Nominal value of time lost searching for a new job	£ 735
Discounted value of time lost searching for a new job	£ 653

Table 35. Calculation of the cost of searching for a new job, Use-1.

- ## Leisure time

The assessment of leisure time aims at characterising the value of time freed from work due to unemployment. As per Dubourg methodology, a reservation wage of 80% of the post-tax expected wage is considered.

Reservation wage (80% of post-tax expected wage)	£ 13 082
Average duration of unemployment (year)	0,7
Nominal value of benefits from leisure time	£ 9 669
Discounted value of benefits from leisure time	£ 8 596

Table 36. Calculation of the value of benefits from leisure time related to unemployment for one job, Use-1.

- ## Recruitment costs

The assessment of recruitment costs (cost of hiring employees) is carried out considering that the estimated duration of recruitment cost is 0,3 year. Please note that, as per the previous impact category, the figure for recruitment cost is a rough estimate whose main purpose is to provide an order of magnitude of this cost.

Estimated duration of recruitment cost (year)	0,3
Gross ('scarred') wage	£ 22 400
Nominal value of recruitment costs	£ 6 720
Discounted value of recruitment costs	£ 5 744

Table 37. Calculation of the recruitment costs for one job, Use-1.

- ### Impact of being made unemployed on future earnings and employment possibilities ('scarring' effect)

Scarring effect reflects the tendency to obtain a job with lower wages when unemployed compared to when employed. A scarring effect value of 20% is proposed by Dubourg and will be used in the present assessment.

Scarring effect (average reduction in output following reemployment)	20%
Duration of scarring effect	6 years
Nominal value of lost output due to scarring	£ 33 600
Discounted value of lost output due to scarring	£ 26 097

Table 38. Calculation of the discounted value of lost output due to scarring for one job, Use-1.

- ### Total cost of unemployment

Individual costs of unemployment are detailed in what follows:

Lost output	£18 399
Job search	£653
Leisure time	-£8 596
Recruitment costs	£5 744
Scarring	£26 097
Total	**£42 298**

Table 39. Individual costs of unemployment, discounted.

Considering the number of jobs lost foreseen in the context of the "non-use" scenario for Use-1, **the total cost of unemployment for the Lincoln site, is as follows:**

Total cost of unemployment	£ 1 057 443
Annualised cost of unemployment	**£ 539 925**

Table 40. Total cost of unemployment, Lincoln

Thus, **the annual cost of unemployment**, derived from the present value of each monetised impact computed in the total cost of unemployment using the appropriate annuity factor, **amounts to £ 539 925 for the Lincoln plating shop**.

4.4.5 Compilation of socio-economic impacts

Description of major impacts	Monetised/quantitatively assessed/qualitatively assessed impacts
1. Monetised impacts	
Producer surplus loss due to ceasing the use applied for	£ [redacted] [1M-3M] (per year) £ [redacted] [1M-5M] (over 2 years)

Social cost of unemployment	**£ 539 925 (per year)** **£ 1 057 443 (over 2 years)**
Sum of monetised impacts	**£** [redacted] [1M-3M] **(per year)** **£** [redacted] [1M-5M] **(over 2 years)**

Table 41. Societal costs associated with Non-Use (#1)

[1]Annualised value is derived from the present value of the monetised impact using the appropriate annuity factor.

4.5 Combined impact assessment

The combined assessment of impacts as developed in previous Sections can be summarised in the table below.

Societal costs of non-use		Risks of continued use	
Monetised impacts (£ [per year[1]] [over 2 years])	£ [redacted] [1M-3M] (per year) £ [redacted] [1M-5M] (over 2 years) (#1).	Monetised excess risks to directly and indirectly exposed workers (£ [per year[2]] [over 2 years])	27 750£ (per year) 52 340£ (over 2 years)
Additional quantitatively assessed impacts ([per year][over 2 years])	N/A	Monetised excess risks to the general population (€ [per year[2]] [over 2 years])	199 957£ (per year) 377 138£ (over 2 years)
Qualitatively assessed impacts ([per year][over 2 years])	N/A	Qualitatively assessed risks ([per year][over 2 years])	N/A
Summary of societal costs of non-use	**£** [redacted] **[1M-3M] (per year)** **£** [redacted] **[1M-5M] (over 2 years) (#1).**	**Summary of risks of continued use**	**227 707£ (per year)** **429 477£ (over 2 years)**

Table 42. Societal costs of Non-Use and risks of continued use (#1)

Notes:

[1] Annualised value is derived from the present value of the monetised impact using the appropriate annuity factor.
[2] Annualised value is derived from the present value of the monetised impact using the appropriate annuity factor over the review period.

4.6 Sensitivity analysis

Even though an effort was made all along the document to outline a scenario based on realistic worst-case hypotheses, the results obtained involve uncertainty. In order to identify and quantify such incertitude, the following Section discusses the main assumptions of the socio-economic analysis.

4.6.1 « Applied for use » scenario

4.6.1.1 Preliminary observation: uncertainty of exposure and risk values

The assessment of exposure to chromium trioxide is mainly based upon ART modeling. In order to reduce the uncertainty on these values it was chosen to rely on values for the 90th percentile.

4.6.1.2 Quantitative uncertainty analysis on mortality costs

Uncertainty analysis of the costs associated with mortality was carried out using the lower value of premature death: £2 940 000.

Using the lower value of premature death adjusted to present value - **£2 951 172** (considering a 19,50% inflation over the period 2012-2022 for the European Union), the total costs associated to mortality amount to:

	WORKERS	GENERAL POPULATION	
		Lung cancer- via inhalation	Small-Intestine cancer - via oral
Costs associated with mortality. over review period, discounted	£33 513	£232 774	£633
TOTAL	**£266 920**		

Table 43. Uncertainty analysis of mortality for Lincoln site

4.6.1.3 Other parameters: qualitative uncertainty analysis

A qualitative uncertainty analysis of the main hypothesis, assumptions and parameters used for the assessment of the "applied for use" scenario is provided below.

APPLICATION	PARAMETER	UNCERTAINTY ANALYSIS
Mortality and morbidity	Cancer localisation	Low uncertainty, since specific case fatality rate for lung and small intestine cancer in the UK have been used.
Medical treatment	Costs of medical treatment	Low uncertainty, since specific costs of medical treatment for lung cancer in the UK have been used. Mid uncertainty, since colorectal cancer values the UK have been considered representative of the small intestine cancer treatment costs.
	Survival rate	Low uncertainty, since specific survival rates for 1 and 3 years after diagnosis of lung and small intestine cancer in the UK have been used.

Table 44. Qualitative uncertainty analysis of the main parameters of the "Applied for Use" Scenario.

4.6.2 "Non-Use" Scenario

4.6.2.1 Uncertainty analysis of the loss of employment

The Applicant has decided to use the costs calculated via the detailed assessment methodology as provided in **Section 4.4.4.1.** as reference value.

However, following the default value method, the total social value of jobs lost in the context of the NUS for Use-1 amounts to **£1 890 000**

4.6.2.2 Other parameters: qualitative uncertainty analysis

A qualitative uncertainty analysis of the main hypothesis, assumptions and parameters used for the assessment of the NUS is provided below.

APPLICATION	PARAMETER	UNCERTAINTY ANALYSIS
Loss of profits	Revenues impacted by the use of the AfA	Low uncertainty: the values used to estimate the loss of revenues are based on a comprehensive inventory of the products concerned by the AfA and the associated revenues.
Loss of employment	Average individual monetised impact	Low uncertainty, since the values used in the detailed assessment are specific for the UK and where possible to the Applicant.

Table 45. Qualitative uncertainty analysis of the main parameters of the NUS.

4.6.3 Conclusion

The results of both the quantitative and qualitative uncertainty analysis presented above do not seem to invalidate the overall results of the AfA: the variability of the parameters assessed rather speaks for an even increased order of magnitude of the risk-benefits ratio for the AfA.

4.7 Information to support for the review period

Linde AMTs AfA complies with the criteria set out by RAC and SEAC in document SEAC/20/2013/03 for a 2-year review period, as follows:

- The costs for developing and implementing the substitution process for the Applicant for Alternative 1 to 2 are expected to be higher than the Cr(VI)-process.
- The Applicant refers to their explanations provided under sections 3.2 and 3.3 of the current documents, which demonstrate that R&D efforts already made did not lead to a fully acceptable alternative. Indeed, remaining R&D and industrialisation work would in the present case at least require a two-year period.
- The Applicant refers to the comparison of impacts which compares benefits and risks of the AfA and which shows annualised monetised impacts of the "applied for use" scenario of £227 707, as compared to an annualised monetised impact of the "non-use" scenario of [redacted]£ [1M-3M] (#1). Remaining risks can be considered low as compared to socio-economic benefits and the situation is not likely to change in the coming years.

5 CONCLUSION

Linde AMT is submitting an AfA to be able to finalise the substitution of chromium trioxide in the step of industrial spraying for the coating of metallic articles subject to harsh environment, to ensure a high temperature corrosion & oxidation resistance, as well as anti-fouling properties or lubricity at high temperature, for automotive, aviation, power generation machinery, Oil and Gas and marine applications.

The Applicant mentioned in the initial AfA that they were not comparing the different alternatives because each one of them was covering specific performances addressed by the Use-1. Consequently, the 3 alternatives together were meant to allow the covering of previous mixtures performances.

Unfortunately, the work of research carried out by Linde AMT on previously under the EU AfA presented alternatives did not allow complete substitution of Cr(VI) for spraying applications. Chrome-free coatings and coating systems (specific combinations of multiple coatings applied in a multi-layer manner) have been developed and tested in R&D to replace about 85% of the coatings currently used. Linde AMT has therefore been evaluating a number of other alternatives which might be suitable for completing the substitution of Cr(VI) in their process. It is important to note that the Applicant is not comparing the different alternatives between themselves in this AfA because each one of them is covering specific performances addressed by the Use-1. Consequently, the two alternatives together are meant to allow the covering of previous mixtures performances and lead towards complete substitution of Cr (VI) from Linde AMT's slurries and processes.

As of today, the main challenges for Linde AMT regarding these newly selected alternatives is scale-up to production, including raw material sourcing, process development, quality control set up, labelling and shipping documents development. Customer approvals and qualifications are also important factors to consider to finalize the complete substitution of Cr (VI) at Linde AMT.

Moving forward with new alternatives to Cr(VI) (which was not possible with previously selected alternatives in the initial AfA) slowed down the process to achieve complete substitution in the originally agreed timeline. However, at the moment, the Applicant is moving to the validation phase of the alternative both at industrial scale and at customers level.

Consequently, in order to finalise the qualification and implementation of Alternative 1 for Use-1, the Applicant applies for an additional 2-year review period.

6 REFERENCES

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ANNEX – JUSTIFICATIONS FOR CONFIDENTIALITY CLAIMS

Blanked out item reference	Page number	Justification for confidentiality
Blank # 1	11, 14, 15, 17, 55, 56, 61, 63	The information regarding the financial figures (revenue, profit, growth rates, R&D costs, cost for the implementation of the alternative, etc.) is trade secret of the Applicant and should therefore be kept confidential due to competition issues. The release of the Applicant's financial figures would give competitors an unfair advantage in the market. This could therefore cause harm to the Applicant' competitive position. The claim for confidentiality on the Applicant' financial figures will remain valid indefinitely.
Blank # 2	11, 13, 25	The information regarding the volume figures (tonnage of substance used) is trade secret of the Applicant and should therefore be kept confidential due to competition issues. The release of the Applicant's volume figures would give competitors an unfair advantage in the market. This could therefore cause harm to the Applicant' competitive position. The claim for confidentiality on the Applicant' volume figures will remain valid indefinitely.