Format for

ANALYSIS OF ALTERNATIVES

and

SOCIO-ECONOMIC ANALYSIS

Legal name of applicant(s):	Indestructible Paint Ltd
Submitted by:	Risk & Policy Analysts Ltd
Date:	20 February 2023
Substance:	Chromium Trioxide (CAS 1333-82-0, EC 215-607-8)
Use title:	Treatment of components used in industrial gas turbines and associated components using coating products containing chromium trioxide to enhance corrosion resistance, chemical resistance, high temperature oxidation resistance, adhesion to components which produce a smooth finish and enhance the technical performance of turbines.
Use number:	2

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List of Abbreviations

Abbreviation	Description
A&D	Aerospace and defence
ADCR	Aerospace and defence chromates reauthorisation
AoA	Analysis of alternatives
APF	Assigned protection factor
CAS No.	Chemical abstract service number
CNI	Critical national infrastructure
CO	Carbon monoxide
CO_2	Carbon dioxide
Cr(VI)	Hexavalent chromium
Cr_2O_3	Chromium oxide
CSR	Chemical safety report
CT	Chromium trioxide
DU	Downstream user
EAR99	Export administration regulation 99
EC	European Commission
EC No.	European community number
ECB	European central bank
ECCN	Export control classification number
ECHA	European chemicals agency
EEA	European economic area
ES	Exposure scenarios
FPSO	Floating production storage and offloading
GOS	Gross operating surplus
GVA	Gross Value Added
H_2S	Hydrogen Sulphide
HAP	Hazardous air pollutants
HSE	Health, safety and environment
HvE	Humans via the environment
IMF	International monetary fund
IP	Indestructible Paint Ltd
LEV	Local exhaust ventilation
LGT	Larger gas turbines
LNG	Liquid natural gas
MCAC	Metallic ceramic aluminium coatings
MRO	Maintenance, repair and operations
No-SAGA	No suitable alternative generally available
NIGEM	National institute global econometric model
NORM	Naturally occurring radioactive material
NOX	Nitrogen oxide
NPV	Net present value
NSS	Neutral salt spray
NUS	Non-use scenario
OEM	Original equipment manufacturers
PAH	Polycyclic aromatic hydrocarbons
PC	Process category
PM	Particulate matter
PPE	Personal protective equipment
PV	Present value

R&D	Research and development
RAC	Risk assessment committee
RPE	Respiratory protective equipment
SAGA	Suitable alternative generally available
SEA	Socio-economic analysis
SEAC	Socio-economic analysis committee
SEG	Similar exposure groups
SGT	Smaller gas turbines
SO_2	Sulphur dioxide
SOX	Sulphur oxide
SVHC	Substance of very high concern
TRL	Technology readiness levels
UK	United Kingdom
VOC	Volatile organic compounds
WCS	Worker contributing scenarios

DECLARATION

We, Risk & Policy Analysts Ltd, who are submitting on behalf of the Applicant, Indestructible Paint Ltd, are aware of the fact that further evidence might be requested by ECHA to support the information provided in this document.

Also, we request that the information blanked out in the "public version" of the Analysis of Alternatives and Socio-economic Analysis is not disclosed. We hereby declare that, to the best of our knowledge as of today (20th February 2023), the information is not publicly available, and, in accordance with the due measures of protection that we have implemented, a member of the public should not be able to obtain access to this information without our consent or that of the third party whose commercial interests are at stake.

Signature:

Date, Place: 20th February, 2023, RPA Ltd.

Max La Vedrine

1 SUMMARY

1.1 Description of the use and importance of chromium trioxide

Chromium trioxide (EC No.: 215-6078, CAS No.: 1333-82-0) formulations are produced by the applicant, Indestructible Paint Ltd (hereafter referred to as IP), a UK company. Downstream users of IP use these formulations as part of coatings to protect industrial gas turbines and related industrial equipment and components. The chromium trioxide formulations are typically applied to components by specialist coating companies at several different sites in the EEA/UK.

IP is a formulator (an upstream actor in the supply chain) of chromium trioxide formulations, applying for authorisation to cover the downstream users use of the formulations for their coatings needs. Chromium trioxide formulations fulfil several key technical criteria that are specified by original equipment manufacturers (OEMs). The formulations are used as slurry and diffusion coatings a process of coating components followed by a heat treatment. The volume of chromium trioxide used is driven by the demand from downstream users. In total, annual demand for industrial uses is in the range of 100 kg - 1 tonne per year for the combined EEA and UK markets.

1.2 Availability and suitability of alternatives

Key downstream users have been engaged in efforts to substitute chromium trioxide-based slurry coatings since 2014. More than 20 coatings were considered as part of initial screening tests. As a result of the initial screening tests, four candidate Metallic Ceramic Aluminium Coatings (MCAC) have been identified and are currently undergoing further development. In addition to this, two candidates for alternative diffusion coatings have been identified. At present, these coatings are not technically feasible and readily available, and have only been produced in quantities for laboratory scale testing. The coatings are currently at a stage where site-based and in-field engine testing is the next part of the development process. During this engine testing it will be established if the coatings demonstrate the technical feasibility criteria needed such as: corrosion protection / active corrosion inhibition, high heat resistance, high temperature oxidation resistance, cyclic heat corrosion resistance, adhesion to substrate, chemical resistance (hydraulic fluids, engine oils, fuel); and smooth surface finish.

It is likely the coatings will be a successful replacement for chromium trioxide-based coatings. However, additional testing may be required to make sure that the alternatives have sufficient technical performance in the more challenging offshore environments. The scheduled testing will take several years to complete as it is intended to replicate the typical operational running time of industrial gas turbines. The planned research and development are described in more detail within the substitution plan.

1.3 Requested review period

IP is seeking a long (i.e. a 12 year) review period. The length of the review period requested is based on the ongoing status of the research and development testing allowing for sufficient time for additional certification, and implementation as well as allowing some contingency time. A 12-year review period will also provide market certainty to existing downstream user supply chains. These downstream users are those EEA and UK companies that are reliant on the ongoing use of chromium trioxide coatings. These consist of two main downstream users. The first of these are OEMs, these are the manufacturers of industrial gas turbines and related equipment, they are responsible for setting the technical criteria, the coating specifications (e.g. coating thickness) and quality checks prior to final assembly. The other users are applicators, that are companies specialised in applying coating products to components. Applicators may also conduct maintenance, repair and operations (MRO) activity on site for industrial gas turbines (along with other sectors). As part of the MRO activity components are recoated.

A 12-year review period is also requested to allow operational objectives to be met without undue supply disruption, market loss and profit/job loss in the downstream supply chain. Non-authorisation or a granted review period shorter than 12 years would likely result in significant loss of market share and profit of OEMs, applicators and MROs. The review period is expected to start at the end of 2024 and run until the end of 2036.

1.4 Applied for use and non-use scenarios

In the applied for Use scenario, IP will continue to produce chromium trioxide formulations (covered in a separate Application for Authorisation[1]) to be used by downstream users who will be covered by this application for authorisation. In practice, the chromium trioxide formulation activity is driven by the demand by downstream users. The demand is expected to gradually decrease while downstream users identify and transition to alternatives during the requested 12-year review period.

There are several different OEMs who use chromium trioxide formulations to coat and protect critical components. Different OEMs are likely to be at slightly different stages of research and development. Key technical feasibility criteria exist for turbines that are used in more challenging environments.

Therefore, there are likely to be two main non-use scenarios. The first, and perhaps more likely, is OEMs will require components to be coated with chromium trioxide formulations until an alternative has been identified and implemented. Therefore, OEMs will use applicators and MRO companies located outside of the EEA and UK. This scenario will lead to the closure of several applicators' and MROs' facilities. The relocation of these activities will likely lead to OEMs relocating some of their manufacturing and final assembly to countries outside of the EEA and UK.

In the other non-use scenario, OEMs may risk switching to an alternative that has not yet been proven to be a successful alternative. This non-use scenario would mean applicators and MROs remain operational in the EEA and UK, but this scenario would involve significant risks for OEMs. Furthermore, the shorter operational and maintenance cycles are likely to put significant pressure on the existing supply chains. The additional maintenance would increase costs and lost operational time will impact users of industrial gas turbines.

1.5 Human health and environmental impacts from the continued use of chromates

Estimates of the excess lifetime cancer risks for both workers and humans via the environment are calculated in the CSR. In total, it is estimated that 150 EEA and 180 UK workers are directly exposed at downstream users sites.

Combining these figures with exposure estimates leads to an estimated 4.29E-02 (EEA) and 5.15E-02 (UK) of additional fatal lung cancer cases and 1.14E-02 (EEA) and 1.37E-02 (UK) would be additional

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[1] UK Application for Authorisation: Use of chromium trioxide in the formulation of mixtures intended for supply to authorised industrial gas turbine and related uses

morbidity cases. These translate to monetised residual risks for directly exposed workers of around €133,227 (EEA) and €159,873 (UK (£142,263)) in total over the length of the requested 12-year review period (end of 2024-end of 2036).

Exposures have also been taken into account for local residents and local workers. Combining these with exposure estimates leads to an estimated 2.17E-01 (EEA) and 2.61E-01 (UK) additional fatal lung and intestinal cancer cases and 6.93E-02 (EEA and UK) would be additional morbidity cases. These translate to monetised residual risks of around €674,090 (EEA) and €808,908 (UK (£719,810)) in total over the length of requested 12-year review period (end of 2024-end of 2036).

Combining the two values together results in estimated, monetised residual risks from the continued chromium trioxide formulation activities of ca. €834,411 (EEA) and £890,228 (UK) in total over the 12-year review period.

No environmental assessment was carried out as chromium trioxide has not been identified as a substance of very high concern in relation to its effects on organisms in the environment. Furthermore, the use of chromium trioxide at OEM and applicators sites is low and the releases to environmental compartments from downstream users from these activities is also low and the combination of dry air filters further reduces the environmental releases before air is released to the ambient air. Any hexavalent chromium (Cr(VI)) from chromium trioxide is expected to reduce to Cr(III) under most environmental conditions, thus limiting any potential impact of Cr(VI) to the immediate vicinity of the source.

1.6 Environmental costs from a refused authorisation

In the non-use scenario where coating takes place outside the EEA and UK, environmental emissions will increase due to the greater distances components will need to be transported for applicator and MRO activity. In the non-use scenario where an unproven alternative is used there will be greater environmental emissions from more regular MRO activity. Running turbines less efficiently will reduce the power output of turbines and increase the overall environmental emissions from the turbine. Both non-use scenarios may impact the European Commissions and UK Governments hydrogen strategies.

1.7 Economic costs of a refused authorisation

The supply chain associated with the manufacturing of industrial gas turbines using chromium trioxide coatings includes upstream suppliers of materials and several downstream users. The total economic costs to all downstream users from a refused authorisation are estimated as being €55 – 354 million (EEA) and £179 – 184 million (UK) over 2 years (present value at 4%). At 4 years (present value at 4%) the costs are €106 – 681 million (EEA) and £344 – 353 million (UK). The costs would be greater over the 12-year review period. The downstream economic impacts on the customers of OEMs have not been included in these calculations. These downstream economic impacts are expected to be highly significant due to the use of industrial gas turbine in several different industrial and non-industrial sectors including sectors that are considered as being critical to national infrastructure.

1.8 Social impacts of a refused authorisation

The main social costs arise from redundancies resulting from the ceasing of chromium trioxide coating activities. Direct employment losses are considered only for workers at OEM, applicators and MROs sites. The associated social costs of unemployment are estimated at €1,548 million for EEA and £437 million for the UK.

These losses equate to the period for which these workers would remain unemployed. Direct, indirect and induced employment losses may be underestimated due to the potential impacts on downstream users (and customers) from the loss of one (or more) chromium trioxide formulators from the market and a greater anticipated impact on OEMs, applicators, MROs and the wider supply chain.

1.9 Wider economic impacts

Wider economic impacts could be very significant due to the wide use of industrial gas turbines in several different sectors including their use in critical national infrastructure. The impacts on the downstream users of industrial gas turbines are not quantified but have been described qualitatively. These may include a loss of competitiveness for the EEA/UK industry, changes in trade flows, impacts on government revenues and national security.

1.10 Comparison of benefits and costs

The aggregated present value benefits from the continued use of chromium trioxide formulations as part of coating activity are estimated at €1,603 – 1,902 million (EEA) and £616 – 621 million (UK) (2 years) or €1,654 – 2,229 million (EEA) and £781 – 790 million (UK) when including all of the above economic impacts and taking into account residual risks.

The resulting benefit-to-cost ratios are large due to the potential lost producer surplus and the low human health risks due to the limited number of workers exposed, the risk management measures in place and the low releases from sites.

2 Aims and scope of the analysis

2.1 Aims of this analysis

Chromium trioxide has been placed in Annex XIV on the grounds of its carcinogenic and mutagenic effects. Adverse effects are discussed in the Chemical Safety Report (CSR). These effects have no identified threshold for hexavalent chromium compounds, including CrO3. The formulations produced by Indestructible Paint (hereafter referred to as IP) contain chromium trioxide and fall under Annex XIV entry number 16 on the REACH Authorisation List with a Sunset Date of 21 September 2017. This means that use of the substance in the European Economic Area (EEA) after that date would require an Authorisation, unless stated its use is exempt. The sunset date for substances falling under this entry was 21 March 2016. IP was a member of a previous CTAC consortium application covering the formulation and specific downstream uses of chromates. The end of these review periods is the 21 September 2024.[2] The granted authorisations were also grandfathered in the UK following the UK's departure from the EU.

IP is applying for authorisation as an upstream applicant to cover its own formulation activities in the UK and the use of their products by downstream users in both the EEA and UK. This approach is set out in the ECHA (2021) guide[3] on how to apply for authorisation. According to the guidance, an (upstream) applicant (not necessarily located within the EEA) can apply for the downstream uses within the EEA (see the diagram on the left in **Figure 2-1**).

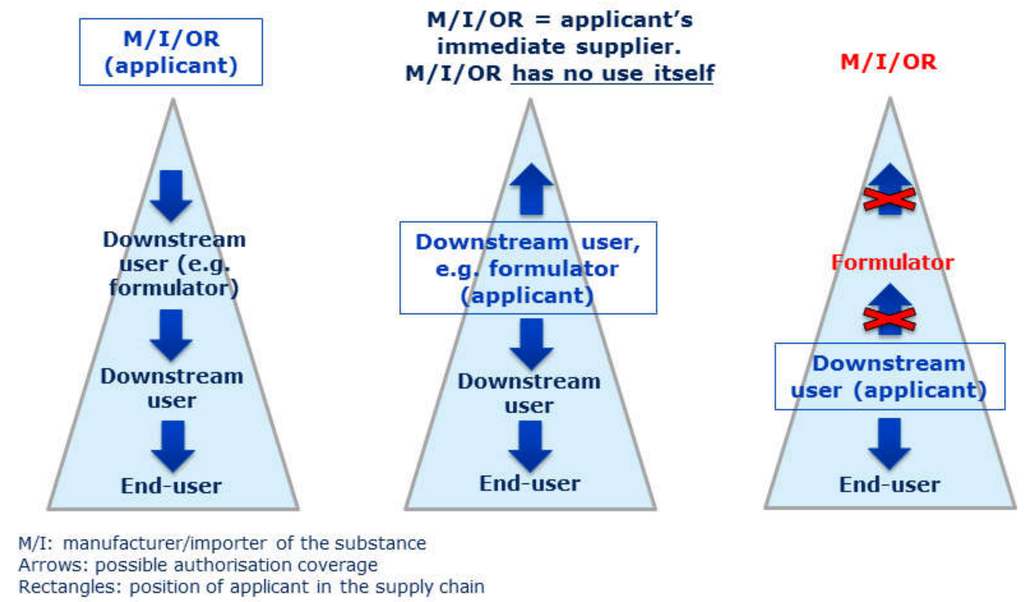

Figure 2-1: Supply chain coverage in applications for authorisation
Source: ECHA (2021)

IP is a UK company, located in Birmingham, specialist in the formulation of high-performance coatings used for a range of challenging applications such as aircraft engines, air frames, defence paints, power generation and industrial gas turbines. IP supplies its coatings to most of the world's aerospace engine

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[2] Adopted commission decision C/2020/8797, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.C_.2020.447.01.0005.01.ENG&toc=OJ%3AC%3A2020%3A447%3ATOC

[3] ECHA: How to apply for authorisation, available at: https://echa.europa.eu/documents/10162/17229/apply_for_authorisation_en.pdf/bd1c2842-4c90-7a1a-3e48-f5eaf3954676?t=1612886216792

and industrial turbine manufacturers. Coatings supplied by IP are resistant to oxidation, high temperature and water and provide sulphide protection resistant.

In the situation illustrated above, being the formulator, IP is the upstream actor applying for authorisation via an OR for its downstream users that are located in the EEA.

Downstream users consist primarily of Original Equipment Manufacturers (OEMs), applicators and Maintenance, Repair and Operations (MRO) companies.

Applicators are companies who are specialised in applying coating products to components. Companies that conduct applicator activities may also conduct MRO activity on site for industrial gas turbines (along with other sectors). As part of the MRO activity components are recoated. Hereafter, applicators and MROs are described together. Within the supply chains applicators/MROs are the companies that use the largest volume of chromium trioxide products formulated by IP, OEMs only use small volumes as part of touch up activity to repair scratches.

End-users are the customers of OEMs and are the users of the turbines and coated components. The OEMs will set out the key technical criteria, the products that should be used to achieve the criteria and how the coating product should be applied.

To allow the continuation of the use by downstream users, a similar formulation application is being submitted covering the formulation and downstream use of chromate products for use in the aerospace and defence sector.[4] There are strong similarities between both formulation and downstream user applications. The ongoing formulation activities at IP’s site are reliant on both downstream uses. However, this application is focused on the downstream users of IP’s chromium trioxide containing coatings as part of controlled processes for industrial uses (i.e. non-aerospace uses).

Chromium trioxide-based slurry coating products are well established and known for their high performance, in particular their corrosion resistance properties. They have been key components in the longevity of aerospace, marine and industrial components. The product formulations containing chromium trioxide that are produced by IP are consequently used in the UK, EEA and non-EEA markets.

Chromium trioxide has been used in a core range of IP high performance coating products; these products include IP9183-R1, IP9442, IP9184 colours, IP9447, IP9444, IP1041, and PL177 (hereafter referred to as the IPcote range). **Figure 2-2** below provides an example of where some of these different products are used within a turbine. The high-performance coatings are applied to several components including the intake through all the compressor stages, and even into the hot end of the turbine engine. Although the turbine in **Figure 2-2** is designed for the aerospace industry, industrial gas turbines are similar to those used in the aerospace industry and IPs products perform a similar function.

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[4] Commonly known as the Aerospace and Defence Chromates Reauthorisation (ADCR) Consortium applications

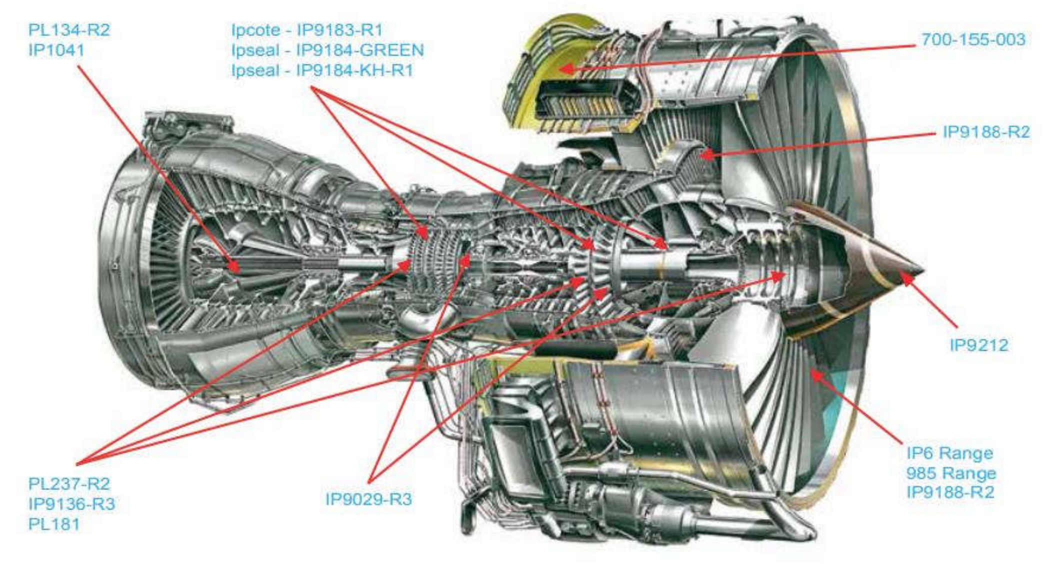

Figure 2-2: Cross section of an aerospace turbine showing the components protected with different IP products.
Source: Indestructible Paint

While IP have made efforts to develop an alternative (such as CFIpal[5]) that may lead to the substitution of chromium trioxide, the companies that are responsible for selecting an alternative are the downstream users of IP. The downstream users covered by this application are those downstream users who use the chromium trioxide products for industrial applications (i.e. not the aerospace and defence sector). Industrial applications include the application of the products to parts of power generation and industrial gas turbines for manufacturing, non-manufacturing sectors and emergency back-up power. The IPcote formulations are applied to components as part of surface treatment processes that alter the surface of metal substrates.

IP is applying for authorisation to cover their downstream users use of IPcote chromium trioxide containing products for industrial purposes. This combined AoA and SEA document aims to discuss and demonstrate the following:

- The R&D that downstream users (and IP) have undertaken towards the identification of a feasible and suitable alternative for chromium trioxide. This will include an assessment of the time that would be required to switch to a technically feasible alternative.
- The socio-economic impacts that would arise for the subsequent downstream users and supply chains of IP using the IPcote product range. The knock-on effects to other sectors including the energy industry, transport sector, utility sectors, oil & gas industry (onshore and offshore), the manufacturing sector and as part of backup emergency power generation, if IP was not granted authorisation will also be assessed.
- The societal and environmental impacts of the continued use of chromium trioxide versus a non-use scenario, including employment/unemployment costs, human health and environmental impacts.

The review period requested by IP, on the behalf of their downstream users, is 12 years.

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[5] https://indestructible.co.uk/product/cfipal-chrome-free-diffusion-coating/

2.2 Scope of this analysis

2.2.1 Downstream user activities within the scope of Authorisation

At the downstream user application stage, IP's IPcote chromium trioxide containing products fulfil several key technical functionalities. The functionalities achieved by applying high-performance coatings help to protect key components of industrial gas turbines. Industrial gas turbines are used in several challenging environments. These include high temperature, high pressure and corrosive environments (including those where salt and hydrogen sulphide are present). In the industrial gas turbine sector, the turbines, the components and the high-performance coatings applied to key components, need to operate for prolonged durations, therefore it is important that the components do not suffer from fatigue which may cause the components to become worn or corroded. Excessive wear and corrosion will damage the turbine and potentially lead to catastrophic part failure and the destruction of the turbine.

IP consulted with the downstream user supply chain as part of this application and several downstream users provided data to support the application. This includes information from OEMs (who have supplied information on their efforts to identify alternatives, market information and socio-economic information) and companies who apply chromium trioxide to components (hereafter referred to as applicators/MROs, who have supplied occupational exposure data and socio-economic information) in controlled environments. The OEMs design and manufacture turbines, whereas applicators/MROs apply the chromium trioxide containing products to key components to agreed specifications set by the OEMs.

Based on consultation with IP's supply chain, the situation is characterised by applicators/MROs who typically use the majority of the IPcote products (>99%), whereas industrial gas turbine manufacturing companies (OEMs) appear to use small amounts as part of small 'touch up' work to repair light scratches. However, some OEMs may spray their own components. Due to the large number of industrial gas turbines being manufactured each year and the existing number of turbines in operation, the coating of new and existing components is a significant operation, therefore service companies (applicators/MROs) have been setup to fulfil these requirements.

The business activities of applicators/MROs vary. For some, a significant part of their business activity is focused on the application of chromium trioxide containing product formulations and other MRO associated activity of industrial gas turbines. Some applicators offer different coating solutions (i.e. those that do not contain chromium trioxide) for different materials, different types of metal treatment services and other service offerings for a range of different markets. Chromium trioxide slurry coating applications typically make up a lower proportion of the overall business for those companies which offer several services.

Although efforts to identify an alternative have been ongoing for several years, the aim of this authorisation is to allow downstream users more time to identify and develop an alternative, to allow the alternative to be tested, to undergo certification with applicators/MROs covering a wide range or turbine components and to be implemented for industrial purposes.

2.2.2 Temporal scope

The temporal boundaries of the analysis need to consider:

- When impacts would be triggered;
- When impacts would be realised; and
- For how long IP's customers would, as a minimum, require the continued us of chromium trioxide containing products.

The impact assessment periods used in this analysis and the key years are presented in **Table 2-1**.

Table 2-1: Temporal boundaries of impact assessment			
Present value year		2021	
Start of discounting year		2024	
Impact baseline year		2024	
Scenario	**Impact type**	**Impact temporal boundary**	**Notes**
		Main analysis	
"Applied for Use"	Mortality and morbidity of workers	12-year period with cancer effects occurring in 20* years' time to account for latency	The analysis is based on the length of requested review period. This takes into consideration the anticipated review periods to be requested by downstream users for the implementation of alternative substances or technologies. Sensitivity analysis is based on the length of working lifetime used in RAC's Exposure-Risk Relationship
	Mortality and morbidity of humans exposed via the environment	12-year period with cancer effects occurring in 20* years' time to account for latency	The main analysis is based on the length of the requested review period. This takes into consideration the anticipated review periods to be requested by downstream users for the implementation of alternative substances or technologies. The sensitivity analysis is based on the length of the general population lifetime used in RAC's Exposure-Risk Relationship
	Environmental impacts	12 years	Based on the length of requested review period
"Non-use"	Loss of profit along the supply chain	2 and 4 years assessed; 12 years would also be relevant	Based on the length of requested review period
	Loss of employment	1 to over 3 years	Average period of unemployment in the UK (Dubourg, 2016b)
*A latency period of 20 years has been assumed here for both lung and bladder cancer. In reality, cancer cases may occur sooner following exposure or much later – for example, research has found that cases of bladder cancer have not occurred until 30 plus years from some occupational exposure situations.			

As IP's downstream supply chain require a long review period, IP are seeking a long (i.e. a 12 year) review period. This review period is requested to provide industrial OEMs enough time to identify, test and implement an alternative. A long review period will also help to prevent the potential downstream impacts described as part of the non-use scenario.

2.2.3 Geographic scope

IP's production site is located in Birmingham in the UK. The location of the production site is shown in **Figure 2-3**. The main activity of the site is the formulation of products (including those containing chromium trioxide) designed for the surface treatment of metal substrates.

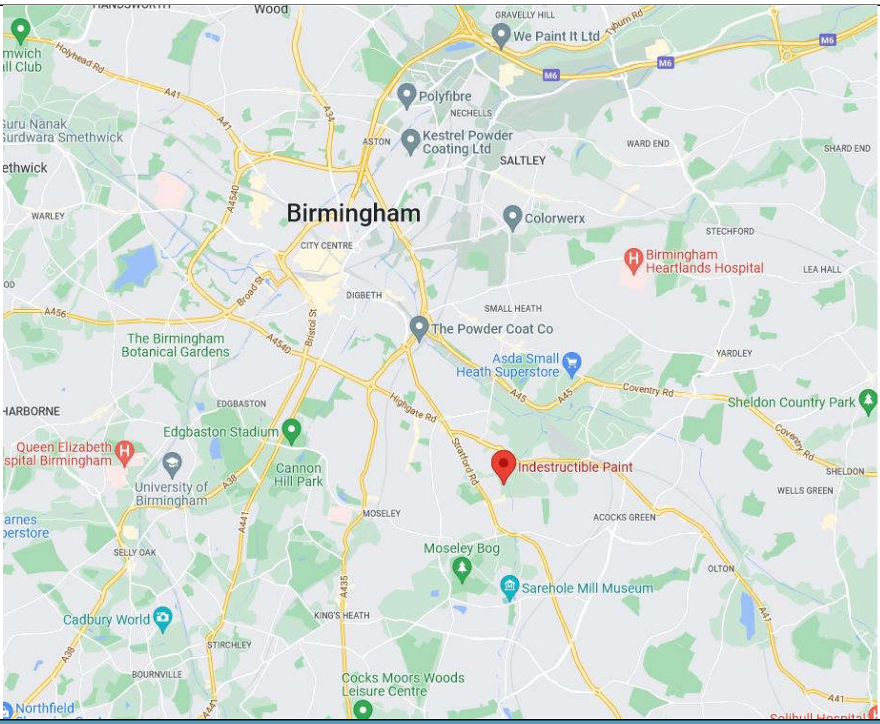


Figure 2-3: Indestructible Paint's production site in Birmingham, UK (via Google maps)

The chromium trioxide formulations are sold to customers within the UK, the EEA and outside the EEA, an overview of these known customers is provided in **Table 2-2**. Indestructible Paint track supply of material globally, customers are required to provide end user details via completed form. No customers can have product without completion of this form.

Table 2-2: Overview of customer locations

Current UK based customers	
Markets	Industrial users, aerospace & defence, applicators, distributors
Current EEA based customers	
Countries	#C, D [redacted]
Markets	Industrial users, aerospace & defence, applicators, distributors
Current rest of the world-based customers	
Countries	[redacted]
Markets	Industrial users, aerospace & defence, applicators, distributors

Source: Indestructible Paint

In the non-use scenario, there will be impacts on downstream customers in the EEA, UK and around the rest of the world; however, the geographic scope of the analysis presented herewith is focused on actors within the EEA and UK. The focus, therefore, is on the downstream uses of chromium trioxide-based products within the EEA and UK (although similar impacts may occur in countries outside of the EEA and UK). IP's customers include distributors, although IP expects that the end markets are likely to include industrial users (the focus of this application) and aerospace & defence (the focus of the ADCR application), the products might be used in other countries and for other uses that IP are unaware of. However, where used within the EEA and UK, chromium trioxide should only be used where authorised.

Currently the EEA and UK market consists of downstream users that hold an authorisation and who source chromium trioxide products from an existing supplier. In the future, downstream users might need to change their existing supplier based on the granted authorisation applications. As described in section 4.7.3, an existing competitor that produces chromium trioxide formulations may leave the market. OEMs in the competitors supply chain may need chromium trioxide solutions for several more years as they continue to identify and implement an alternative.

Continued use will allow IP's downstream users to keep applying proven high-performance products to new components and as part of MRO activity. The review period will allow relevant downstream users more time to identify, test, perfect, certify, and implement suitable alternatives. In the non-use scenario, supply chains will be affected and significant impacts are expected to occur amongst downstream users in the supply chain, this will include impacts on OEMs, applicators/MROs, several downstream users of industrial gas turbines and impacts on society. An overview of IP's relevant supply chain is provided in **Figure 2-4**.

Figure 2-4 represents a relatively simply supply chain, however, OEMs who are the key downstream users, have supply chains with greater complexity. An example of the complexity of an aerospace OEM supply chain is illustrated in **Figure 2-5**, the industrial gas turbine supply chain will be similar. The figure also highlights the global nature of these relationships and the interlinkages that exist between suppliers in different geographic regions.

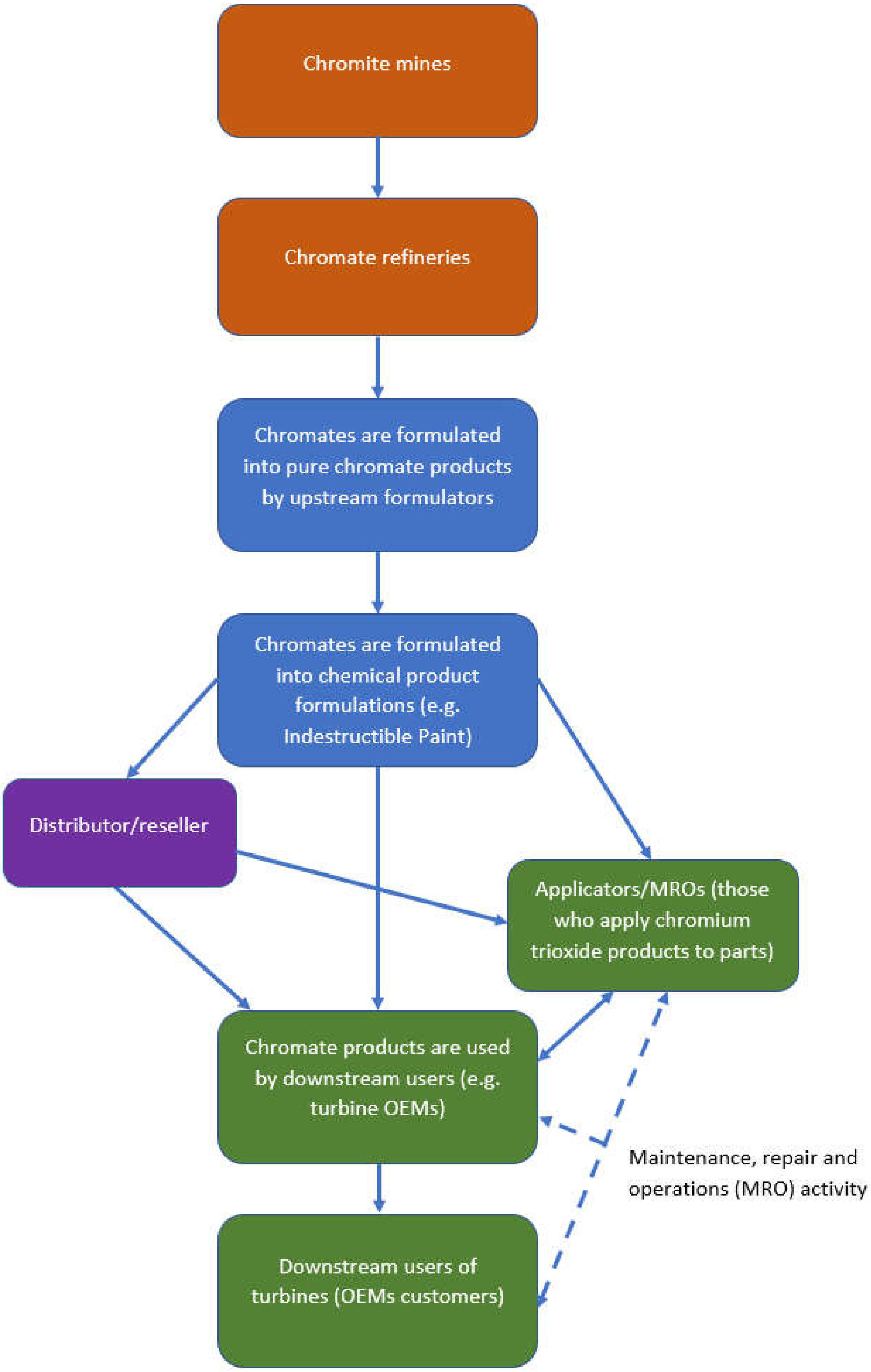
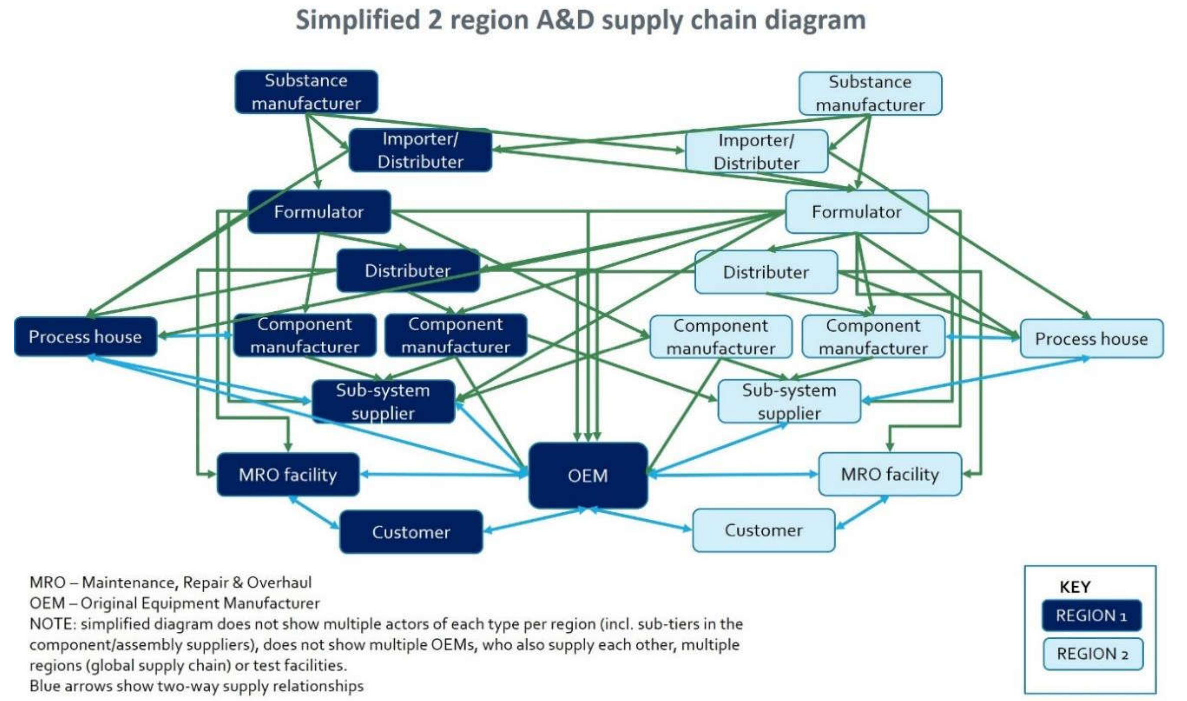


Figure 2-4: Overview of the relevant supply chains directly and indirectly impacted



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

Figure 2-5: Complexity of supply chain roles and relationships within the A&D sector

Relevant supply chains

At present, IP directly provides IPcote products to several distributors, manufacturing companies and applicators/MROs. The companies operating in the EEA and UK are summarised in **Table 2-3**.

Table 2-3: Overview of customer, locations and type of downstream user focus

Company	Region*	Downstream user focus
#C, D (whole table) [redacted]		

Table 2-3: Overview of customer, locations and type of downstream user focus

Company	Region*	Downstream user focus
[redacted]	[redacted]	[redacted]

Table 2-3: Overview of customer, locations and type of downstream user focus

Company	Region*	Downstream user focus
[redacted]	[redacted]	[redacted]

Source: Indestructible Paint
MRO = Maintenance, Repair and Operations
*Some business may have more than one entity, these entities may operate across several countries which operations in the UK, EU and rest of the world

The known companies summarised in **Table 2-3**, are broken down into broad categories and regional location in **Table 2-4**. The table focuses on the EEA, EEA/UK, UK and Switzerland, companies located around the rest of the world are not included in either table. In some cases the companies represented in **Table 2-3** and **Table 2-4** may consist of more than one legal entity, specific entities may have different business focuses (e.g. a specific range or market of industrial gas turbines).

Table 2-4: Overview of customers broken down by region and broad categorisation

Region	Total
EEA	[redacted] (total <50)
Aerospace (and aeroderivative maritime) OEM	#C, D (whole table) [redacted]
Aerospace and Industrial OEM	
Applicator/MRO	
EEA/UK	[redacted] (total <10)
Aerospace OEM	[redacted]
Distributor	
Industrial OEM	
UK	[redacted] (total <50)

Table 2-4: Overview of customers broken down by region and broad categorisation

Region	**Total**
Aerospace OEM	[redacted]
Aerospace and Industrial OEM	[redacted]
Applicator/MRO	[redacted]
Distributor	[redacted]
Distributor, Laboratory	[redacted]
Industrial OEM	[redacted]
Laboratory	[redacted]
Switzerland	[redacted] **(total <10)**
Aerospace and Industrial OEM	[redacted]
Sum total	[redacted] **(total <100)**

This application is focusing on the industrial OEM and the applicators/MRO companies in this supply chain. Of the downstream users, there are a total of #C, D OEMs that manufacture industrial gas turbines (#C, D) and a total of 22 applicators/MROs (#C, D). The number of OEMs may be underrepresented and some OEMs may be split into different entities. Also, the number of sites may be underestimated as several OEMs and applicators/MROs are known to operator more than one site.

Although a number of industrial downstream users have been included in **Table 2-3**, the number of downstream users using IP's IPcote range may be greater than the number included in the table. The number of downstream users may also increase if competitors of IP leave the market. **Table 2-5** below includes some of the main global gas turbine manufacturers. The table is not a complete list of industrial gas turbine manufacturers, for example others are included in **Table 2-3**. Industry associations include lists of their members, associations include EU Turbines[6] and the European Turbine Network (ETN)[7], in particular ETN have 119 members from 22 countries who are active in the whole supply chain of the turbine sector.

Table 2-5: Global industrial gas turbine manufactures

Company	**Operating in Europe**
Ansaldo Energia	Yes
Baker Hughes	Yes
Bharat Heavy Electricals	Unclear
GE Power	Yes
MAN Energy Solutions	Yes
MAPNA Group	No
Mitsubishi Power	Yes
Nanjing Turbine & Electric Machinery (Group)	No
Shanghai Electric Group	Unclear
Siemens Energy	Yes
Solar Turbines (Caterpillar)	Yes

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[6] https://www.euturbines.eu/members/

[7] https://etn.global/membership/members-map/

The four largest industrial gas turbine manufacturers at the global level are regarded as being GE Power, Siemens Energy, Mitsubishi and Ansaldo Energia.[8] [9] [10]

Presently, all industrial gas turbine manufacturers are expected to use chromates to protect key components.

The global industrial gas turbine MRO market consists of three main market segments, OEM service plans, independent service providers and in-house MRO activity. OEMs offer service plans as part of an aftercare service; they may work with independent service providers to achieve this. Independent service providers are expected to dominate the global market, this is attributed to the fact that independent service providers offer much more flexibility by offering various service options.[11] Moreover, independent service providers are likely to be more cost-effective than OEMs. In-house service teams help to ensures the constant operation of turbines along with prompt maintenance and overhaul services with minimal lost time and manpower. However, for several downstream users of turbines, maintaining in-house capabilities for MRO activities will present challenges and be an additional business expense if only one or a few turbines are being used by the business. Furthermore, the in-house MRO activities of companies may not include the ability to apply slurry coatings to components.

2.2.3.1 Estimated number of downstream user sites

Based on a consultation exercise and customer information held by IP, it would appear that the coating of industrial components is undertaken at a relatively small number of sites across the EEA and UK – around [redacted] applicators/MROs ([redacted]) were identified with the number of assumed sites being almost up to twice this number (assumed 15 EEA and 18 UK sites). Through consultation it is clear that some applicator/MRO sites provide slurry coating services to more than one OEM, equally OEMs may also have components coated at more than one applicator/MRO site. The OEMs indicated that they use external applicators to apply coatings to their components, but it cannot be excluded that some OEMs may apply coatings onsite as part of newly manufactured turbines or as part of MRO services.

There are [redacted] known OEMs that manufacture industrial gas turbines ([redacted]), although the total number of OEMs could be slight larger (assumed 10 EEA OEMs and 4 UK OEMs).

As part of this application IP engaged in a consultation with their known downstream users as summarised in **Table 2-3**. The application is based on information received from and engagement with these downstream users.

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[8] https://www.power-technology.com/buyers-guide/gas-turbine-suppliers/

[9] https://www.envisioninteligence.com/blog/gas-turbine-manufacturers-market-share/

[10] https://www.globaldata.com/companies/top-companies-by-sector/power-utilities/global-gas-turbine-manufacturers-by-capacity/

[11] https://www.coherentmarketinsights.com/market-insight/gas-turbine-mro-market-in-the-power-sector-5172

2.2.3.2 Geographic distribution

Based on the responses to the consultation exercise (SEA questionnaire) and the known locations of customers, the anticipated geographical distribution of sites applying coatings or undertaking occasional touch up activities is shown in **Table 2-6** (sites in Switzerland are not included).

Table 2-6: Number of sites undertaking slurry coating and touch up activity

Country	# Sites
[redacted] #C, D (whole table)	2
[redacted]	1
[redacted]	1
[redacted]	5
[redacted]	3
[redacted]	1
[redacted]	1
[redacted]	1
[redacted]	2
[redacted]	1
[redacted]	2
[redacted]	1
[redacted]	2
Total EEA sites	**23**
Total UK	**16**
Sum Total	**39**

2.2.4 Customers

The end actors within this supply chain are the customers of industrial gas turbines manufactured by OEMs that have chromium trioxide coatings. There is widespread use of industrial gas turbines across several different industries. Directly and indirectly, the majority of the global population benefits from the use of industrial gas turbines, especially the populations of the EEA and UK. Specific industrial sectors and societies benefiting from industrial gas turbines are described in more detail in section 4.7.5.

3 ANALYSIS OF ALTERNATIVES

3.1 SVHC use applied for

Chromium trioxide in slurries for coating metal surfaces offers protection primarily in the following sectors:

- The power generation industry – enabling the longevity of machinery (gas turbine engines) and providing enhanced efficiency due to the smooth surfaces created;
- Oil and gas industry – protection of offshore turbines in challenging environments;
- Manufacturing sectors – enabling sites to benefit from power generation and in some cases the combination of power generation and heat;
- Non-manufacturing sectors – where industrial gas turbines are used for power generation and/or heat, including hospitals, utilities, landfill and incineration, district heating;
- Back-up power generation – enabling the longevity that turbines may need to be activated in emergency situations (including hospitals and airports); and
- The aerospace sector – in turbine and certain aircraft components (these uses are covered in the ADCR application).

A more detailed list of sectors is provided in **Table 4-28**. The applicant, IP, is applying for authorisation to allow downstream users to continue using chromium trioxide containing products as part of slurry coating applications for the protection of ferrous alloys in industrial gas turbine and related equipment for non-aerospace and aeroderivative applications.

3.2 Analysis of substance in scope

3.2.1 The substance

The following substance is the subject of this analysis of alternatives (AoA) and socio-economic analysis (SEA):

Table 3-1: Substance of this analysis

Substance	Intrinsic properties[1]	Latest application date[2]	Sunset date[3]
Chromium Trioxide **EC No.: 215-6078** **CAS No.: 1333-82-0**	Carcinogenic (category 1A) Mutagenic (category 1B)	21 March 2016	21 September 2017

[1] Referred to in Article 57 of Regulation (EC) No. 1907/2006
[2] Date referred to in Article 58(1)(c)(ii) of Regulation (EC) No. 1907/2006
[3] Date referred to in Article 58(1)(c)(i) of Regulation (EC) No. 1907/2006

This substance is categorised as a substance of very high concern (SVHC) and is listed on Annex XIV of Regulation (EC) No 1907/2006[12]. Chromium trioxide is an inorganic compound which is an acidic anhydride of chromic acid and is a strong oxidising agent. Adverse effects of chromium trioxide are discussed in the Chemical Safety Report (CSR).

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[12] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32013R0348&qid=1644848496011#ntr2-L_2013108EN.01000401-E0002

Typical slurry composition

A slurry is an aqueous suspension containing solid particles (metallic or ceramic) in a liquid carrier and a liquid binder. These constituents can be phosphoric acid, chromic acid, graphite, and ceramic or aluminium powder. During curing, the liquid carrier evaporates but the liquid binder remains to hold the particles in suspension. During the final heat treatment (in specific environments), the binder is removed, and a coating adhered to the substrate is left.

Application process

The coating is applied through a treatment process consisting of multiple pre-treatments, main treatment and post-treatment steps. The slurry coating is applied to the metal substrate through spray and brush methods. The coating is then cured before being made electrically conductive by a physical burnishing step (for sacrificial coatings) and then cured again at a higher temperature.

For industrial uses, slurry coatings are typically applied by being sprayed onto the substrate. Due to the known hazardous properties of chromates, these spraying applications take place in highly controlled environments. The spraying operations are performed by trained individuals and the spraying takes place in spray booths. Workers will wear personal protective equipment such as, protective overalls, gloves and respiratory protection. The respiratory protection may be a half face mask or full hood protection with an external oxygen source.

In **Figure 3-1** six images show part of the coating process. The first of these show turbine parts that have been blasted and are ready for coating. The second image shows a spray booth. The third image shows an operative wearing respiratory protective equipment (RPE) and personal protective equipment (PPE) while they mix the coating on rollers (contained within the blue box). The fourth image shows the spray booth safety requirements including the spray booth clearance certificate, the clearance time is the duration after spraying has finished that operatives should not enter the booth without RPE, or should not remove RPE while in the booth. The fifth image shows the filtration system used by operatives for breathing air. The sixth image shows a typical spraying process. The spray operative is wearing full PPE including a disposable suit, chemically resistant gloves, safety boots and air fed RPE (the operative has had an RPE face fit test). During spraying continuous air flows from the ceiling of the room and out through the floor with filtration in the grated flooring. Not shown in the image is a display of the remaining booth clearance time (activated when spraying finishes).

Figure 3-1: Images showing part of the coating application process at an applicator/MRO site

3.3 Surface treatment processes

For operations with high performance requirements in demanding environments, the use of Cr(VI)-containing treatments is essential to ensure the decades-long quality and safety of the end product. Sometimes these coatings will be comprised of a base layer and top-coat, both of which can contain Cr(VI).

This combined AoA-SEA is limited to chromium trioxide-based slurry coatings, both sacrificial and high temperature (diffusion) coatings are grouped under slurry coatings.

3.3.1 Slurry coating

The slurry coating formulation and application dates back to the 1960s when a heat-curable binder using phosphoric acid, chromic acid and graphite was patented.[13] It was later discovered that the addition of aluminium powder benefitted the formulation further. The formulation could be sprayed onto metal substrates and once cured at 600°F (315°C), oxidation and corrosion were prevented up to 1000°F (538°C). It was discovered in later years that if cured for 90 minutes at a slightly higher temperature, 1050°F (565°C), the surface would become electrically conductive and was galvanically

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[13] Development of a Novel Hexavalent-Chromium-Free Sacrificial Aluminium-Ceramic Paint, available at: https://finishingandcoating.com/index.php/plating/1214-development-of-a-novel-hexavalent-chromium-free-sacrificial-aluminum-ceramic-paint, accessed 2 February 2023

sacrificial to steel. This coating has since been used by almost all turbine manufacturers since the mid-80s.

Slurry coatings are applied to metal (steel, nickel) alloy components within gas turbine engines, such as compressor blades, compressor discs, engine casings and vane assemblies.

The term slurry coatings covers two types of coating: sacrificial coatings and high temperature (diffusion) coatings.

3.3.1.1 Sacrificial coating

A sacrificial coating may be applied through automatic or manual spray application methods onto steel “cold” end components and are oxidised at a lower electrical potential than the metal substrate. The components are then cured at temperatures > 1000°F (538°C) and burnished to densify aluminium particles. The film formed is bonded to the metal substrate and the electrically conductive coating provides sacrificial-galvanic corrosion resistance, where the aluminium particles are oxidised preferentially to the substrate itself. These sacrificial coatings will provide protection up to 540°C, above these temperatures the aluminium component of the coating may react with the steel substrate and form a brittle phase which compromises the mechanical strength of the coated part. For the purpose of this AoA, we will refer to sacrificial coatings as metallic ceramic aluminium coatings (MCACs).

Typical processing steps can include degreasing, masking, grit blasting, paint application, stoving, burnishing, seal coat application and inspection (See **Figure 3-2**). Pre-treatment steps are typically done to ensure the metal surface is ready for the main treatment application. In the case of slurry coatings, pre-treatment steps will include cleaning, degreasing, and grit blasting the surface of the substrate to be treated. After application of the aluminium basecoat, it may be necessary to burnish to densify the aluminium particles in the slurry to establish electrical conductivity and galvanic corrosion protection between the aluminium coating and steel substrate.[14]

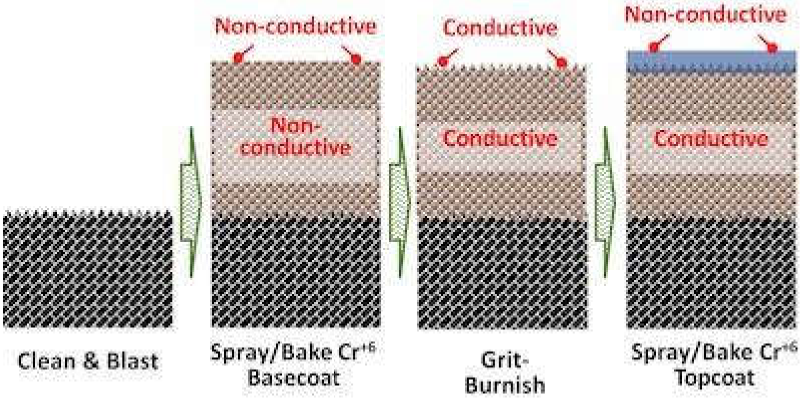

Figure 3-2: Process for aluminium-chromate/phosphate systems used in gas turbine engines
Source: *https://finishingandcoating.com/index.php/plating/1214-development-of-a-novel-hexavalent-chromium-free-sacrificial-aluminum-ceramic-paint*

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[14] Proven corrosion prevention for over 30 years, available at: https://www.ge.com/content/dam/gepower-new/global/en_US/downloads/gas-new-site/resources/reference/gecc-1-white-paper-gea33172a.pdf, accessed 2 February 2023 [redacted] #C, D

3.3.1.2 High-temperature (diffusion) coating

Diffusion aluminide protective coatings are formed through high temperature processes, where the metal (aluminium and/or silicon) in the coating melts and diffuses through or reacts with the surface of the substrate metal.[15] These coatings will most likely be used in high temperature sections of gas turbine engines that need to resist hot corrosion and high temperature oxidation. Nickel or cobalt-based superalloys[16] are typically used in these high temperature areas, therefore, once the aluminium is diffused it will form a nickel- or cobalt- aluminide surface layer. When the superalloy is then processed or exposed to high temperatures (>870°C), the aluminium will be oxidised and form an alumina scale, thus acting as a corrosion resistant barrier.[15] The high content of aluminium in the surface as a result of the diffusion coating process ensures that a fully protective alumina coating is established even if the surface is damaged. These diffusion coatings can be applied through spraying methods as well as pack cementation processes and chemical vapour deposition. High-temperature diffusion coatings will typically provide protection for parts that will operate above 700°C.

High-temperature coatings without diffusion can also be used in certain applications. These non-diffusion high-temperature coatings are normally applied to nickel base alloys, where the aluminium and/or silicon component is replaced with a component with a melting point higher than the >700°C operating temperature of the coated part. This component can be either a combination of high-melting point metals or alloys or ceramic particles. Since the solid component of the slurry coating does not melt or react with the substrate during curing, the resulting coating is a matrix of metal or ceramic particles incapsulated within a solid Cr_2O_3 matrix. This coating layer is comprised of metals which are not electrochemically active and is not burnished, therefore, corrosion resistance of this type of coating is not supported by the sacrificial mechanism. The coating instead provides corrosion resistance mainly through the barrier mechanism where corrosive compounds such as oxygen are physically blocked from contacting the substrate. These coatings normally operate in the same temperature ranges as slurry diffusion coatings and provide similar key functionalities.

3.3.1.3 Key functionalities of slurry coatings

Slurry coatings provide functionalities that can fulfil application specific requirements for long-term operation. The functional properties offered by IPcote chromium trioxide products are shown in **Table 3-2**. Additional key technical criteria are described in Section 3.4.2.

Table 3-2: Key functionalities of chromium trioxide-based surface treatments

Functionality	Description
Corrosion resistance	Corrosion is the oxidation process of a substrate (in this case metallic substrates) coming into contact with the surrounding environment (e.g., water, air or other metals). The ability of engine components to withstand these chemical reactions is critical.
High temperature oxidation resistance (dry heat resistance)	The coating must provide resistance to oxidative corrosion of parts which are subject to high temperature working environments of the

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[15] Genova, V., Paglia, L., Pulci, G., Bartuli, C., & Marra, F. (2021). Diffusion Aluminide Coatings for Hot Corrosion and Oxidation Protection of Nickel-Based Superalloys: Effect of Fluoride-Based Activator Salts. *Coatings 2021, Vol. 11, Page 412*, *11*(4), 412. https://doi.org/10.3390/COATINGS11040412

[16] https://material-properties.org/what-are-superalloys-definition/

Table 3-2: Key functionalities of chromium trioxide-based surface treatments

Functionality	Description
	system. Corrosion resistance must be achieved for temperatures up to 540°C for MCAC, and >750°C for high-temperature diffusion coatings.
Resistance to humidity and hot water	The coating must be impervious to water and moisture and must not degrade after contact.
Adhesion	Adhesion to substrate and/or subsequent coatings or paints. An additional layer of coating can offer increased corrosion, oxidation and weather resistance. However, the coating must remain adhered to the substrate even when bent or deformed.
Chemical resistance	Chemical resistance to hydraulic fluids, engine oils and fuels

3.3.1.4 Uses of slurry coatings

Slurry coating applications on gas turbine engines are used due to the functional properties of chromium trioxide, enabling the use of turbine engines in many industries such as power generation, oil and gas, and industrial power generation for chemical/ rubber and plastics, buildings and infrastructure, food and beverage, paper, metals / ceramics and glass, and cement. Aeroderivative gas turbine engines were manufactured based off designs of engines used in the aerospace industry. These engines are lightweight and compact making them suitable for use in power generation and the oil and gas industries. The use of these protective coatings has the following benefits:

- Corrosion resistance;
- Dry heat resistance;
- Resistance to humidity and hot water;
- Cyclic heat-corrosion resistance; and
- Performance benefits when applied to components related to the gas flow (e.g. blades).

The coatings provide a smoother finish that can help reduce the build-up of contaminants that could impact gas flow that in turn could degrade performance. Without protective coatings, it is expected that contaminant build-up could impact maintenance and servicing intervals. Effectively halving them and reducing overhaul periods to between 2 – 4 years.

Gas turbine engines are a continuous flow internal combustion engine, producing electricity by expanding natural gas. Gas turbines operate under extreme conditions and typically, for these applications, the engines themselves will be exposed to harsh environments. These extreme conditions include several different factors:

1. **Operational conditions**: the operational conditions of gas turbines means that the components need to be able to withstand temperatures in excess of 1000°C.

2. **Temperature and humidity**: gas turbines are used by end users who operate the turbines all year-round in different environmental climates. Gas turbines therefore need to be able to operate in:
    a. Tropical conditions where the environment is hot and humid, here average temperatures are greater than 18°C year-round and there may be more than 150 cm of precipitation each year;

b. Dry conditions where the environment is typically hot and very dry due to very little precipitation and moisture rapidly evaporating;
c. Temperate conditions where the environment is typically warm and humid in summer and mild in winter;
d. Continental conditions where the environments have warm to cool summers. The winters may involve strong winds and snowstorms, where the temperatures can drop to below -20°C; and
e. Polar conditions where the environmental conditions are extremely cold year-round.

Therefore, turbines need to be able to withstand different ambient conditions. As reported by Pinilla Fernandez et al. (2021) higher ambient temperatures negatively affects gas turbine performance while high ambient humidity impacts performance and limits inlet air cooling. Humid air is less dense than dry air and this may significantly affect the output of turbines.

3. **Salt**: industrial gas turbines are used on offshore oil & gas infrastructure (including jack-up, fixed, semi-submersible, spar, tension leg platforms and floating production storage and offloading (FPSO) units) to help power the installation and ensure the health & safety of the workforce and the operations. However, offshore environments are typically more challenging than onshore environments due to weather and sea states. Salt aerosols are created offshore and nearshore, a gas turbine inlet air filter system designed for coastal, marine and offshore installations must be designed to handle salt in its wet, dry and dynamic phases. When salt reaches a gas turbine, it can foul and corrode the compressor section, but more importantly, the sodium in the salt combines with the sulphur in the fuel (if present) to cause highly accelerated corrosion in the hot section of the gas turbine (Stalder & Sire, 2001). Salt ingestion can also accumulate on the compressor blades and reduce the aerodynamic efficiency of the turbine.

   The removal of salt in the air is therefore of primary concern to all those involved in the design and operation of gas turbines. Salt removal systems are manufactured in various guises. The concept, however, remains the same — salt capture upstream of the compressor stage. The drawback to this method of salt removal is that it results in a decrease in air pressure entering the compressor and this will consequently bring about a decrease in the overall system performance. As the requirement to remove more and more salt contaminant increases, the pressure drop across the method of filtration required to achieve this, increases.

4. **Hydrogen Sulphide (H_2S)**[17]: Hydrogen sulphide is a colourless gas that is poisonous, corrosive and flammable. It occurs naturally in crude petroleum, natural gas and hot springs and is also formed in the decay process of organic material. It is commonly found in the oil and gas industry and acidifies water that can cause corrosion or pitting on carbon steel[18]. Corrosion from this can severely reduce the operating life of these components.

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[17] https://www.osha.gov/sites/default/files/publications/hydrogen_sulfide_fact.pdf accessed 10 February 2023

[18] https://media.neliti.com/media/publications/230076-the-roles-of-h2s-gas-in-behavior-of-carb-eb1196bb.pdf accessed 10 February 2023

5. **Other contaminants:** Natural gas extracted from a natural gas field is typically used to power offshore installations. In addition to salts and H_2S, raw gas may also contain heavier gaseous hydrocarbons, liquid hydrocarbons, sulphur, nitrogen, helium, carbon dioxide, water vapour, mercury and naturally occurring radioactive material (NORM). Any chemical products used as part of oil & gas field production chemistry (i.e. chemical products used as part of drilling, production, well stimulation and pipeline operations) may also be present. These substances may be present in the gas and the protective coatings help protect the metal substrate from corrosion.

6. **Prolonged operational needs**: Gas turbines operate for several years and must be able to withstand the elements they are exposed to. The turbines and components are complex expensive pieces of equipment designed to operate for this time period. Protective coatings help ensure this is possible, protecting the metal substrate from corrosion.

7. **Rapid start up and shutdown**: The oil and gas industry can quickly generate energy when it is needed, effectively powering large grids, versus wind, solar or tidal energy that is dependent on the weather for energy.

8. **Fuels**: gas turbines are increasingly being designed and tested to run on different fuels and mixtures of fuels, these include natural gas, biogas, off-gas from a refinery or chemical plant, distillate oil and hydrogen. The fuel composition and resulting properties, specifically the hydrogen–carbon ratio, the available output power, operability, and emissions of the engine can vary significantly. Varying the hydrogen–carbon ratio significantly may lead to critical combustion operability issues that need to be considered such as auto-ignition, flashback, blowout, and combustion instabilities (Burnes & Camou, 2019). It is important that gas turbines are tested and able to withstand different fuel mixtures. In the future there will likely to be a transition from natural gas to hydrogen and biomethane as outlined in the UK Hydrogen Strategy (HM Government, 2021) and REPowerEU Plan (European Commission, 2022).

9. **Blade size and computability**: It is important for all components within the gas turbine to meet design specifications, it is essential coatings can be applied uniformly on blades and other complex components.

For these reasons, the functional requirements offered by chromium trioxide are essential for longevity and successful operation of engine components.

Chromium containing products are applied on various gas turbine components and other equipment components that require the functionality offered. These products could be applied on steel or another kind of superalloy, depending on where the component is located in the turbine (hot end or cold end).

The high temperature oxidation and corrosion resistance provided to these components from these coatings aid in serviceability and overhaul. Between overhaul and maintenance intervals these components must be able to complete 40,000 to 64,000 hours of service (higher is typically better for end user). In addition, the small design margins of turbine components do not allow for any surface deterioration from corrosion.

3.3.2 Purpose of the use of chromium trioxide

Chromium trioxide has been used for decades in the surface treatment of metal alloys, mainly for its corrosion protection properties. Chromium trioxide is used in a wide range of metallic surface treatment methods, including electrochemical and chemical treatments, as well being as an active component within coating formulations.

In MCAC and diffusion coatings, the formulation is acidic, and during coating the functionality of chromium trioxide is to prevent excessive attack of the acid towards the aluminium and metal substrates. The chromium trioxide in these formulations acts as a passivator within a water based Metallic Ceramic Aluminium Coating (MCAC) slurry and stabilises the formulation by the formation of a thin layer of chromium oxide (Cr_2O_3) on the surface of each aluminium particle. During the curing process of all slurry coatings, a ceramic network of Cr_2O_3 and phosphate is formed and binds the aluminium particles to form a cohesive, stable coating. The MCAC can be applied to a range of ferrous alloys and once cured Cr(VI) cannot be detected, but the inherent properties of the Cr(VI) within the coating formulation are essential in providing the key performance criteria of the coating. The MCAC slurry coating provides the functional requirements needed for use in extreme environments where gas turbines operate, such as offshore oil and gas production.

3.4 Description of the function(s) of the chromate and performance requirements of associated products

3.4.1 Introduction

The development of technical feasibility criteria for chromates (Cr(VI)) in slurry coatings has been based on a combination of assessment of previous AfAs, consultation with downstream users, and a review of available scientific literature.

Through the use of detailed written questionnaires, downstream users were asked to review the technical feasibility criteria and provide details of the measurable, quantifiable technical performance criteria which the chromates meet in this use and that any alternatives (substances and technologies) would also need to meet before they are considered as possible replacements.

Functions imparted by slurry coatings identified by downstream users in the context of in scope activities are as previously mentioned in **Table 3-2**:

- Corrosion resistance;
- High temperature oxidation resistance (Dry heat resistance);
- Cyclic heat-corrosion resistance;
- Adhesion to substrate;
- Chemical resistance (hydraulic fluids, engine oils, fuel); and
- Smooth surface finish.

It is understood that all of the above are considered key functions imparted by slurry coatings, and therefore any alternative must be able to demonstrate the same level of performance in each criterion.

It is important to note that whilst Cr(VI) based coatings are used to prevent corrosion, in some instances it is still likely some degree of corrosion or mechanical wear and tear can occur after prolonged service life and will be experienced due to the extreme environments these components are subjected too. These coatings are reparable using non-destructive methods. The coating can be fully stripped and reapplied without damaging the underlying substrate.

This demonstrates the need for a Cr(VI)-free alternative to show the same level of performance and repairability. An alternative that cannot meet these standards could compromise the long-term performance of components.

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

3.4.2 Standards and specifications in the evaluation of technical feasibility criteria

Proposed alternative candidates will be screened against the key functions and technical feasibility criteria of slurry coatings. These criteria can be measured against performance standards and methodologies established within the industry.

In the context of the AoA, the importance of the performance thresholds and standards are multifold; to ensure reproducibility of the testing methodology, define acceptable performance parameters and determine if the proposed candidate exhibits regression or is comparable in performance to the benchmark Cr(VI) substance. Examples of standards used for screening proposed candidates are presented in **Table 3-3**.

Table 3-3: Technical feasibility criteria alternatives must meet

Number	Criteria	Requirement	Description
1	**Corrosion resistance**	*1000+ hours of neutral salt spray resistance. Red corrosion acceptable in the base of the scribe, but there shall be no corrosion creep beneath the coating to a distance greater than 1mm from the edge.* *Conducted as per ASTM B117 or ISO 9227*	The extreme conditions in which engines/engine sites are located (e.g., coastal and offshore) warrants the need for corrosion resistance to avoid failures such as, [redacted] #F.
2	**Water solubility**	*Resistance to water at 80°C for 100 hours followed by a bend and adhesion test to ensure there is no breakdown of the coating.*	The coating system should not dissolve when operating in wet environments, the coating system undergoes a non-reversible reaction when cured and cannot be dissolved. If the coating is removed, the components will be subject to aqueous corrosion and/or oxidation attack.
3	**Oxidation resistance (Dry heat resistance)**	*Resistance to dry heat exposure at 600°C for 1000 hours. Followed by a bend test with no delamination in excess of 3 mm from the panel.*	This is applicable to turbine casings, centre casings, high pressure inserts and diffusers. The coating should not degrade or breakdown when exposed to heat for prolonged periods of time.

Table 3-3: Technical feasibility criteria alternatives must meet

Number	Criteria	Requirement	Description
4	**Chemical resistance**	*Resistance to engine chemicals such as, oil, diesel and cleaning products (solvent spray, acetone, etc.) Oil 100 hours at 150°C, Acetone 10x wipes with a cloth, solvent degreaser (ecomate) 10x wipes with a cloth*	The coating should not be removed by chemical substances commonly present in engines. If the coating is removed, the components will be subject to aqueous corrosion and/or oxidation attack.
5	**Adhesion**	*1 mm cross hatch mechanical test, result of the test should be Class 1 or 2* *Conducted as per BS3900Part E6*	The coating should adhere to the substrate after water and heat exposure.
6	**Applicability**	*Spray tests to determine the ability to be applied to gas turbine components*	The coating should be able to be applied easily with uniform layers to a range of components shapes and sizes
7	**Coating thickness**	*42 – 100 µm* *Measured non-destructively by a magnetic probe in 5 locations and conducted as per ASTM B499 or ISO 2178.*	The coating thickness should be uniform across the whole component part
8	**Surface finish**[19]	*The measurement should be conducted over a length of* #F *and measured in Ra µm.* *For* #F *components the average should be a maximum of* #F *µm and no single measurement* #F *µm* *Ideal is 0.5 – 0.9 Ra µm*	The surface finish will affect compressor efficiency, application difficulties can lead to rougher finishes. The surface finish should be as smooth as possible.
9	**Conductivity**	*The base coat must be conductive after burnishing and have a resistance of ≤15 ohms*	Electrical conductivity will provide sacrificial galvanic protection.
10	**Cyclic heat corrosion (oxidation salt spray)**	*10 cycles of 20+ hours neutral salt spray (NSS), 2 hours at 450°C.* *After 10 cycles there shall be no corrosion creep greater than 1mm from the scribe.*	An accelerated corrosion test that gives an indication of coating performance in engines that spend a significant amount of time offline.

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

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[19] The average height of microscopic peaks and valleys on a surface measured by a profilometer. Ra is the average surface roughness in micrometres or microinches.

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

3.4.2.1 Technical feasibility criterion 1: Corrosion resistance

Due to the extreme conditions in which gas turbine engine components are subjected to (Section 3.3.1), it is important that they are protected from corrosion. Corrosion can cause significant amounts of damage and cause premature failure leading to increased maintenance and replacement. Corrosion resistance is especially important in situations where the component is relatively inaccessible and cannot be easily or frequently inspected. Additionally, resistance is necessary to prevent corrosion during intermediate manufacturing steps.

Corrosion resistance testing is performed through corrosion testing in artificial environments, these can consist of acetic acid salt spray tests or neutral salt spray tests. Based on information provided by downstream users, components should pass 1000+ hours of neutral salt spray testing.

Sacrificial slurry coatings (MCACs)

The electrically conductive aluminium layer in a sacrificial coating provides galvanic corrosion protection to the substrate that has been treated. The oxidation of aluminium particles occurs at a lower potential than the oxidation of the substrate, therefore corroding in place of the substrate protecting it from corrosion. Corrosion resistance is also provided by a simple barrier mechanism, where the coating physically prevents corrosive agents form accessing the substrate.

High-temperature (diffusion) coatings

In these types of coatings corrosion protection is not provided by Cr(VI) but by the metallic particles present in the formulation. Typically, aluminium and/or silicon particles are present within the diffusion formulations, that are then diffused in the surface of the substrate to be coated. This increased metallic concentration at the surface promotes the formation a corrosion resistant alumina or silica layer. In some instances, the corrosion resistance of the oxide layer is increased by the presence of chromium. For nickel-based alloys or superalloys, the proportion of chromium within the substrate required to form a protective Cr_2O_3 layer is approximately 20% wt. and is slightly higher for cobalt-based alloys or superalloys. However, it is important to note that chromium can only be incorporated into the diffusion layer by inclusion of chromium metal into the metallic component of the slurry, rather than from aqueous chromium trioxide.

The role of Cr(VI) in high temperature diffusion formulations is to improve the stability of the metallic component coating during application and storage and provides corrosion resistance to the aluminium particles within the coating formulation.

An additional type of slurry coating used in some situations are slurry coatings without diffusion (slurry barrier coatings). These are coatings where galvanic corrosion protection is not provided by the metallic particles, since the coating is not burnished and is non-electrically conductive. Therefore, corrosion resistance is provided mostly by a barrier mechanism where the metallic particles suspended in a ceramic Cr_2O_3 matrix forms a non-porous layer and prevents corrosive materials from accessing the substrate.

3.4.2.2 Technical feasibility criterion 2: Water solubility

Although some slurry coating formulations are water-based, once cured they form a ceramic matrix which should be impervious to water. The coating system must not dissolve when operating in wet environments or decrease in performance afterwards. The current acid-based systems (passivated with chromium trioxide) undergo a non-reversible reaction when cured and cannot subsequently be dissolved.

These coating systems must withstand a water resistance test for 100 hours at 80°C, followed by an adhesion, ball drop and bend test.

3.4.2.3 Technical feasibility criterion 3: Oxidation resistance (dry heat resistance)

High temperature oxidation resistance is critical for some components used in turbine engines, such as turbine casings, centre casings, high pressure inserts and diffusers. For these hotter components, the aqueous corrosion resistance is less critical, but the MCAC also protects against this high temperature oxidation.

For both types of slurry coatings, MCACs and high temperature diffusion, high temperature resistance is needed due to the environments in which the components that are coated are used. Under these high temperature conditions, the coating should be able to remain adhered to the substrate without any cracking, blistering or delamination.

MCACs are typically used on components that need temperature resistance up to 540°C. Additionally, to retain the structure of the densified aluminium coating temperatures should not exceed this. The chromium oxide present in the formulation combines with other substances in the formulation such as phosphates. This forms a binder and results in a high bonding strength that is resistant to cracking, blistering and delamination at these temperatures.

High temperature diffusion coatings are typically used on superalloy components that need to be temperature resistant at a minimum of 750°C. The thermal resistance here is similar to that of MCACs in which the ceramic chromium oxide binder prevents the cracking, blistering and delamination of coatings at temperatures exceeding 700°C. Therefore, any coatings or substances must pass an oxidation resistance test for 1,000 hours at 600°C.

3.4.2.4 Technical feasibility criterion 4: Chemical resistance

The chemical resistance of these components refers to their ability to resist contact with fluids that may be present in the engine, such as, lubricants, hydraulic fluids, greases, fuels, solvents, de-greasers, cleaning fluids, and de-icing fluids. The coating resists many organic substances, such as solvents, lubricants, and greases. This resistance can be attributed to the insolubility of chromium oxide.

Resistance to these common engine chemicals is tested through multiple methods including, oil resistance for 100 hours at 120°C, repeatedly wiped with an acetone cloth 10 times, and a solvent degreaser wiped 10 times. If the coating is removed through these test methods, the underlying substrate will then be subjected to corrosion.

3.4.2.5 Technical feasibility criterion 5: Adhesion

The coating should not inhibit the adhesion of subsequent layers such as paints, primers, adhesives, and sealants. In addition, the coating must strongly adhere to the substrate surface such that the coating does not readily blister, peel or otherwise deform under normal operating conditions of the part. In coating formulations containing Cr(VI), adhesion promotion is achieved by both chemical and mechanical means, where the formed Cr_2O_3 binder is covalently bonded to the substrate through Fe^{III}-O-Cr^{III} linkages, and where the insoluble and rigid Cr_2O_3 ceramic is mechanically bound through microscopic defects in the substrate surface.

3.4.2.6 Technical feasibility criterion 6, 7 and 8: Applicability, coating thickness and surface finish

The coating system must be readily sprayable to be applied to the turbine components and pass spray tests. If a coating is not readily sprayable this can lead to the risk of flash rusting of steel substrates while the coating is being applied, inability to coat complex shapes due to the coating drying too quickly, and a coating that is too thin and requires additional layers. Additionally, the ability to do small manual touch ups is required due to frequent dents and scratches during assembly processes.

The coating thickness of the system is important to ensure the coating is uniform on components in which this is critical. Rotating components have tight tolerances and therefore the addition of millimetres on each surface could have a large impact. The coating, as indicated by downstream users, should have a maximum thickness of 0.008 – 0.016 mm. However, this will require a case-by-case assessment for each component.

The surface finish can affect the performance of component efficiency. A rough surface could lead to an accelerated decrease in performance due to fouling and can sometimes be attributed to the application. These small changes could have direct impacts on the compressor performance. A coating system should have a surface roughness of 0.5 - 0.8 Ra.

A smooth surface finish is essential for coated parts which operate within gas path environments such as turbine fan blades. A rough surface can induce turbulent flow of the gas across the part, reducing the efficiency of the turbine. In addition, a smooth surface reduces the impact of erosion by solid particles (e.g., grit) within the gas stream.

All of these things would compromise the production process and could lead to an increase in manufacturing costs or failures.

3.4.2.7 Technical feasibility criterion 9: Conductivity

Conductivity is important for MCACs to provide sacrificial galvanic protection. This means that the surface must be conductive after burnishing and this is what conductivity testing is looking for. The industry standard to check this is to check the coating using a voltmeter, therefore it is not strictly a measure of conductivity.

The surface after burnishing should have a resistivity of ≤15 ohms.

3.4.2.8 Technical feasibility criterion 10: Cyclic heat-corrosion resistance (oxidation salt spray)

Cyclic corrosion tests are used to simulate real-world scenarios. Therefore, this testing method includes both wet and dry conditions to give a more accurate representation of operating environments. These multi-step testing cycles can include immersion, humidity, condensation, salt fog and heat.

For a substance to qualify for use as a sacrificial coating it must pass this accelerated corrosion test for 10 cycles of 20 hours neutral salt spray followed by 2 hours at 450°C. This requirement was obtained through downstream user consultation.

3.5 Market analysis of products manufactured with the Annex XIV substance

The markets where IP's products are used (along with those formulated by competitors) are described in more detail in section 4.

IPcote products are sold to customers within the UK, EEA and rest of the world. The products are primarily used by companies for industrial, aerospace and defence purposes (including aeroderivative uses in the marine sector).

3.6 Annual volume of the SVHC used

The annual volume of IP's chromium trioxide products used for industrial purposes is:

- UK: up to #A, G kg (100 kg - 1 tonne) CT/year
- EEA: up to #A, G kg (100 kg - 1 tonne) CT/year
- Other markets: up to #A, G kg (100 kg - 1 tonne) CT/year

The annual average tonnages used have been in this range for the past several years. This trend is expected to continue for the next several years before it begins to decrease as downstream users begin to substitute chromium trioxide with alternative solutions.

The annual volume may increase if a competitor leaves the market and there is increased demand for IP's chromium trioxide products to meet this demand (see section 4.7.3).

3.7 Efforts made to identify alternatives

3.7.1 Research and development

3.7.1.1 History of the use of chromium trioxide by downstream users

Downstream users indicated their use of chromium trioxide-based products began in the 1970's. While IP's chromium trioxide-based products began being used by key downstream users as early as 2005, in some instances this replaced an equivalent product that was being used at the time.

3.7.1.2 Recent research on alternative chromium free coatings

Key downstream users indicated investigations into alternative products began as early as 2014. It total, it was indicated that more than 15 coatings were considered. Specifically, the coatings identified were[20]:

[redacted]

After preliminary laboratory tests and assessments, four alternative coatings were considered to be the most promising for MCACs and shortlisted for rainbow engine testing.[22] They are as follows:

[redacted]

Another two coatings were identified to be the most promising diffusion coatings. These replacements are considered to be different technologies to the MCACs. Diffusion coatings are used for hot end nickel alloys or turbine blades, whereas the MCACs are used for steel alloy cold end components. Therefore, there is no read across between the two coating technologies because of the different temperatures in application and within their use. These are identified as:

[redacted]

These coatings have undergone preliminary laboratory testing and are in preparation for engine testing. Although these coatings are going to engine testing it is important to note that downstream users indicated they would not currently be able to conduct business with these alternatives due to their readiness level. Performance is inferior to chromium trioxide-based coatings and further development would be required.

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[20] [redacted]

[21] [redacted]

[22] Rainbow engine testing is where two or more alternatives identified are tested on different turbine blades within an industrial gas turbine at the same time to increase testing efficiency and to allow a direct comparison of their technical performance.

3.7.2 Consultations with customers and suppliers of alternatives

Two types of consultation were undertaken for the purposes of this combined AoA-SEA:

- Consultation with the Applicant to gather information on downstream users and information on volumes placed on the market and number of customers; and
- Consultation with downstream users to gather information on their uses, supply chains, R&D into alternatives, and responses under the Non-Use Scenario.

Further details of each are provided below.

Consultation with the Applicant

Information was gathered from the applicant on their supply chains and on quantities sold per annum. The applicants may act as a downstream user themselves (e.g. formulator, distributor) and/or as a distributor for other applicant's/formulators of the chromates for use in slurry (diffusion) coatings.

Please note: a separate AoA-SEA was done to address impacts to the applicant (IP).

Consultation with Downstream Users

Consultation with downstream users was carried out to collect a range of data relevant to both the AoA and the SEA. This consultation was carried out with downstream users of IPcote products. Consultation was in the form of detailed questionnaires followed by bilateral communication via email and interviews. The questionnaires collected information relating to:

- Products used and associated volumes;
- Supply chains;
- Key functionalities provided by the substance;
- Alternatives tested and reasons for failures;
- Likelihood of substitution before 2024;
- Importance of chromate-using processes to the turnover of companies;
- Numbers of employees in use of the chromates as well as the total number of employees at sites that would be directly impacts under the Non-Use Scenario; and
- Economic and social impacts under the Non-use Scenario.

3.7.3 Identification of possible alternatives

The alternatives identified by downstream users of MCAC slurry and diffusion coatings are those which have been developed to remove hexavalent chromium and replace it with various combinations of non-Annex XIV substances. The functionality provided by Cr(VI) in MCAC slurry and diffusion coatings is complex and many key functionality criteria are strongly interrelated. As a result of this, there is no single substance which can be used as a 'drop-in' replacement to Cr(VI) and alternative formulations are normally a proprietary mixture of a wide range of binders, stabilisers and other materials in an attempt to achieve the same functionality as the incumbent coatings.

The exact formulations of alternative coatings are not normally disclosed to downstream users by formulators, and therefore classification of the identified alternatives under their specific constituents is not possible. However, all alternative coatings can be categorised as chromium (VI) free slurry coatings, where chromium trioxide has been replaced with a binder containing inorganic and/or organic substances.

The alternatives identified by key downstream users during research and development can be found below in **Table 3-4**. A technical feasibility classification was provided for each alternative to indicate its feasibility as a potential replacement to chromium trioxide-based products. For MCACs, alternatives with a technical feasibility classification below 3, were eliminated. This was due to specific technical criteria not being met in two critical tests, e.g., #F and #F. Many alternative candidates were eliminated at this stage and no reformulations took place to advance the coatings.

Table 3-4: Identified alternatives

Number	Alternative name	Technical Feasibility Classification	Development stage
MCAC coatings			
1	#F (whole table)	3	Under assessment for [redacted] Awaiting rainbow testing
2	[redacted]	1	Eliminated/disregarded
3	[redacted]	3	This coating formulation will become obsolete once reformulated[24]. Candidate progressed to rainbow testing.
4	[redacted] (After modifications to the formulation, changed name to [redacted])	2	Now called [redacted]
5	[redacted]	-	Eliminated/disregarded
6	[redacted]	2	Eliminated/disregarded
7	[redacted]	1	Eliminated/disregarded
8	[redacted]	2	Eliminated/disregarded
9	[redacted]	2	Eliminated/disregarded
10	[redacted] ((After modifications to the formulation, changed name to [redacted]	2	Eliminated/disregarded
11	[redacted]	2	Eliminated/disregarded
12	[redacted]	3	Awaiting rainbow testing
13	[redacted]	3	This coating formulation will become obsolete once reformulated[25].

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[23] #F

[24] #F

[25] Formulator indicated they wish to reformulate

Table 3-4: Identified alternatives

Number	Alternative name	Technical Feasibility Classification	Development stage
	[redacted]		Candidate progressed to rainbow testing.
Diffusion coatings			
14	[redacted]	5	Laboratory tests approved, awaiting application trials and production scale-up.
15	[redacted]	4	Waiting for laboratory test approval.

Technical feasibility classification:
1 – We do not know
2 – Technically infeasible, not a real alternative
3 – Theoretically feasible, as a last resort, but overall, technically poor
4 – Technically promising but not yet ready, requires further research
5 – Feasible to replace IP's chromium trioxide containing product(s) in some situations/processes/products
6 – Feasible to replace IP's chromium trioxide containing product(s) in all situations/processes/products

Mechanical laboratory testing was carried out on test panels coated with the aforementioned coating systems. These mechanical tests will give a good indication to the quality of the coating, however there is no correlation between this and how it performs in service. To determine the coatings performance in service, an engine test or rainbow test is carried out. This would consist of coating rainbow test blades with the alternative coating systems and installing them in a test engine. This would then run for a specified time-period ideally in the environments these engines might operate.

3.7.4 Shortlist of alternatives

Shortlisted alternatives (**Table 3-5**) were determined based on a technical feasibility level of 3 or above and the coatings' ability to meet certain technical feasibility criteria. While these seem to be the most promising alternative candidates, they still have significant performance issues and lack robustness in comparison to hexavalent chromium coatings.

Table 3-5: Shortlisted alternatives

Number	Alternative name	Technical Feasibility Classification	Description
MCAC coatings			
1	#F (whole table)	3	2 layers of base coat (Al-particles in a silicate matrix) + 1 layer topcoat (phosphate based)
2	[redacted]*	3	2 layers of base coat (Al-particles in a silicate matrix) + 1 layer topcoat (phosphate based)
3	[redacted]	3	2 layers of base coat (Al-particles in a phosphate matrix) + 1 layer topcoat (phosphate based)
4	[redacted]	3	2 layers of base coat (Al-particles in a phosphate matrix) + 1 layer topcoat (phosphate based)
Diffusion coatings			
5	[redacted]	5	Can be applied as a single or multilayer Silicon Aluminide coating, applied as a slurry and diffused into the substrate material

Table 3-5: Shortlisted alternatives

Number	Alternative name	Technical Feasibility Classification	Description
6	[redacted]	4	Can be applied as a single or multilayer Silicon Aluminide coating, applied as a slurry and diffused into the substrate material

Technical feasibility classification:
1 – We do not know
2 – Technically infeasible, not a real alternative
3 – Theoretically feasible, as a last resort, but overall, technically poor
4 – Technically promising but not yet ready, requires further research
5 – Feasible to replace IP's chromium trioxide containing product(s) in some situations/processes/products
6 – Feasible to replace IP's chromium trioxide containing product(s) in all situations/processes/products
* [redacted]

These coating candidates will begin site-based and in field engine testing to determine their performance levels in practice. Upon completion of gathering baseline performance data during the 1,000-hour engine test. There are some downsides to this such as location. It is regarded as "clean" with good filtration, so therefore, may not be representative of the location where these engines are running. It is likely further developments to the coating systems will be made before beginning the in-field engine testing. It should be noted that typically engines will complete 64,000 hours between overhaul intervals and therefore the in-field rainbow engine tests will complete 64,000 hours of testing. This test would take ~7-8 years of engine running and is the main reason for a 12-year review period.

3.8 Assessment of shortlisted alternatives

3.8.1 MCAC alternative coating systems

Over the course of 2014 to present, key downstream users, consisting of formulators and applicators, worked together to research alternative chromium free coating systems. After multiple rounds of testing, it was determined that four of these MCACs would enter a final phase of testing and then be subjected to a rainbow engine test to determine their suitability for service; although it was found that these coatings were not as robust as the current chromium-based coating systems. The alternatives assessed in this section were considered to be the most promising. The testing done on candidate coatings before engine testing is shown below in **Table 3-6**.

Table 3-6: Testing done candidate coatings

Test	Historical or additional test	Technical feasibility demonstrated
Resistance to aqueous media	Test added since changes in the formulation led to some coatings softening with exposure to water	Water solubility, adhesion
Neutral salt spray	Historical	Corrosion resistance
Metallographic investigations	Test added since the revised formulations showed some significant differences in microstructure that may affect performance	Applicability, coating thickness, surface finish
Visual appearance	Historical	Applicability

Table 3-6: Testing done candidate coatings

Test	Historical or additional test	Technical feasibility demonstrated
Roughness Rz/Ra	Historical	Surface finish
Thickness of coating	Historical	Coating thickness, applicability
Electrical resistance of base coat	Historical	Conductivity
Cure test / chemical resistance	Historical	Chemical resistance
Adhesion	Historical	Adhesion, dry heat resistance, water solubility
90° bend test	Historical	Adhesion, dry heat resistance, water solubility
Ball drop impact	Historical	Adhesion, dry heat resistance, water solubility
Chemical compatibility	Historical	Chemical resistance
Oxidation salt spray	Historical	Oxidation resistance
Resistance to continuous dry heat	Historical	Oxidation resistance (Dry heat resistance)
Resistance to aqueous media (SiWashW)	Test for Larger Gas Turbines (LGT)	Water solubility
Corrosion fatigue test	Historical LGT test – but results also relevant for Smaller Gas Turbines (SGT)	Corrosion resistance
High cycle fatigue resistance	Additional test to ensure coating application does not affect fatigue response	-
Overspeed erosion test	Additional test to give an indication of relative erosion resistance	-

In an update provided by downstream users at the end of 2022, it was indicated that two of the coatings will be re-formulated ([redacted] and [redacted]) and one suffered application issues ([redacted]). Therefore, only [redacted] has been applied to the rainbow test blades and is ready to be fitted for engine testing.

A potential alternative must fulfil all key functionalities required for gas turbine engine applications to successfully substitute chromium trioxide in coating systems. In addition, demonstrating equivalent in-service performance levels, or operation hours, to chromium-based coatings would be required. This is due to the number of hours an engine operates between overhaul periods. Lack of performance could lead to blade failures resulting in engine failure, this is equivalent to a ~[redacted] (range €/£ 1-5) million cost.[26]

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[26] The price/unit cost for new industrial gas turbines is higher than this and it is dependent on several factors

3.8.1.1 Alternative 1: #F

General description

The exact formulation is proprietary to #F. However, the coating system consists of 2 layers of base coat (Al-particles in a phosphate matrix) + 1 layer topcoat (phosphate based).

This coating formulation has since become obsolete and reformulated by #F. Due to application issues, it was reformulated from a phosphate-based coating to a silicate-based coating.

The candidate was tested on steel alloys at laboratory scale.

Availability

Development of this alternative is still currently in the research stage; it is estimated that a review period of at least 12 years is needed. Refer to Section 4.2.3 for more information.

Safety considerations

The composition of the formulation is propriety, but the alternative is indicated as being chrome free, therefore it is expected that the alternative will result in a lower risk and improved health and safety performance compared with the current chromate containing solutions. The formulators of the alternative have been mindful not to develop alternatives with substances with an equally or more hazardous classification.

Technical feasibility

This alternative is still in development but has undergone multiple rounds of laboratory testing before being considered for engine testing. The laboratory tests can be found below in **Table 3-7**. An arbitrary peer-reviewed scoring system was used for each test, including a weighting system to demonstrate the importance of each test. The scoring system was based on 1-9 and compared to the performance of the current reference chromium containing coating system. For example, a test with a score of 1 was considered in some instances a failure and a test with a score of 9 was a good result. The "override criteria" were the only two tests that had a definitive pass or fail score. These scores need to be a 7 or above to pass.

Table 3-7: Laboratory testing of chrome free alternative #F

Test	Technical feasibility demonstrated	Weight	Score	Comments from testing laboratory
Resistance to aqueous media	Water solubility, adhesion	8	1	This is considered a failure. #F (whole table)
Neutral salt spray	Corrosion resistance	9	5	This is considered a failure. [redacted]
Metallographic Investigations	Applicability, coating thickness, surface finish	4	7	[redacted]
Visual appearance*	Applicability	-	-	[redacted]

Table 3-7: Laboratory testing of chrome free alternative [redacted]				
Test	**Technical feasibility demonstrated**	**Weight**	**Score**	**Comments from testing laboratory**
Roughness Rz/Ra	Surface finish	8	1	[redacted]
Thickness*	Coating thickness, applicability	-	-	[redacted]
Electrical resistance of base coat	Conductivity	7	9	[redacted]
Cure test/chemical resistance	Chemical resistance	3	1	[redacted]
Adhesion	Adhesion, oxidation resistance (dry heat resistance), water solubility	8	3	[redacted]
90° bend test	Adhesion, oxidation resistance (dry heat resistance), water solubility	4	7	[redacted]
Ball drop impact	Adhesion, oxidation resistance (dry heat resistance), water solubility	6	5	[redacted]
Chemical compatibility	Chemical resistance	7	5	[redacted]
Oxidation salt spray	Oxidation resistance	6	7	[redacted]
Resistance to continuous dry heat	Oxidation resistance (Dry heat resistance)	4	1	[redacted]
Resistance to aqueous media (SiWashW)*	Water solubility	-	-	[redacted]
Corrosion fatigue resistance	Corrosion resistance	7	5	[redacted]
High cycle fatigue test	-	7	9	[redacted]
Overspeed erosion test	-	9	4	[redacted]
Score:	54% (High risk)			
* These criteria were not considered in the scoring of the alternative coatings				

Over the years this coating has been reformulated throughout testing in order to meet criteria. During the first phase of testing, "override criteria" were used to immediately eliminate some coating systems for further consideration. These coatings were either reformulated or withdrawn from consideration by the formulators. The "override criteria" included the [redacted] and [redacted]

[redacted] tests. These tests can be seen in **Table A2-1** as well as the overspeed erosion test performed only on the candidate coatings considered for rainbow testing.

This coating looked to be promising but suffered from #F of the #F during application. After reformulation, the second round of neutral salt spray testing demonstrated an increase in performance after the coating had been reformulated to address the issues in the first round of testing. However, the quality of the coating is quite varied between the first round of tests and between applicators, despite application methods being described. The quality of the coating can be detrimental to the success of how the coating system performs; therefore, this coating would need a reformulation or to have improvements made. It is important that any new coating is suitable for application in a laboratory setting as well as in a production setting. The formulator has indicated the coating has undergone reformulation and is now a silicate-based coating rather than a phosphate-based system.

The testing laboratory deemed this alternative candidate as a high-risk substitute to the current chromium-based coating systems. This is likely due to the continued issues with the #F during testing as well as application methods producing variable coating qualities. The results of the rainbow engine test will be able to give a better indication of this alternatives in-field performance.

Economic feasibility

It should be considered that a change in coating system could incur additional costs. These additional costs could affect not only the formulator and applicator but the consumer as well. It was indicated during consultation that a single downstream user has already spent between #F whilst another indicated #F (range €0.1-7.5 million) was invested for the work already done to develop an alternative. It can be assumed a similar amount will be spent again to continue development.

Changes to manufacturing sites to accommodate an alternative coating would incur additional costs to redevelop and redesign processes and eliminate current coatings. A novel coating system would likely add additional component inspection steps. Lastly, if the coating has a decreased service life the components will need replacing more frequently putting a higher demand on manufacturing facilities. A decreased service life would also mean increased maintenance and component replacement adding to operating costs for the consumer.

Downstream users asked suppliers of the candidate alternative coatings to provide quotations for coating an #F. These costs are shown below in **Table 3-8**.

Table 3-8: Estimated costs for using [redacted]

Coating	Cost estimate per engine (k€)	Increase compared to [redacted] (%)
[redacted] (reference coating)	[redacted]	-
[redacted] (reference coating)*	[redacted]	-
[redacted]	[redacted]	[redacted] (similar)
#B, F (whole table)		

These higher costs are attributed to an increase in coating layers. The current chromium coatings consist of one or two layers, while these replacement coatings would likely need to be at least three layers. The coatings are manually sprayed and then cured in an oven between coats and therefore the increase in costs is mostly due to increased labour costs.

Suitability of Alternative 1 in general

In conclusion, the use of this alternative could be considered as not readily technically feasible, because the formulators still need time to reformulate, test and fully implement it. This time corresponds to the testing and qualification processes required of this industry. At its current development stage, it would be considered high risk to replace chromium trioxide-based coating systems with [redacted]. Additionally, readiness is such that only lab quantities have been produced, while there's been no indication that scale-up would be a concern, it is likely there could be issues with transitioning the process to large scale production.

3.8.1.2 Alternative 2: [redacted]

General description

The exact formulation is proprietary to [redacted]. However, the coating system consists of 2 layers of base coat (Al-particles in a silicate matrix) + 1 layer topcoat (phosphate based). The coating system also consists of [redacted] to assist in the protection of water exposure and salt spray tests.

The candidate was tested on steel alloys at laboratory scale.

Availability

Development of this alternative is still currently in the research stage; it is estimated that a review period of at least 12 years is needed. Refer to Section 4.2.3 for more information.

Safety considerations

The composition of the formulation is propriety, but the alternative is indicated as being chrome free, therefore it is expected that the alternative will result in a lower risk and improved health and safety performance compared with the current chromate containing solutions. The formulators of alternative have been mindful not to develop alternatives with substances with an equally or more hazardous classification.

Technical feasibility

This alternative is still in development but has undergone multiple rounds of laboratory testing before being considered for engine testing. The laboratory tests can be found below in **Table 3-9**. A scoring system was used for each test, including a weighting system to demonstrate the importance of each test. An arbitrary peer-reviewed scoring system was used for each test, including a weighting system to demonstrate the importance of each test. The scoring system was based on 1-9 and compared to the performance of the current reference chromium containing coating system. For example, a test with a score of 1 was considered and in some instances a failure and a test with a score of 9 was a good result. The "override criteria" were the only two tests that had a definitive pass or fail score. These scores need to be a 7 or above to pass.

Table 3-9: Laboratory testing of chrome free alternative #F

Test	Technical feasibility demonstrated	Weight	Score	Comments from testing laboratory
Resistance to aqueous media	Water solubility, adhesion	8	7	#F (whole table)
Neutral salt spray	Corrosion resistance	9	7	[redacted]
Metallographic Investigations	Applicability, coating thickness, surface finish	4	7	[redacted]
Visual appearance*	Applicability	-	-	[redacted]
Roughness Rz/Ra	Surface finish	8	5	[redacted]
Thickness*	Coating thickness, applicability	-	-	[redacted]
Electrical resistance of base coat	Conductivity	7	9	[redacted]
Cure test/chemical resistance	Chemical resistance	3	9	[redacted]
Adhesion	Adhesion, oxidation resistance (dry heat resistance), water solubility	8	9	[redacted]
90° bend test	Adhesion, oxidation resistance (dry heat resistance), water solubility	4	9	[redacted]
Ball drop impact	Adhesion, oxidation resistance (dry heat resistance), water solubility	6	7	[redacted]
Chemical compatibility	Chemical resistance	7	9	[redacted]
Oxidation salt spray	Oxidation resistance	6	7	[redacted]
Resistance to continuous dry heat	Oxidation resistance (Dry heat resistance)	4	7	[redacted]
Resistance to aqueous media (SiWashW)*	Water solubility	-	-	[redacted]
Corrosion fatigue resistance	Corrosion resistance	7	5	[redacted]

Table 3-9: Laboratory testing of chrome free alternative [redacted]

Test	Technical feasibility demonstrated	Weight	Score	Comments from testing laboratory
High cycle fatigue test	-	7	9	[redacted]
Overspeed erosion test	-	9	7	[redacted]
Score:	87% (Minor risk)			

* These criteria were not considered in the scoring of the alternative coatings

During the first phase of testing, "override criteria" were used to immediately eliminate some coating systems for further consideration. These coatings were either reformulated or withdrawn from consideration by the formulators. The "override criteria" including the [redacted] and [redacted] tests. These tests can be seen in **Table A2-2** as well as the overspeed erosion test performed only on the candidate coatings considered for rainbow testing.

Of the alternative candidate coatings tested, this was determined to be one of the most promising. During salt spray testing this candidate had the least amount of [redacted] after testing with little damage to the topcoat. The most prominent issue that seemed to arise during testing was the application of the coating. The variation in applicators seemed to influence the [redacted] that resulted in some [redacted], this was most noticeable during dry heat exposure and subsequent bend testing. The increase in [redacted] also affected the [redacted] of the coating. However, there was some improvement after the first dry heat exposure test where the panel suffered extreme delamination prior to a bend test being conducted. The second round of dry heat exposure testing did not indicate any delamination or spallation until after the bend test was conducted. Alternatively, during adhesion, bend and cure testing without prior exposure to aqueous media or dry heat, the coating did not appear to suffer any major changes.

A downstream user raised significant issues with the application of the [redacted] coating. The three-layer coating system consists of a base coat, mid-coat and topcoat. The [redacted] was used to compensate for the [redacted]. This creates a challenge during processing as it is necessary to [redacted]. The [redacted] can be difficult to remove and achieving uniformity across the component is difficult. The difficulties have resulted in the [redacted] being completely removed on sharp leading and trailing aerofoil edges, this prevents the adhesion of the topcoat or seal coat to these areas. For these reasons, this particular downstream user does not believe this to be a viable option due to these challenges.

During overspeed erosion testing, [redacted] coating demonstrated equivalent resistance to a current chromium-based coating system [redacted]. These initial results are promising; however, laboratory-based tests cannot be used to make an accurate prediction of the coatings performance in the field. The testing laboratory deemed this coating as a minor risk to substitute the current chromium-based coating systems. These risks may be due to the application issues this coating has suffered with.

An update provided at the end of 2022 indicated that [redacted] was applied to test blades for a rainbow engine testing and were rejected and sent back to the applicator. The rejection was due to a surface finish of [redacted]. The issue is currently being assessed prior to continuing with the rainbow test.

Economic feasibility

Economic investments and costs to manufacturers, applicators and consumers will be similar to what has previously been outlined in Section 3.8.1.1.

Downstream users asked suppliers of the candidate alternative coatings to provide quotations for coating an [redacted] #F. These costs are shown below in **Table 3-10**.

Table 3-10: Estimated costs for using [redacted]

Coating	Cost estimate per engine (k€)	Increase compared to [redacted] (%)
[redacted] (reference coating)	[redacted]	-
[redacted] (reference coating)*	[redacted]	-
[redacted]	[redacted]	[redacted] (higher)

[redacted] #B, F (whole table)

Previous issues with application of this coating would result in higher costs, any change or increase in complexity of preparing the base metal for coating and application would increase internal labour costs. Additionally, there could be an increase in lead time for more complex processes. As indicated previously, the complexity of a three-coat system would require at least 50% more time to process. The increase in labour costs is the primary source contributing to the increased costs. Additionally, any complications with applying the coating could lead to increased lead time that could amount to large sums of money lost, refer to Section 4.7.1 for more information.

Suitability of Alternative 2 for the applicant and in general

In conclusion, the use of this alternative could be considered as not readily technically feasible, because the downstream users still need time to continue development, test and fully implement it. This time corresponds to the testing and qualification processes required of this industry. At its current development stage, it would be considered a risk to replace chromium trioxide-based coating systems with [redacted] #F.

3.8.1.3 Alternative 3: [redacted] #F

General description

The exact formulation is proprietary to [redacted] #F. However, the coating system consists of a base coat, seal coat, cured, second base coat, second seal coat, cured and a topcoat. The two layers of base coat are Al-particles in a silicate matrix and the topcoat is phosphate based. The coating system consists of these [redacted] #F to assist in the protection of water exposure and salt spray tests.

The candidate was tested on steel alloys at laboratory scale.

Availability

Development of this alternative is still currently in the research stage; it is estimated that a review period of at least 12 years is needed. Refer to Section 4.2.3 for more information. [redacted] #F

Safety considerations

The composition of the formulation is propriety, but the alternative is indicated as being chrome free, therefore it is expected that the alternative will result in a lower risk and improved health and safety performance compared with the current chromate containing solutions. The formulators of alternative have been mindful not to develop alternatives with substances with an equally or more hazardous classification.

Technical feasibility

This alternative is still in development but has undergone multiple rounds of laboratory testing before being considered for engine testing. The laboratory tests can be found below in **Table 3-11**. A scoring system was used for each test, including a weighting system to demonstrate the importance of each test. An arbitrary peer-reviewed scoring system was used for each test, including a weighting system to demonstrate the importance of each test. The scoring system was based on 1-9 and compared to the performance of the current reference chromium containing coating system. For example, a test with a score of 1 was considered and in some instances a failure and a test with a score of 9 was a good result. The “override criteria” were the only two tests that had a definitive pass or fail score. These scores need to be a 7 or above to pass.

Table 3-11: Laboratory testing of chrome free alternative [redacted] #F

Test	Technical feasibility demonstrated	Weight	Score	Comments from testing laboratory
Resistance to aqueous media	Water solubility, adhesion	8	9	#F (whole table)
Neutral salt spray	Corrosion resistance	9	5	[redacted]
Metallographic Investigations	Applicability, coating thickness, surface finish	4	7	[redacted]
Visual appearance*	Applicability	-	-	[redacted]
Roughness Rz/Ra	Surface finish	8	9	[redacted]
Thickness*	Coating thickness, applicability	-	-	[redacted]
Electrical resistance of base coat	Conductivity	7	9	[redacted]
Cure test/chemical resistance	Chemical resistance	3	9	[redacted]
Adhesion	Adhesion, oxidation resistance (dry heat resistance), water solubility	8	9	[redacted]
90° bend test	Adhesion, oxidation resistance (dry heat	4	9	[redacted]

Table 3-11: Laboratory testing of chrome free alternative #F

Test	Technical feasibility demonstrated	Weight	Score	Comments from testing laboratory
	resistance), water solubility			
Ball drop impact	Adhesion, oxidation resistance (dry heat resistance), water solubility	6	7	[redacted]
Chemical compatibility	Chemical resistance	7	9	[redacted]
Oxidation salt spray	Oxidation resistance	6	7	[redacted]
Resistance to continuous dry heat	Oxidation resistance (Dry heat resistance)	4	5	[redacted]
Resistance to aqueous media (SiWashW)*	Water solubility	-	-	[redacted]
Corrosion fatigue resistance	Corrosion resistance	7	9	[redacted]
High cycle fatigue test	-	7	9	[redacted]
Overspeed erosion test	-	9	6	[redacted]
Score:	92% (Minor Risk)			

* These criteria were not considered in the scoring of the alternative coatings

This coating has undergone multiple re-formulations and continues to be developed. At the beginning of the project this coating was known as #F and after re-formulation, now goes by the name #F. This coating is considered as one of the most promising alternatives and has consistently been a front-runner for consideration. The first round of testing showed significant issues with resistance to dry heat. This was investigated and it was determined to be the low temperature variant of the coating and it was therefore not surprising the coating failed. During long-term hot water exposure, the coating #F and there was #F with subsequent #F; the re-formulation of the coating addressed this issue.

After re-formulation the coating was applied by a robotic arm and was re-tested. It was observed that the coating then passed the #F test with no blistering or delamination but suffered a decrease in performance for salt spray testing shown from #F and some #F in the crosscut corrosion test. Due to this technical criterion being an "override" criteria, this is considered as a failure. Nevertheless, this re-formulated coating is still currently considered a front-runner offering compromised corrosion resistance but is able to withstand hot water exposure. However, this increased #F could be attributed to an increase in number of coating layers from 3 to 5. The change in layer application number along with the robotic application would cause a significant increase in application costs.

During overspeed erosion testing, #F coating demonstrated equivalent resistance to a current chromium-based coating system #F. These initial results are promising; however, laboratory-based tests cannot be used to make an accurate prediction of the coatings performance in the field. The testing laboratory deemed this coating as a minor risk to substitute the current chromium-based coating systems. These risks may be due to the application issues this coating has suffered with along with the reduction in corrosion resistance.

An update provided at the end of 2022 indicated that #F was applied to a set of rainbow test blades, however, it has also been indicated that #F will re-formulate their coating to address the need for a robotic arm to apply the coating. This re-formulated coating has recently finished in-house testing and will be sent out for outside lab testing shortly. It is likely it will be at least a year before considering a rainbow engine test for these new reformulated coatings. Whilst the rainbow test blades have already been coated for the engine it is likely these results won't be considered if the manufacturer has already made the coating obsolete.

Economic feasibility

Economic investments and costs to manufacturers, applicators and consumers will be similar to what has previously been outlined in Section 3.8.1.1.

Downstream users asked suppliers of the candidate alternative coatings to provide quotations for coating an #F. These costs are shown below in **Table 3-12**.

Table 3-12: Estimated costs for using [redacted]

Coating	Cost estimate per engine (k€)	Increase compared to [redacted] (%)
[redacted] (reference coating)	[redacted]	-
[redacted] (reference coating)*	[redacted]	-
[redacted]	[redacted]	[redacted] (significantly higher)

#B, F (whole table)

These higher costs are attributed to the robotic arm needed for spraying as well as the increase in coating layers.

Suitability of Alternative 3 for the applicant and in general

In conclusion, the use of this alternative could be considered as not readily technically feasible, because the downstream users still need time to continue development, test and fully implement it. This time corresponds to the testing and qualification processes required of this industry. At its current development stage, it would be considered a minor risk to replace chromium trioxide-based coating systems with #F.

3.8.1.4 Alternative 4: #F

General description

The exact formulation is proprietary to #F. However, the coating system consists of 2 layers of base coat (Al-particles in a phosphate matrix) + 1 layer of topcoat (phosphate binder). The coating has a small amount of #F [redacted] in the binder system, with the topcoat being #F [redacted].

The candidate was tested on steel alloys at laboratory scale.

It is possible this coating may be applicable for larger industrial gas turbines that are typically used in less extreme environments where corrosion protection is not as important. This could be an indoor clean environment with air filtration, using clean/treated fuels and a low chance of exposure to contaminants.

Availability

Development of this alternative is still currently in the research stage; it is estimated that a review period of at least 12 years is needed. Refer to Section 4.2.3 for more information.

Safety considerations

The composition of the formulation is propriety; however, the alternative is not indicated as being chrome free, it is likely that the alternative does not contain hexavalent chromium. Although the alternative will result in a lower risk and improved health and safety performance, the use of chromium trioxide may continue if this alternative is chosen.

A summary of the key identifiers and hazard properties of some chromium (III) based substances which may be relevant to alternative slurry coating formulations is shown below in **Table 3-13**.

Table 3-13: Substances in Cr(III)- based substances - key identifiers and hazard properties

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

Table 3-13: Substances in Cr(III)- based substances - key identifiers and hazard properties

Substance	EC number	CAS number	Hazards (REACH)(a)	Hazards (CLP)(b)
			reaction.	

(a) – Hazard classification according to the notifications provided by companies to ECHA in REACH registrations
(b) – Hazard classification provided by companies to ECHA in CLP notifications
Source: ECHA – Search for chemicals (https://echa.europa.eu/home)

Technical feasibility

This alternative is still in development but has undergone multiple rounds of laboratory testing before being considered for engine testing. The laboratory tests can be found below in **Table 3-14**. A scoring system was used for each test, including a weighting system to demonstrate the importance of each test. An arbitrary peer-reviewed scoring system was used for each test, including a weighting system to demonstrate the importance of each test. The scoring system was based on 1-9 and compared to the performance of the current reference chromium containing coating system. For example, a test with a score of 1 was considered and in some instances a failure and a test with a score of 9 was a good result. The “override criteria” were the only two tests that had a definitive pass or fail score. These scores need to be a 7 or above to pass.

Table 3-14: Laboratory testing of chrome free alternative #F

Test	Technical feasibility demonstrated	Weight	Score	Comments from testing laboratory
Resistance to aqueous media	Water solubility, adhesion	8	5	#F (whole table)
Neutral salt spray	Corrosion resistance	9	3	[redacted]
Metallographic Investigations	Applicability, coating thickness, surface finish	4	7	[redacted]
Visual appearance*	Applicability	-	-	[redacted]
Roughness Rz/Ra	Surface finish	8	9	[redacted]
Thickness*	Coating thickness, applicability	-	-	[redacted]
Electrical resistance of base coat	Conductivity	7	9	[redacted]
Cure test/chemical resistance	Chemical resistance	3	9	[redacted]
Adhesion	Adhesion, oxidation resistance (dry heat	8	7	[redacted]

Table 3-14: Laboratory testing of chrome free alternative #F

Test	Technical feasibility demonstrated	Weight	Score	Comments from testing laboratory
	resistance), water solubility			
90° bend test	Adhesion, oxidation resistance (dry heat resistance), water solubility	4	7	[redacted]
Ball drop impact	Adhesion, oxidation resistance (dry heat resistance), water solubility	6	3	[redacted]
Chemical compatibility	Chemical resistance	7	9	[redacted]
Oxidation salt spray	Oxidation resistance	6	5	[redacted]
Resistance to continuous dry heat	Oxidation resistance (Dry heat resistance)	4	7	[redacted]
Resistance to aqueous media (SiWashW)*	Water solubility	-	-	[redacted]
Corrosion fatigue resistance	Corrosion resistance	7	9	[redacted]
High cycle fatigue test	-	7	9	[redacted]
Overspeed erosion test	-	9	5	[redacted]
Score:	78% (High Risk)			

* These criteria were not considered in the scoring of the alternative coatings

During the first phase of testing, "override criteria" were used to immediately eliminate some coating systems for further consideration. The "override criteria" included the #F and #F tests. These tests can be seen in **Table A2-4** as well as the overspeed erosion test performed only on the candidate coatings considered for rainbow testing.

Throughout testing, this coating system has undergone multiple reformulations and name changes. Based on laboratory tests, this coating was not considered to be one of the most promising alternatives. It was indicated by key downstream users that this coating did not pass the "override criteria", #F to be specific, but has been included as a candidate coating nonetheless. This is because its use in some clean environments on LGT, where corrosion and exposure to water is unlikely, would be considered adequate. The coating demonstrated issues in adhering to mild steel panels and after exposure to water, failed adhesion tests, tests on stainless steel substrates showed better results. Turbine blades are stainless steel not mild steel, therefore, it was indicated this coating may be suitable for blades but not casings.

In the final phase of laboratory testing, panels exposed to neutral salt spray suffered heavy red corrosion on the scribe, while the topcoat failed on the ball drop panels as well as #F [redacted]. Additionally, during the overspeed erosion test, performance was slightly inferior to current

Cr(VI)-based coating systems. There was increased loss of the coating on the tip of the blade. At the end of 2022, it was indicated that rainbow test blades have been coated with #F and are ready to be fitted to an engine.

Due to the decrease in performance demonstrated by this coating in comparison with the others and the reference coating, the testing laboratory indicated this would be a high risk to replace the current chromium containing coating systems.

Economic feasibility

Economic investments and costs to manufacturers, applicators and consumers will be similar to what has previously been outlined in Section 3.8.1.1.

Downstream users asked suppliers of the candidate alternative coatings to provide quotations for coating an #F. These costs are shown below in **Table 3-15**.

Table 3-15: Estimated costs for using [redacted]

Coating	Cost estimate per engine (k€)	Increase compared to [redacted] (%)
[redacted] (reference coating)	[redacted]	-
[redacted] (reference coating)*	[redacted]	-
[redacted]	[redacted]	[redacted] (higher)

#B, F (whole table)

These higher costs are attributed to an increase in coating layers. The current chromium coatings consist of one or two layers, while these replacement coatings would likely need to be at least three layers. The coatings are manually sprayed and then cured in an oven between coats and therefore the increase in costs is mostly due to increased labour costs.

Suitability of Alternative 4 for applicant and in general

In conclusion, the use of this alternative could be considered as not readily technically feasible, because the downstream users still need time to continue development, test and fully implement it. This time corresponds to the testing and qualification processes required of this industry. At its current development stage, it would be considered a high risk to replace chromium trioxide-based coating systems with #F.

3.8.2 Conclusion on shortlisted MCAC alternatives

In conclusion, there is not currently a technically feasible alternative available that can deliver the same level of performance as Cr(VI)-based coating systems. The current alternative coatings considered as candidates are continuing to be developed **Table 3-16**.

Table 3-16: Traffic light scoring of candidate coatings

#F (whole table)	[redacted]	[redacted]	[redacted]
High risk replacement	Medium risk replacement	Medium risk replacement	High risk replacement

Green – technically feasible and commercially available
Amber – Promising, but not readily technically feasible and not commercially available
Red – Not readily technically feasible and not commercially available

There are two candidates that appear to be the most promising alternatives and following re-formulation to address application issues will be subjected to engine testing. As no engine testing has taken place all alternatives are considered to be medium risk as a minimum.

This reformulation and subsequent laboratory testing could take a minimum of one year to complete, assuming there are no unforeseen difficulties or failures. The following engine tests will be highly complex with multiple engine tests being conducted in parallel in varying environmental conditions. These engine tests could then be followed up with more testing if required. Therefore, this testing stage could take up to 9 – 10 years to be fully complete. See Section 4.2.3 for information on the substitution plan and R&D activities planned for the review period. There is a possibility, however, that all four candidates fail the engine testing and are deemed as technically infeasible.

3.8.3 Diffusion coating alternative systems

These coatings are different to MCAC's and cannot be compared to each other. Diffusion coatings are used for hot end nickel turbine blades, while MCAC's are used for steel cold end components. The variations in operating temperature and application do not make these coating systems interchangeable and are not suitable replacements for MCAC's. The coatings are diffused into the metal substrate at high temperatures (~870°C), which is above the heat treatment temperature of the steel components. Therefore, coating components with this would destroy the mechanical strength of metal substrate.

Key downstream users have identified two alternative chrome free diffusion coatings. These alternative coatings are more advanced in the research and development stages than the MCAC's and look to be promising alternatives for replacement of chromium-based diffusion coatings.

3.8.3.1 Alternative 1: [redacted]

General description

The exact formulation is proprietary to [redacted].

Availability

Development of this alternative is still currently in the research stage; it is estimated that a review period of at least 12 years is needed for the completion of R&D for alternative coatings, however, it is likely these diffusion coatings could become available before the 12-year review period ends. Refer to Section 4.2.3 for more information.

Safety considerations

The composition of the formulation is propriety, but the alternative is indicated as being chrome free, therefore it is expected that the alternative will result in a lower risk and improved health and safety performance compared with the current chromate containing solutions. The formulators of alternative have been mindful not to develop alternatives with substances with an equally or more hazardous classification.

Technical feasibility

It has been indicated that this alternative coating has passed the laboratory testing phase of development and is awaiting application trials. This will also include a scale-up of production, however it is likely this change will take several years to complete and address any unforeseen problems.

3.8.3.2 Alternative 2: #F

General description

The exact formulation is proprietary to #F.

Availability

Development of this alternative is still currently in the research stage; it is estimated that a review period of at least 12 years is needed for the completion of R&D for all alternative coatings, however, it is likely these diffusion coatings could become available before the 12-year review period ends. Refer to Section 4.2.3 for more information.

Safety considerations

The composition of the formulation is propriety, but the alternative is indicated as being chrome free, therefore it is expected that the alternative will result in a lower risk and improved health and safety performance compared with the current chromate containing solutions. The formulators of alternative have been mindful not to develop alternatives with substances with an equally or more hazardous classification.

Technical feasibility

It has been indicated that this alternative coating has completed the laboratory testing phase of development and once approved will await application trials. This will also include a scale-up of production, however it is likely this change will take several years to complete and address any unforeseen problems.

3.8.4 Conclusions on shortlisted diffusion coatings

Alternative diffusion coatings are likely to become available as alternatives for use on components at the hot end of an industrial gas turbine, however these are not suitable for components intended for use at the cold end of turbines. The difference in operating temperature and metal substrate means these technologies are not interchangeable.

4 SOCIO-ECONOMIC ANALYSIS

4.1 Introduction

Section 3 provided an analysis of the alternatives with respect to the technical feasibility, economic feasibility, availability and suitability of alternatives. The assessment highlights the importance of Cr(VI) for corrosion protection and the other key functions delivered by coating turbine blades and other key components. Although some of the relevant downstream users supporting this use are at more advanced research and development stages and may implement an alternative for some components, there are still components where an alternative is yet to be identified. This point is particularly relevant for those turbines used in more challenging environments.

Until proven alternatives are available which deliver an equivalent level of technical functionality, until they are internally qualified, validated and certified with applicators/MROs for the coating, use of the chromium trioxide in slurry coatings will continue to be required. Their use is essential to meeting key performance criteria and other safety requirements. This is why there are no alternatives which can be considered "generally available" in the context of providing a suitable alternative for all turbine uses.

Ideally the alternative would be as compatible with the existing manufacturing processes to allow for efficient application as part of new coating activity and as part of MRO activity.

For some components, alternatives are expected to become technically qualified and certified in the near future, but time is needed to industrialise and implement them into the value chain. The qualification and certification process with applicators/MROs can take up to three years to complete due to the large number of components.

For those substances still in the R&D phase, final validation tests are set to take place. Turbine manufactures suggest that a 64,000-hour final validation test should be run, the reason for this is that typically turbines would complete 64,000 operational hours between overhaul intervals. The 64,000 operational hours is equivalent to a minimum of 2666 days or 7.3 years. This is the minimum timeframe required, a series of 64,000 hours tests would ideally take place to cover all the different challenging environments where turbines are used. This time does not include any contingency time, further time for reformulation and added testing or the time required for qualifying and certification with applicators/MROs.

Given the large number of gas turbines in use, implementing the alternative as part of new gas turbines and as part of MRO activity will likely take several years to complete. Due to the large number of gas turbines in use, if an unproven alternative (i.e. an alternative that has not completed final validation testing or qualifying and certification) is implemented and technical challenges are encountered, existing MRO supply chains are likely to be put under pressure.

Even then, issues may remain with legacy spare parts and where certification of components using alternatives is not technically feasible or available due to design control [redacted] #C

As a result, as demonstrated by the substitution plan, the OEMs and relevant applicators/MROs will require up to 12 years to complete substitution across all components and final products. Although some turbine components may be able to switch to an alternative earlier in the review period, the criteria and testing requirements for gas turbines intended to be used in more challenging environments means the R&D for these alternatives will take longer to conclude and implement.

The remainder of this section provides the following supporting information to describe the continued use scenario:

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

4.2 Continued use scenario

4.2.1 Summary of substitution activities

IP are separately applying for the continued formulation of chromium trioxide mixtures in the UK. This application covers the downstream use of chromium trioxide formulations which remains vitally important for several downstream users. Once downstream users have successfully identified and implemented alternatives, the chromium trioxide formulation activities and its use by authorised downstream users will reduce accordingly.

Chromium trioxide is known to be an important substance in the EEA and UK gas turbine industry (it is also important to the EEA and UK aerospace industry) due to several key functionalities described in Section 3. Chromium trioxide product formulations can also be applied easily to a range of substrates, and it can have coatings applied on top. The technology is proven and treated surfaces can be protected for several years.

A number of industrial gas turbine OEMs initiated substitution activity in 2014, chromium trioxide product formulations have been used to protect gas turbines for over 50 years. IP's chromium trioxide products have been used for more than 10 years to protect gas turbines.

R&D into developing alternative coatings for the industrial gas turbine sector by OEMs in IP's known supply chain started around 10 years ago and it may take several more years to identify, test, certify and implement an alternative on an industrial scale. The long running cycles of gas turbines creates challenges in identifying alternatives as turbines may run constantly for years with minimal downtime. The alternative(s) should ideally be tested for 64,000 operational hours (7-8 years) before a proven alternative can be successfully confirmed. Turbines will typically be overhauled as part of MRO activity at 64,000 hours (or another duration), the components will be maintained and be refit to the turbine for further service life, some components may not require replacing until 100,000 hours or more of service. Gas turbines are typically designed, manufactured and maintained for use phases of around 30-40 years (the timelines are similar for related aerospace and defence uses).[27] Chromium trioxide products are applied to several turbine components (blades, discs, casings, shafts, bolts, brackets etc.) to help protect key components and extend the service lifetime of the turbine. This creates challenges for the gas turbine industry as the very long product and equipment lifetimes can be impacted by regulatory developments.

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[27] https://www.asd-europe.org/sites/default/files/2022-08/ASD%20SiA%20Guidance_v1_Nov2017_1_0.pdf

To date OEM's have tested more than 20 alternatives, including several reformulated products. The most promising alternatives will be tested as part of a final validation test.

4.2.2 Conclusion on suitability of available alternatives in general

IP (along with their competitors) are product formulators, and the downstream OEMs are responsible for defining the technical feasibility criteria and conducting R&D. Efforts to date by downstream users to identify an alternative are described in Section 3.

As described in section 3, OEM's have tested a wide range of alternatives. Some of the challenging operating environments that OEM gas turbines operate in has meant that some formulations that are claimed to be alternatives may not be suitable.

Although some alternatives are promising, a suitable alternative(s) in general has not yet been confirmed and additional R&D is required.

4.2.3 Substitution plan

4.2.3.1 Factors affecting substitution

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

- Functionality and ability to meet performance requirements of the current chromium coatings (technical feasibility);
- Availability of the alternative;
- Suitability of the alternative into current processes;
- Process changes such as equipment, training, health and safety (technical challenges and economic feasibility);
- A substitution process which is subject to customer requirements; and
- Economic feasibility, including the capital and operational cost of moving to an alternative and the costs of implementing the alternative across the supply chain.

Each factor will contribute to the achievement of milestones that must be met to realise delivery of the substitute(s) to Cr(VI) for slurry coating. They require continuous review and monitoring to ensure that the substitution plan progresses through its phases and all changes are clearly documented. Monitoring of progress markers associated with the substitution plan includes planned steps and targeted completion dates.

4.2.3.2 List of actions and timetable with milestones

Multiple test candidates to replace Cr(VI) in slurry coatings have been investigated and have been progressed but are not yet available. This substitution plan will outline the planned continued development and testing of the alternatives discussed in Section 3. As previously mentioned, a 12-year review period is being sought to allow for ample time for substitution. Activities throughout this 12-year period could/will include things such as:

- Reformulation of alternatives;
- Laboratory testing;
- Rainbow engine testing;
- Rainbow testing across challenging environments;

- Assessment and analysis;
- Qualifying and internal certifications; and
- Implementation.

It was concluded in the analysis of alternatives that there are not currently readily technically feasible alternatives available that can deliver the same level of performance as current chromium-based coating systems. The candidate coatings indicated in the analysis of alternatives are currently undergoing developments and reformulation as indicated by some of the formulators. These new formulations will likely undergo the laboratory tests indicated in Section 3 and upon successful completion will enter into a phase of site-based and in-field engine testing.

Initial site-based 1,000-hour engine testing scheduled to begin in 2023 at the earliest, will be carried out on the four candidate coatings. There are some downsides to this test, in that it is not coastal and is regarded as a “clean” environment with good filtration, making this test not representative of the operating conditions in which some of these gas turbines will be located. Although this test is not as good as a 64,000-hour rainbow test, given the current state of uncertainty regarding the candidate coating developments it was not considered worthwhile to carry out this lengthy test as the coatings are becoming obsolete as developments continue. The initial site-based testing will give a good indication of how the coatings will perform in “real-life” conditions and given the results could be subjected to 64,000-hour in-field rainbow engine test.

Due to the length of these engine tests and the analysis required on the coatings afterwards, this means the engine testing phases could last between 8 – 10 years. See **Figure 4-1** for an example of the R&D timeline.

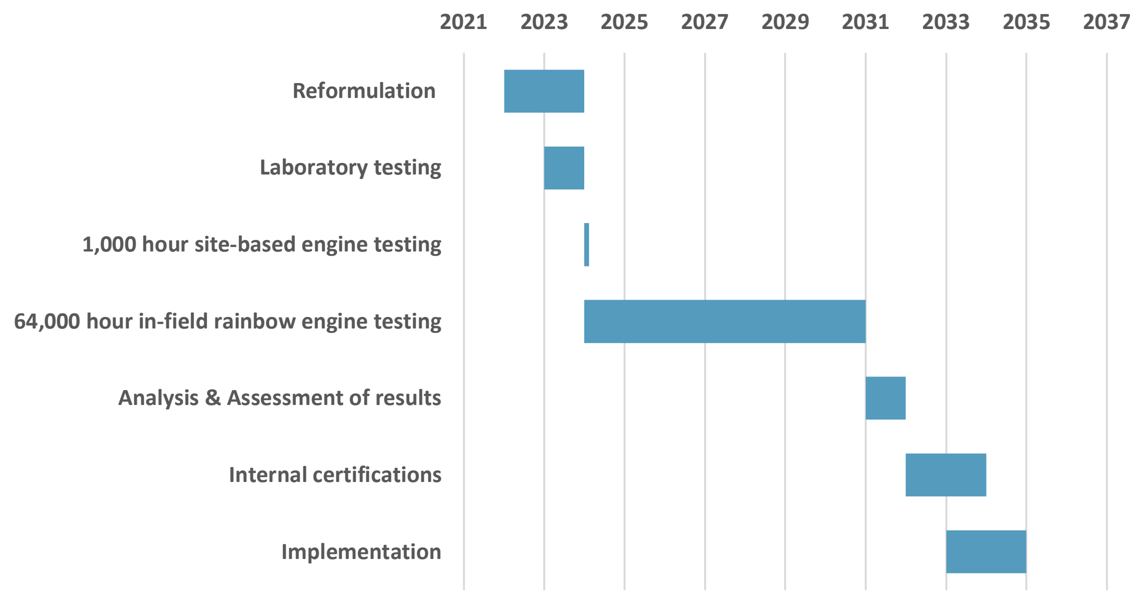


Figure 4-1: Timeline of R&D Activities

The subsequent analysis of the coatings following the 64,000-hour engine test could include things such as determining the degradation of the coating and assessing its performance integrity. Typical MRO intervals are based around the expected lifetime of a compressor. Some of the turbine customers in discussion to take part in the rainbow testing have indicated they would not be willing to have turbines recalled early for inspection or servicing as this will impact their business operations. Therefore, the rainbow test blades are unlikely to be thoroughly inspected or analysed during the 7 – 8 years it takes to run the rainbow test. This is another reason that candidate coatings entering into this test should be at a suitable technical feasibility and will not be obsolete after only a few years of testing. If a leading candidate is determined after 64,000 hours there may be a need for additional testing as the original test may not represent all of the different conditions an engine might be exposed. In which case, there may be a need for further testing in more challenging environments, for example offshore environments. For this reason, OEMs will seek to run parallel rainbow tests across different environments. It is possible that all of the candidates could lack the required performance, and therefore further reformulation and R&D may be required.

If alternative coatings were successful, then there is the aspect of commercialisation and production. Availability is such that only lab quantities have been produced. There is, however, some uncertainty if some of these coatings could be scaled-up due to previous difficulties in coating components for R&D engine testing.

Lastly, the alternative coating must be certified and accepted by the OEM. This could take up to three years for applicators/MROs to coat all the different turbine components with the new alternative coating. As part of the alternative(s) products implementation, the components coated will be inspected before final turbine assembly, if the coating is inadequate components will be returned to the applicator for re-coating.

Thus, a 12-year review period would allow contingency time and for a smoother transition to an alternative(s). However, as it is possible there will be two different alternatives, one for larger turbines used in more stable environments and another for more challenging environments, this may allow for some turbines to transition to an alternative earlier during the review period.

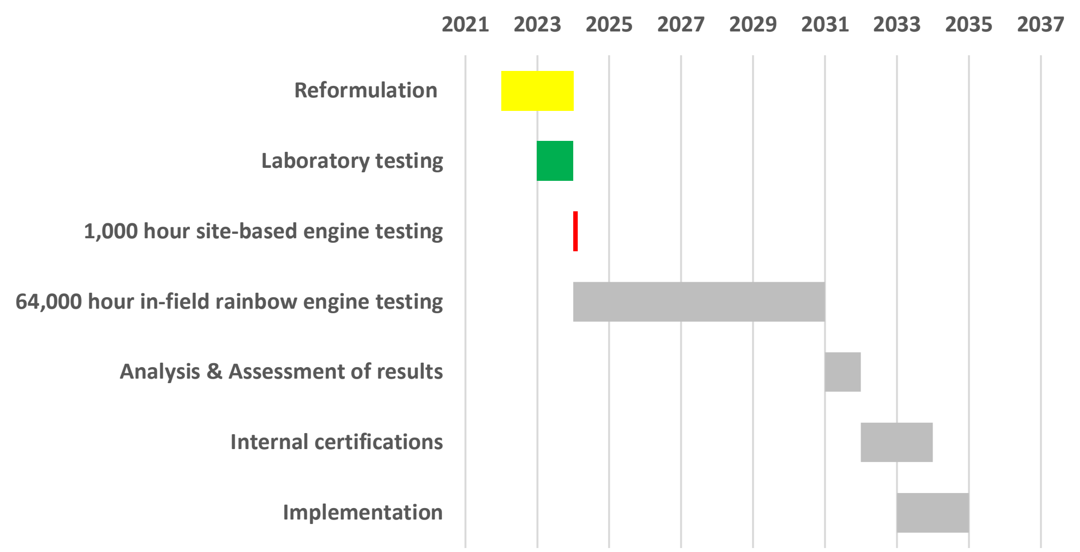
4.2.3.3 Monitoring of the implementation of the substitution plan

Detailed laboratory reports have been produced and archived throughout the research and development stages. It is expected that similar laboratory reports will document reformulations, the upcoming engine tests and further milestones.

4.2.3.4 Conclusions

Given the current state of alternatives development, it cannot be determined if there will be a suitable alternative by the end of the review period. While there are a few promising alternatives with regard to laboratory testing, this does not mean these coatings will be successful in the field. The candidate coatings identified in Section 3 will continue to undergo development and dependant on their success will progress through the stages previously laid out. The current development stage of each alternative can be seen below in **Figure 4-2**.

As a recap from the analysis of alternatives section, two of the candidate coatings are undergoing reformulation and laboratory testing ([redacted] and [redacted]). It is likely it will be at least a year before these coatings complete the laboratory tests and are ready for engine tests. Another coating ([redacted]) that failed [redacted] when applied to test components is currently being analysed further to determine how this problem can be solved, it cannot be determined how long this will take or if it will need reformulation. Applicators that have tried [redacted] on complex components indicate major constraints and issues with its application are unlikely to be overcome. Lastly, the coating that failed salt spray testing (#F [redacted]), is awaiting engine testing and although it failed these corrosion tests, it may be suitable for use on LGT in less extreme environmental conditions.



🟨 #F (whole figure) [redacted] ; 🟩 [redacted] ; 🟥 [redacted]

Figure 4-2: Timeline of R&D activities for each MCAC candidate coating

The diffusion coatings have progressed further in their development stage, and likely an alternative chrome free diffusion coating will become available. Of the two coatings analysed, one has progressed further than the other (#F [redacted]). It has completed and passed all laboratory testing and will begin application trials. This is still likely to take several years despite testing being complete.

4.3 Risks associated with continued use

4.3.1 Classifications and exposure scenarios

Chromium trioxide was included in Annex XIV of Regulation (EC) No 1907/2006 due its intrinsic CMR properties. Chromium trioxide is classified as a Carcinogen 1A and a Mutagen 1B under the CLP Regulation. The most important route of exposure and target organs are inhalation causing lung cancer and oral exposure causing intestinal cancer. The substance is also classified as a Skin and Respiratory Sensitiser 1 and is a Reproductive Toxicant 2. These endpoints are not examined in this SEA.

The hazard evaluation follows recommendations given by RAC (ECHA/RAC, 2015):

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

The risks associated with continued used during the requested review period are discussed in the sections below. Although there will be an ongoing risk to human health, as shown in the CSR, the risk to human health and humans-via-the environment from the activities of downstream users is low.

A full overview of the harmonised classification of chromium trioxide is presented in **Table 4-1**.

Table 4-1: Harmonised classification of chromium trioxide

Hazard Class and Category Code(s)	Hazard Statement Code(s)
Ox. Sol. 1	H271
Acute Tox. 3	H301
Acute Tox. 3	H311
Skin Corr. 1A	H314
Skin Sens. 1	H317
Acute Tox. 2	H330
Resp. Sens. 1	H334
Muta. 1B	H340
Carc. 1B	H350
STOT RE 1	H372
Aquatic Acute 1	H400
Aquatic Chronic 1	H410
Repr. 2	H361F

Source: ECHA[28]

4.3.2 Impacts on humans

4.3.2.1 Overview of exposure scenarios

All sites that perform slurry coating activities for industrial gas turbines and related components are specialised industrial sites. In the EEA and UK, they have rigorous internal, health, safety and environment (HSE) organisational plans. A mix of technical, organisational and personal-protection-based measures are in place to reduce workplace exposures. The sites adhere to best practices to reduce workplace exposures and environmental emissions as technically and practically feasible. Some sites are able to apply automated processes. The feasibility and the degree of automation can vary between different sites and depend, among other factors, on the size of the site and the frequency of coating activities. See the CSR for further details of measures in place.

The OEM industry is characterised by components being designed and manufactured by OEM’s and related parties in the OEM supply chain, while chromium trioxide coating operations are carried out by applicators. Applicators act independently from OEM’s, they offer professional services which include the coating of new turbines and MRO work on existing turbines. Applicators have limited knowledge of the key technical functionality and tolerances of coating products, applicators apply coatings and conduct MRO work based on agreed specifications.

In IP’s chromium trioxide gas turbine supply chain, the applicators use >99.9% of the total volume of chromium trioxide product formulations. The OEM’s do not apply the formulations to components. The use of chromium trioxide formulations at OEM’s sites is rare and this only consists of applying

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[28] https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/14356 (accessed 10 January 2023)

small amounts of product formulations to scratches. The use consists of small quantises being manually brushed onto the affected area and these activities are carried out according to standard operating procedures.

To further help demonstrate the limited impact on human health, additional information is included in the CSR from the safe use and exposure of IP's chromium trioxide products applied as part of the same use in the aerospace and defence industry.

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

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

With respect to worker exposures, **Table 4-2** lists all the exposure scenarios (ES) and contributing scenarios assessed in the CSR.

Table 4-2: Overview of exposure scenarios and their contributing scenarios

ES number	ES number	ES number
ES1-IW1	Slurry coating – use at industrial site	
Environmental contributing scenario(s)		
ECS 1	Slurry coating - use at industrial site leading to inclusion (of Cr(VI) or the reaction products) into/onto article	ERC 5
Worker contributing scenario(s)		
WCS 1	Spray operators	PROC 5, PROC 7, PROC 8a, PROC 8b, PROC 9, PROC 10, PROC 28
WCS 2	Maintenance and/or cleaning workers	PROC 28
WCS 3	Incidentally exposed workers	PROC 0
Exposure scenario for industrial end use at site: ES1-IW1 PROC = process category, WCS = worker contributing scenarios		

4.3.2.2 Worker assessment

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

Workers are exposed to chromium trioxide via inhalation while there is no risk of oral exposure. As discussed in more detail in the CSR, dermal exposure as a potential risk for reprotoxic effects were also considered. Workers wear protective gloves and respiratory equipment, despite these measures a very conservative approach to exposure was taken. Therefore, the main focus of the quantitative exposure estimation and risk characterisation for the worker population is on the carcinogenic effects of inhalation exposure, i.e. lung cancer.

Table 4-3 outlines the main processes associated with the coating of turbine components with chromium trioxide formulations.

Table 4-3: Summary of tasks involving exposure to chromium trioxide during coating activities

#	Description of tasks	Concentration of chromium trioxide (Cr(VI))	Operational conditions	Frequency	Duration
WCS1	**WCS1: Spray operators** Task 1: Slurry coating by manual spraying in a spray booth	max. 6% (w/w) Cr(VI)	LEV Ventilation rate: > 10 ACH	1-240 batches per year	Up to 120 min/batch
	WCS1: Spray operators Task 2: Slurry coating by brushing	max. 6% (w/w) Cr(VI)	LEV Natural ventilation	1-240 batches per year	20-30 min/batch
	WCS1: Spray operators Task 3: Stirring paint, loading/unloading spray gun, and decanting of product	max. 6% (w/w) Cr(VI)	LEV Natural ventilation	1-240 batches per year	10-45 min/batch
	WCS1: Spray operators Task 4: Cleaning activities – cleaning of equipment and workplace	max. 6% (w/w) Cr(VI)	LEV Ventilation rate: > 10 ACH	1-240 batches per year	<60 min/batch
	WCS1: Spray operators Task 5: Waste management – Handling of solid waste	max. 6% (w/w) Cr(VI)	LEV: situation-dependant Natural ventilation	1-240 batches per year	<15 min/batch
WCS2	**WCS2: Maintenance and/or cleaning workers** Task 1: Infrequent repairs of equipment	max. 6% (w/w) Cr(VI)	LEV/No LEV Natural ventilation	4 times per year	Up to 120 min/batch
	WCS2: Maintenance and/or cleaning workers Task 2: Maintenance of LEV system (filter change) and cleaning of spray booth	max. 6% (w/w) Cr(VI)	LEV: no for filter change; yes for cleaning of spray booth Natural ventilation	4 times per year	Up to 480 min
				12 times per year	Up to 160 min
				52 times per year	Up to 30 min
WCS3	**WCS3: Incidentally exposed workers** Task 1: Activities with indirect Cr(VI) exposure	max. 6% (w/w) Cr(VI)	Local LEV arms (for quality control) Natural ventilation	Up to 240 days per year	Up to 480 min

Source: Indestructible Paint CSR

Concentration of Cr(VI) <3.1% (w/w), concentration of Cr(VI) based on ranges of CT (up to 6% (w/w)) in slurry coating products

CT = Chromium Trioxide; LEV = local exhaust ventilation, PROC = process category, WCS = worker contributing scenarios

4.3.2.2.1 Worker protection measures and environmental controls

Downstream users implement a series of technical and organisational measures as part of their processes, in order to minimise exposure of employees and the environment to chromium trioxide. These are described in further detail within section 9.2.2.3 of the CSR, these include:

- Technical measures implemented at the sites include:

  - Manual spraying is conducted in spray booths, which are connected to a local exhaust ventilation (LEV) system.
  - LEV is always used where possible and relevant.
- Organisational measures
  - Annual monitoring programmes are implemented for air monitoring of occupational exposure to Cr(VI), which are representative of the range of tasks undertaken where exposure to Cr(VI) is possible, including tasks involving process and maintenance operations.
  - The paint area in which slurry coating spraying is conducted in spray booths is restricted either by barriers / signage or through strict procedure during the spraying activity and for a specific time after the spray application has ceased.
  - Only trained personnel are allowed to work in the paint area.
  - The effectiveness of the risk management measures and operational conditions in place are regularly reviewed and, as applicable, measures are introduced to further reduce exposure and emissions.
  - LEV systems are inspected and maintained according to the manufacturer´s specification.
  - For tasks where respiratory protective equipment (RPE) is needed to control exposure it is used in accordance with standard procedures for use and maintenance, including procedures for fit testing of RPE masks which are applied in accordance with relevant standards (see **Table 4-4**).
  - The provision of PPE for the workers is organised by a designated responsible person.
  - The conditions of the PPE are checked regularly.
  - A program of PPE management is implemented on site which includes PPE selection, training for correct wear/removal of the PPE, storage of PPE, cleaning or renewal and distribution of the PPE, communication via workplace signage or working instructions at the workplace.
  - Training on chemical risks is periodically done for workers handling chemicals. Safety Data Sheets and instructions for hazardous chemicals handling are available.
  - Training at the workplace is given periodically and work instructions are available on how to carry out specific tasks through standard operating procedures, e.g., how to load the spray gun safely.
  - Cleaning of company supplied uniforms is organised by the site, or contaminated clothes are renewed.
  - Slurry coatings are stored in a designated area.

Table 4-4: Summary of tasks involving exposure to chromium trioxide during downstream user activities

#	Description of tasks	PPE/RPE applied
WCS1	**WCS1: Spray operators** Task 1: Slurry coating by manual spraying in a spray booth	Chemical resistant gloves, chemical protective clothes, full mask with P3 filter or P3 combination filter (APF 20) or powered filtering device incorporating a hood, helmet, or full mask (APF 40), fresh air hose breathing apparatus - full mask, hood or helmet (APF 40), eye protection
	WCS1: Spray operators Task 2: Slurry coating by brushing	
	WCS1: Spray operators Task 3: Stirring paint, loading/unloading spray gun, and decanting of product	
	WCS1: Spray operators Task 4: Cleaning activities – cleaning of equipment and workplace	
	WCS1: Spray operators Task 5: Waste management – Handling of solid waste	
WCS2	**WCS2: Maintenance and/or cleaning workers** Task 1: Infrequent repairs of equipment	Chemical resistant gloves, chemical protective clothes, half mask FFP3 (APF 10), half mask with P3 filter (APF 10), half mask with P3 combination filter (APF 10) or full mask with P3 filter or P3 combination filter (APF 20), eye protection
	WCS2: Maintenance and/or cleaning workers Task 2: Maintenance of LEV system (filter change) and cleaning of spray booth	
WCS3	**WCS3: Incidentally exposed workers** Task 1: Activities with indirect Cr(VI) exposure	Standard PPE (not intended for protection against chromates)

Source: Indestructible Paint CSR
APF = Assigned Protection Factor

4.3.2.2.2 Exposed worker population

As can be determined from the tables in this section (and as reported and the CSR), different operator rules are involved in the contributing scenarios. It should also be recognised that this is a conservative estimate, because where the number of workers performing each task is given as a range (**Table 4-5**); the upper limit in each range is used in the calculations provided in this SEA.

The numbers of workers exposed includes exposure to chromium trioxide from a total of 7 sites. These are known sites where there is exposure with supporting occupational exposure monitoring. IP have knowledge of their existing costumers and have consulted with their current downstream supply chain. Information provided by downstream users (industrial and aerospace) is used in this application and some assumptions are made on the total number of sites and workers exposed as part of coating activities for industrial uses.

As described in section 4.7.3.1, any changes to the current market suppliers of chromium trioxide products may have an impact in the future on the exposed worker population from IP's products.

Table 4-5: Allocation of personnel at downstream user sites and the worst-case number workers exposed for each WCS

#	Description of tasks	Number of workers per line, per shift (worst case)
WCS1	**WCS1: Spray operators** Task 1: Slurry coating by manual spraying in a spray booth	On average 5 per day
	WCS1: Spray operators Task 2: Slurry coating by brushing	
	WCS1: Spray operators Task 3: Stirring paint, loading/unloading spray gun, and decanting of product	
	WCS1: Spray operators Task 4: Cleaning activities – cleaning of equipment and workplace	
	WCS1: Spray operators Task 5: Waste management – Handling of solid waste	
WCS2	**WCS2: Maintenance and/or cleaning workers** Task 2: Maintenance of LEV system (filter change) and cleaning of spray booth	On average 3 per day
WCS3	**WCS3: Incidentally exposed workers** Task 1: Activities with indirect Cr(VI) exposure	On average 2 per day

Source: Indestructible Paint CSR

4.3.2.2.3 Chromium trioxide exposures at OEM plants

The use of chromium trioxide formulations at OEM plants is rare, the use and number of workers exposed is significantly less than the WCS1, Task 2 slurry coating by brushing.

The occasional touch up activities of light scratches follow internal standard operating procedures using similar protective measures described above. Only a few OEM sites will repair scratches on site.

Due to the infrequency and very small amounts that are used, OEM sites are not included in the risk associated with continued use.

4.3.2.2.4 Chromium trioxide exposures at applicator sites

As noted in the CSR, aqueous chromium trioxide solutions formulated by IP are used in batch-wise processes, there are typically a maximum of 240 days per year at sites were chromium trioxide containing products are applied to components.

The product formulations are liquids. A benefit of using liquid forms is that exposure to chromate dust has been reduced. However, the use of liquids as part of spraying activity creates aerosol. To reduce respiratory risk, the use of respiratory equipment is mandatory when handling, preparing, mixing and applying chromium trioxide containing products.

Section 9.2 of the CSR provides a detailed description of tasks and exposure risks. The number of bystanders at sites engaged in other activity is low (on average around 2 per day). The use of chromium trioxide formulations is organised in batch-wise spraying operations. When spraying operations are in progress access to the spraying areas is restricted to only those personnel involved in spraying operations.

Therefore, the chromium trioxide spraying areas are not permanent working areas. Workers only access these areas where required. This is evident from the information provided in **Table 4-3**.

4.3.2.2.5 Excess lifetime cancer risks

The findings of the CSR with respect to worker exposures, are summarised in **Table 4-6**, which presents the excess lung cancer risks to workers involved in slurry coatings treatment related activities. The risks are calculated using a combination of measured inhalation data and modelling for different SEGs (Similar Exposure Groups). The SEGs include:

- WCS1: Spray operators for slurry (diffusion) coatings using CT are usually involved in numerous activities related to the painting process. Most of their working time they spend in a paint area where the spray booths are located and where the painting processes, including preparatory work (e.g., sand blasting and masking) and post-treatments such as curation of parts, take place. Activities in the area comprise tasks with direct or without direct Cr(VI) exposure.
- WCS2: Maintenance and/or cleaning workers typical activities of infrequent repairs of equipment as well as maintenance of LEV system (filter change) and cleaning of spray booth related to the use with potential direct exposure to Cr(VI) are described below in detail together with the working conditions. They are supported by worker air monitoring data covering maintenance activities, if available. In summary, internal maintenance workers perform infrequent repair activities in the paint area when defects occur. External maintenance/cleaning workers usually clean the spray booths and maintain the installed LEV systems which also includes filter changing.
- WCS3: Incidentally exposed workers do not carry out tasks with direct Cr(VI) exposure potential themselves but may incidentally be exposed from such activities due to inhalation background exposure in the work area. Due to the organisation of sites and achieving an efficient work process, incidentally exposed workers must perform their tasks in or near the paint area, as these are necessary activities related to either slurry coating or to other processes carried out in the paint area and cannot be relocated to other areas at the sites.

Table 4-6 sets out the excess lifetime cancer risk for workers involved in each of the above tasks.

Table 4-6: Excess lifetime cancer risk by SEG

#	SEG	Average number of workers per site	Excess lifetime lung cancer risk [1/ug/m^3)
WCS1	Spray operators	5	2.00E-03
WCS2	Maintenance and/or cleaning workers	3	1.22E-04
WCS3	Inicidentally exposed workers	2	8.52E-04

Source: Information from CSR

Note: 90th percentile values calculated for the sites, excess lung cancer risk refers to 40 years of occupational exposure

4.3.2.3 Humans via the environment

4.3.2.3.1 Exposed local populations

For local exposure assessment, workers near the site who are not directly exposed to chromium trioxide (or Cr(VI)) along with populations living in the vicinity of it have to be considered. **Table 4-7** below summarises the number of people estimated to be locally exposed to downstream users and **Figure 4-3**, **Figure 4-4** and **Figure 4-5** show the notional circle area of the 1 km radius around downstream user applicator sites.

Table 4-7: Total number of workers and residents locally exposed

Downstream user site	Directly exposed workers	Residents	Workers	Total
[redacted] #D, E (whole table)	12	[redacted]	[redacted]	[redacted]
	14	[redacted]	[redacted]	[redacted]
	2	[redacted]	[redacted]	[redacted]
	38	[redacted]	[redacted]	[redacted]
	8	[redacted]	[redacted]	[redacted]
	10	[redacted]	[redacted]	[redacted]
Sum total	-	**53,290**	**22,150**	**75,440**
Average	-	**8,882**	**3,692**	**12,573**
Total assumption of all 15 EEA applicator/MRO sites	150	**133,225**	**55,375**	**188,600**
Total assumption of all 18 UK applicator/MRO sites	222	**159,870**	**66,450**	**226,320**
Total assumption of all 33 EEA/UK applicator/MRO sites	372	**293,095**	**121,825**	**414,920**

Sources:

[redacted]

#D, E

[redacted]

Figure 4-3: Location of downstream user sites (via Google maps)

[redacted]

#D, E

[redacted]

Figure 4-4: Location of downstream user sites (via Google maps)

[redacted]

#D, E

[redacted]

Figure 4-5: Location of downstream user sites (via Google maps)

[redacted]

4.3.2.3.2 *Excess lifetime cancer risks*

The assessment of risks for humans via the environment presented in the CSR has been carried out for the general population at the local level only. No regional assessment has been carried out as it can be assumed that Cr(VI) from any source will be reduced to Cr(III) in most environmental situations and therefore the effects of Cr(VI) as such are likely to be limited to the area around the source, as described in the EU Risk Assessment Report for chromates (European Chemicals Bureau, 2005). The approach to not perform a regional assessment for human Cr(VI) exposure via the environment as part of AfAs for chromate uses was also supported in compiled RAC (Risk Assessment Committee) and SEAC (Socio-economic Analysis Committee) opinions, as described for example in the *Opinion on an Application for Authorisation for Use of Sodium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites and sealings of anodic films* (ID 0043-02). This states that regional exposure of the general population is not considered relevant by RAC.[29]

The assessment presented in the CSR is based on measured data for emission to air and wastewater. For this assessment combined exposure of humans via the inhalation (air) and the oral (uptake of water and fish) route is considered. Data were available from 13 sites undertaking slurry coatings[30] to act as the basis for estimating exposure concentrations and associated risks. The resulting worst case 90th percentile risk estimates are presented in the table below.

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

Inhalation		Oral		Combined
Local Cr(VI) PEC in air [µg/m3]	Inhalation risk	Oral exposure [µg Cr(VI)/kg x d]	Oral risk	Combined risk
2.93E-04	8.50E-06	1.65E-05	4.28E-07	8.50E-06

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

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

Overall, the figures show that the risks calculated for humans exposed via the environment are low, even when conservative assumptions are used in the modelling approaches. It must be recognised that downstream users perform reductive treatment of filters as part of LEV systems leading to quantitative reduction of Cr(VI) release to the environment where it will rapidly reduce to Cr(III).

4.3.2.4 Residual health risks

Under the applied-for-use scenario, use of chromium trioxide in slurry coatings will continue for a total of 12 years.

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[29] RAC/SEAC "Opinion on an Application for Authorisation for Use of Sodium dichromate for surface treatment of metals such as aluminium, steel, zinc, magnesium, titanium, alloys, composites and sealings of anodic films", consolidated version, 2016; https://echa.europa.eu/documents/10162/658d42f4-93ac-b472-c721-ad5f0c22823c

[30] Consisting of 11 ADCR sites and 2 industrial turbine related sites

In December 2013, the Risk Assessment Committee (RAC) agreed lifetime (i.e. for 40 years and 70 years of exposure) mortality risk estimates associated with carcinogenicity for workers and humans via the environment exposed to Cr(VI) substances.[31] It assumes a linear relationship for both lung and intestinal cancer.

These dose-response relationships are used in the calculations to derive the excess lifetime cancer risks for workers directly exposed to Cr(VI) in downstream users production facilities, other workers in the facility indirectly exposed and members of the general population (local and regional scale). As the excess cancer risk estimates apply to each exposed worker for a total working life of 40 years, they need to be adjusted to reflect exposures over the length of the review period. Exposures are thus treated as separable over time, meaning that annual risk is equivalent to 1/40 of the risk over 40 years of exposure. For members of the general population, excess cancer risks estimates apply for a lifetime of 70 years, meaning that annual risk is equivalent to a 1/70 of the risk of 70 years of exposure.

Table 4-9 indicates the range of excess cancer risks estimated for the total number of workers exposed across all of the different tasks.

Table 4-9: Excess cancer risks for exposed workers in downstream users facilities

Region	Number of workers exposed	Excess cancer risks (task-related)	Excess cancer risks upper-end estimate
EEA	150	4.00E-03	2.00E-03 to 1.22E-04
UK	180	4.00E-03	2.00E-03 to 1.22E-04
Source: CSR			

On the basis of the RCRs, excess cancer risks for local workers, the local general population can be derived. They are summarised in **Table 4-10** below.

Table 4-10: Excess cancer risks for humans via the environment

Local scale			
General population		Workers	
Inhalation	Oral	Inhalation	Oral
8.50E-06	1.32E-08	8.50E-06	1.32E-08
Source: CSR Regional exposure of the general population is not considered relevant by RAC			

4.3.2.5 Morbidity vs mortality

Excess cancer cases need to be split between fatal and nonfatal ones. To this end, estimates of fatality and survival rates associated with lung and colorectum[32] cancer cases were derived from the Cancer Today database, see **Table 4-11** below.

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[31] ECHA (2013): Application for authorisation: Establishing a reference dose response relationship for carcinogenicity of hexavalent chromium. Helsinki, 04 December 2013. RAC/27/2013/06 Rev. 1 (agreed at RAC-27).

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

Table 4-11: Estimated incidence and mortality of cancers across the EU-27 and the UK, both males and females (in 2020)

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

Source: Source: http://gco.iarc.fr/today/home (accessed on 15/08/2022)
Note: Percentages have been rounded

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

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

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

In a similar fashion, the figures from Cancer Today reported Table 4-7 above are applied to the estimates to calculate the total number of additional fatal and non-fatal intestinal cancer cases.[33]

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

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

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

4.3.3 Predicted excess cancer cases with continued use: workers directly exposed

Total excess cancer risk cases are based on the excess lifetime risk estimates derived in the CSR for the different worker contributing scenarios (WCS as presented in **Table 4-6**). These risk estimates reflect the additional safety measures that have been implemented due to the conditions placed on continued use by the initial authorisations. The number of excess cancer cases is calculated by multiplying the number of workers assumed to be exposed in each task by the value of the excess cancer risk given above adjusted for the requested review periods, i.e., over 12 years. This value is then multiplied by the number of workers exposed in each WCS to calculate the total excess cancer cases arising from the continued use of chromates in slurry (diffusion) coatings. **Table 4-12** and **Table 4-13** provide a summary of the results across all WCS for EU and UK workers.

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

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

WCS	Number of persons exposed	LUNG CANCER - Excess lifetime cancer risk	Excess number of lifetime cancer cases	LUNG CANCER - Number of excess lifetime fatal cancer cases	LUNG CANCER - Number of excess lifetime non-fatal cancer cases
WCS1	75	2.00E-03	**1.50E-01**	**1.19E-01**	**3.15E-02**
WCS2	45	1.22E-04	**5.49E-03**	**4.34E-03**	**1.15E-03**
WCS3	30	8.52E-04	**2.56E-02**	**2.02E-02**	**5.37E-03**
		Years - Lifetime	**40.00**	**1.43E-01**	**3.80E-02**
		Years - Review period	**12.00**	**4.29E-02**	**1.14E-02**
		Years - Annual	**1.00**	**3.58E-03**	**9.51E-04**

Table 4-13: Number of excess lifetime cancer cases to UK workers

WCS	Number of persons exposed	LUNG CANCER - Excess lifetime cancer risk	Excess number of lifetime cancer cases	LUNG CANCER - Number of excess lifetime fatal cancer cases	LUNG CANCER - Number of excess lifetime non-fatal cancer cases
WCS1	90	2.00E-03	**1.80E-01**	**1.42E-01**	**3.78E-02**
WCS2	54	1.22E-04	**6.59E-03**	**5.20E-03**	**1.38E-03**
WCS3	36	8.52E-04	**3.07E-02**	**2.42E-02**	**6.44E-03**
		Years - Lifetime	**40.00**	**1.72E-01**	**4.56E-02**
		Years - Review period	**12.00**	**5.15E-02**	**1.37E-02**
		Years - Annual	**1.00**	**4.29E-03**	**1.14E-03**

4.3.4 Predicted excess cancer cases with continued use: humans via the environment

The total number of people exposed as humans via the environment as given in **Table 4-7** is multiplied by the excess cancer risk estimates to calculate the total excess cancer cases arising under the Continued Use scenario. The results are given in **Table 4-14**.

Table 4-14: Number of people in the general public exposed (local assessment) across the EEA and UK

Countries with DUs	No. Sites per country	Exposed local population	Combined excess lifetime cancer risk	Excess number of lifetime cancer cases	Number of excess lifetime fatal cancer cases	Number of excess lifetime non-fatal cancer cases
EEA Total	**15**	**188,600**	**8.50E-06**	**1.60**	**1.27**	**0.34**
		Years - Lifetime cases		**70.00**	**1.27**	**3.37E-01**
		Years - Review period		**12.00**	**2.17E-01**	**5.77E-02**
		Years - Annual		**1.00**	**1.81E-02**	**4.81E-03**
UK	**18**	**226,320**	**8.50E-06**	**1.92**	**1.52**	**0.40**
		Years - Lifetime cases		**70.00**	**1.52**	**4.04E-01**
		Years - Review period		**12.00**	**2.61E-01**	**6.93E-02**
		Years - Annual		**1.00**	**2.17E-02**	**5.77E-03**

4.3.5 Economic valuation of residual health risks

In order to monetise human health impacts, a timeframe that goes from 2024 to the end 2036 (i.e. the 12 year length of the review period) has been used and a 4% discount rate has been employed for calculating net present values. It has been assumed that the levels of exposure for workers and members of the general population remains constant throughout the length of the review period, although this is a very conservative assumption. As OEMs identify, qualify, certify and implement the use of an alternative(s) for coating some components, the use of chromium trioxide formulations will begin to decrease.

The economic valuation of the health impacts takes into account two important welfare components, the costs associated with mortality and morbidity. The basis of our calculations is the study led by the Charles University in Prague[34] and undertaken for ECHA.

That study was critically reviewed by ECHA in 2016 (ECHA, 2016b) and the results of that review have been the basis of the economic valuation performed here[35]. The values used are:

- Value of statistical life for the avoidance of a death by cancer: €3.5 million (2012 prices), and
- Value of cancer morbidity: €0.41 million (2012 prices).

It is appropriate to update these two figures to 2021 prices (updated to second and third quarter values of 2021, more recent data are not available). This has been achieved by use of the Eurostat EU GDP deflator[36]. This suggests that the aforementioned figures should be multiplied by a factor of 1.135. Thus, the following values are employed in the analysis below:

- Value of statistical life (mortality): €3.5 million × 1.135 = €3.97 million (rounded), and
- Value of cancer morbidity: €0.41 million × 1.135 = €0.47 million (rounded)

In addition to these valuations, for the purpose of quantifying human health impacts, consideration has also been given to:

- **Annual medical treatment costs for morbidity**: they are estimated to be €16,818 for lung cancer cases and €15,987 for intestinal cancer cases in 2021 prices.

With regard to direct medical or health care costs, a range of studies were identified that provide estimates of the costs of medical treatment for patients surviving lung and intestinal cancer. These are summarised in **Table 4-15**.

Table 4-15: Alternative estimates of medical treatment costs

Study	Year for prices	Average direct costs in original units (per annum)	Direct costs in € 2021
Lung cancer			
Leal (2012)	2012	£9,071	€ 12,607

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[34] Alberini, A. and Ščasný, M. (2014) Stated - preference study to examine the economic value of benefits of avoiding selected adverse human health outcomes due to exposure to chemicals in the European Union - Part III: Carcinogens.

[35] ECHA - Valuing selected health impacts of chemicals. Available at: https://echa.europa.eu/documents/10162/13630/echa_review_wtp_en.pdf/dfc3f035-7aa8-4c7b-90ad-4f7d01b6e0bc

[36] https://ec.europa.eu/eurostat/databrowser/view/NAMA_10_GDP__custom_3816874/default/table?lang=en

Table 4-15: Alternative estimates of medical treatment costs

Study	Year for prices	Average direct costs in original units (per annum)	Direct costs in € 2021
Braud et al. (2003)	2001	€12,518	€ 17,352
Dedes et al. (2004)	1999	€20,102	€ 20,495
Intestinal cancer (colon, colorectal and rectal cancer taken as proxies)			
Luo et al. (2010)	2000 (assumed)	US$29,196	€ 35,971
Lang et al. (2009)	2006	US$28,626	€ 30,669
York Health Economics Consortium (2007)	2004	£8,808	€ 13,511
York Health Economics Consortium (2007)	2004	£12,037	€ 18,464

The average cost across the four lung cancer studies is €16,818 per annum (2021 prices). The average cost figures reported for intestinal cancer are based on figures produced for colon, rectal and colorectal cancer in the US and UK. The US figures are high compared to the UK data; as a result, the average across the two UK studies is taken here, with this being around €15,987 per case in 2021 prices, taking into account price inflation.

These average medical costs are annual figures and apply to survivors over the period of time that they continue to be treated. With respect to lung cancer morbidity cases, we have taken a percentage survival of 32% after 1 year since diagnosis, 10% after 5 years, 5% after 10 years[37]. With respect to intestinal cancer morbidity cases, we have taken a percentage survival of 76% after 1 year since diagnosis, 59% after 5 years, 57% after 10 years[38]. Based on these time periods, the net present value (NPV) of average future medical costs per lung cancer case is estimated at €29,948 in 2021 prices, using a 4% future discount rate. The NPV of average future medical costs per intestinal cancer case is estimated at €82,287 in 2021 prices. It is noted that a large percentage of people survive intestinal cancer after a period of 10 years and any stream of health care costs incurring after that is not incorporated in our calculations. However, such costs are not likely to be relevant considering that those surviving after such a long period of time can either be considered as definitely cured or probably only in need of a small degree of medical attention.

The valuations of mortality and morbidity were multiplied by the estimated number of additional cancer cases, fatal and non-fatal, that can occur in the applied for use scenario. The basic calculations for the value of an excess cancer case are presented below:

(3) $(\pi \times (€\ 3{,}970{,}000)) + (\sigma \times (€\ 470{,}000 + €29{,}948)$ = Total lung cancer costs

(4) $(\delta \times (€\ 3{,}970{,}000)) + (\eta \times (€\ 470{,}000 + €82{,}287))$ = Total intestinal cancer costs

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[37] These values are based on a study conducted by Cancer Research UK on adults aged 15-99 in England and Wales. https://www.cancerresearchuk.org/health-professional/cancer-statistics/statistics-by-cancer-type/lung-cancer/survival.

[38] These values are based on a study conducted by Cancer Research UK on adults aged 15-99 in England and Wales from 2009-2013. https://www.cancerresearchuk.org/health-professional/cancer-statistics/statistics-by-cancer-type/bowel-cancer/survival#heading-Zero

4.3.5.1.1 Predicted value of excess cancer cases for the Applied for use scenarios: workers directly exposed

As explained in the previous section, exposure to Cr(VI) for the worker population occurs via inhalation and can lead to lung cancer. Total excess cancer risk cases are calculated to reflect differences in activities, task allocation and exposure levels across the site. The number of excess risk cases are calculated by multiplying the number of workers exposed in each task by the value of the excess lung cancer risk.

Table 4-16 applies the economic value of the associated health impacts to these additional statistical cases of cancer to generate the total economic damage costs of the excess lung cancer cases. Under the continued use scenario, the present value costs are **€137,420 for the EEA and £146,594 for the UK**, based on the assumption that chromate-based slurry coatings continue at the current level of use over the entire review period; this will lead to an overestimate of the impacts as the sector transitions to the alternatives over the 12-year period.

Table 4-16: Present value and annualised economic value of mortality and morbidity effects to workers (discounted over 12 years @4% per year, 20 year lag, figures rounded)

	EU Workers		UK Workers	
	Mortality	Morbidity	Mortality	Morbidity
Total number of lung cancer cases	4.29E-02	1.14E-02	5.15E-02	1.37E-02
Annual number of lung cancer cases	3.58E-03	9.51E-04	4.29E-03	1.14E-03
Present Value (PV, 2024)	€ 133,227	€ 4,193	€ 159,873	€ 5,031
Total PV costs	**€ 137,420**		**€ 164,904 (£146,594)**	
Total annualised cost	**€ 14,642**		**€ 17,571 (£15,620)**	

Source: Derived estimates from responses to the SEA questionnaire, Eurostat data and CSR

4.3.5.1.2 Predicted value of excess cancer cases for the applied for use scenarios: man via the environment

Exposures for local workers, local and regional population can arise from inhalation exposures leading to lung cancer or oral exposures (drinking water) leading to intestinal cancer.

Table 4-17 applies the economic value of the associated health impacts to the additional statistical cases of cancer for the general population (humans via the environment) to generate the total economic damage costs of the excess cancer cases. Under the Continued Use scenario, the present value costs are roughly **€696,991 for the EEA and £743,634 for the UK**, based on the assumption that slurry (diffusion) coatings continues over the entire review period at 2024 tonnages; as indicated above, this reflects an overestimate of the levels of exposures as use declines with a transition to the alternatives over the 12 year period.

Table 4-17: Present value and annualised economic value of mortality and morbidity effects to the general population, local assessment (discounted over 12 years @4% per year, 20 year lag, figures rounded)

	EU General Population		UK General Population	
	Mortality	Morbidity	Mortality	Morbidity
Total number of cancer cases	2.17E-01	6.93E-02	2.61E-01	6.93E-02
Annual number of cancer cases	1.81E-02	4.81E-03	2.17E-02	5.77E-03
Present Value (PV, 2024)	€ 674,090	€ 22,902	€ 808,908	€ 27,482
Total PV costs	**€ 696,991**		**€ 836,390 (£743,634)**	
Total annualised cost	**€ 74,266**		**€ 89,119 (£79,238)**	
Source: Derived estimates from responses to the SEA questionnaire, Eurostat data and CSR				

4.3.6 Human health impacts for workers at customers sites

Slurry coatings with chromates results in no hexavalent chromium being present on the end parts or products. As a result, workers in downstream life cycle stages are not exposed to Cr(VI) through slurry coatings.

4.3.7 Impacts on environmental compartments

Releases to the environment are governed by, and comply with, local worker and environmental regulatory requirements. Waste management is described in further detail within the CSR. Exhaust air is released via stacks, and emitted air is treated in scrubbers or by air filters before being released to the ambient air. There are no direct releases to soil and solid waste materials containing Cr(VI) are classified and treated as hazardous wastes according to EU and national regulations. Any solid or liquid waste is collected and forwarded to an external waste management company (licenced contractor) for disposal as hazardous waste.

No environmental assessment is carried out for the following reasons:

- Chromium trioxide has not been identified as a substance of very high concern in relation to their effects on organisms in the environment;
- Releases to environmental compartments from formulation activities are low due to the volumes used and the use of filtration systems; and
- Cr(VI) from chromium trioxide is expected to reduce to Cr(III) under most environmental conditions, thus limiting any potential impact of Cr(VI) to the immediate vicinity of the source.

Environmental impacts are also described as part of the non-use scenario, see section 4.7.4. Although the continued use scenario will see ongoing release to the local environment for several years, the use may result in a lower environmental impact than the impacts as part of the non-use scenario.

4.3.8 Compilation of human health and environmental impacts

4.3.8.1.1 Environmental impacts

Environmental impacts have not been calculated.

4.3.8.1.2 Human health impacts - Worker population

Human health impacts from the formulation activities are compiled in the table below.

Table 4-18: Summary of additional statistical cancer cases for human health

	Excess lifetime cancer risk	Number of exposed people	Estimated statistical cancer cases	Value per statistical cancer case	Monetised excess risk
EEA - Workers					
Directly exposed workers	2.00E-03 - 1.22E-04	120	1.23E-01	€3.97 million	€ 137,420
Incidentally exposed workers	8.52E-04	30	2.56E-02		
EEA - General population					
Local	8.50E-06	188,600	1.27E+00	€3.97 million	€ 674,090 (£599,280)
UK - Workers					
Directly exposed workers	2.00E-03 - 1.22E-04	144	1.47E-01	€3.97 million	€ 164,904
Incidentally exposed workers	8.52E-04	36	2.42E-04		
UK - General population					
Local	8.50E-06	226,320	1.52E+00	€3.97 million	€ 808,908 (£719,136)
Regional	Regional assessment not performed				
Latency (years)	A latency period of 20 years has been assumed here for both lung and bladder cancer				

4.4 Non-use scenario

4.4.1 Response from the industrial gas turbine supply chain

It is important to explain the criticality of identifying a solution that meets the requirements of the different turbine components and one that and can be implemented globally to the extent possible.

In the event that authorisation is not granted, there would be significant impacts on jobs, turnover and the competitiveness of industrial gas turbine manufacturers and the related supply chains (this will include impacts on existing formulators, raw material and industrial gas turbine component suppliers, OEMs, applicators/MROs, existing industrial gas turbine users, forthcoming industrial gas turbine users (those with existing orders) and society). Several key facts and assumptions should be taken into consideration should authorisation not be granted:

- Alternative products, that would allow a successful and smooth substitution, are currently in the process of being identified and will be implemented in the future. However, the testing timelines as part of R&D phases are long.
- In the event of a refused authorisation, EEA and UK OEMs may lose a significant part of their existing market share whereas competitors outside of the EEA and UK who are not subject to the requirements of authorisation may (overtime) replace this market share.

- The market losses and related financial penalties may lead to closure of some production lines and facilities involved in the industrial gas turbine supply chain.
- The EEA and UK will become more dependent on industrial gas turbines being manufactured and maintained outside of the EEA and UK, although some of this market could be regained if an alternative is identified and is able to be implemented at a later date.
- If the alternative(s) does not offer a similar level of technical performance, EEA and UK OEMs may be at a disadvantage compared to those located outside of the EEA and UK as industrial gas turbines manufactured by these OEMs may offer superior technical performance. Therefore, these turbines may be able to operate for longer, with less down time and lower MRO costs than those manufactured by EEA and UK OEMs.

4.4.2 Summary of the consequences of non-use

The inability of companies to undertake slurry coating activities across the EEA and UK using one or more of the chromium trioxide formulations would entail severe consequences. This use is critical to corrosion protection, heat resistance and the other key functionality across a broad range of industrial gas turbines and related components. This includes application to newly produced turbine components and for ensuring on-going corrosion protection, and other beneficial properties, following maintenance and repair activities.

If slurry coatings were no longer authorised and where qualified and certified alternatives are not available, design owners (i.e. OEM companies) would be forced to re-locate some or all of their component production and coating activities outside of the EEA or UK. This would have subsequent effects for other parts of the industrial supply chain, as summarised below.

A refused Authorisation would have impacts on the EEA/UK formulators and the critical set of key functions provided by slurry coatings would be lost to industrial downstream users in the EEA and UK

Due to certification requirements, downstream users would be forced to undertake chromate-based slurry coatings activities outside the EEA/UK or shift to suppliers outside of the EEA/UK

OEMs would shift a proportion of their manufacturing outside the EEA/UK due to the need for slurry coatings. It would be inefficient and costly to transport components and products outside the EEA / UK for coating only (and especially so for touch-up repairs)

Although OEMs may have some ability to shift their production activities outside the EEA / UK, this would result in the loss of profits and jobs

Applicators/MRO's in the EEA / UK would be forced to cease slurry coatings treatments, leading to relocation of this and related activities with consequent impacts on profits and jobs

Relocation of MRO activities would cause significant disruption to industrial gas turbine users

Inefficient and costly supply chains, including MRO activity, may impact downstream users' activities as well as increase their costs

WIDER IMPACTS

Industrial actors such as the oil & gas industry, power generating companies, utility providers and manufacturing companies etc. would face downtimes in power/heat generation

Non-industrial actors such as districts, hospitals, universities, residents, etc would face downtimes in power/heat generation

#C, D, E

Figure 4-6: Impact of relocating business outside the EEA and UK

As indicated in the figure above, because slurry coatings must be applied promptly to protect against corrosion and, depending on the follow-on process to ensure the next process step is successful, there would be significant subsequent effects for other parts of the supply chains. The most likely outcome would be the relocation of large portion of the value chain (production, repair and maintenance) outside of the EEA and UK. This non-use scenario would still require chromium trioxide formulators to continue to produce relevant formulations, this point is discussed further in section 4.7.3. As OEMs are committed to the substitution of chromium trioxide, moving production and applicator/MRO activities outside of the EEA and UK would likely be a relatively short term and expensive option whilst a proven alternative is being identified. However, once these activities have been relocated outside the EEA and UK as part of a refused authorisation, these activities may not return to the EEA and UK.

Once an alternative has been identified for the industrial gas turbine industry, it is expected that the global gas turbine industry will likely move to the same or a similar solution as part of a move away from chromates.

In a non-use scenario, where both EEA and UK applicators and MROs are no longer able to use chromium trioxide product formulations, this would impact the existing applicator/MRO market in a relatively short amount of time. This would have severe impacts on OEMs as it is very unlikely that there is enough available capacity outside the EEA and UK to replace this lost capacity. Applicators outside of the EEA and UK are also likely to have existing orderbooks for several months. OEMs typically require the applicator/MRO to pass internal certification requirements, a process that can take up to three years to complete. This impact will have severe impacts on OEMs which will likely face penalties, fines and liquidated damages, this point is discussed further in 4.7.1.1.

Therefore, although relocation of businesses is a realistic option, alternatively, OEMs could look to switch early to a promising research and development candidate that could continue to be coated by EEA and UK applicators/MROs. However, although candidates have been subject to several tests, a proven alternative has not yet been successfully identified. Substituting to an unproven alternative would create business risks to OEMs and their downstream customers as the unproven alternative may not offer a similar level of technical performance and this could have severe consequences on OEMs, customers and society.

4.4.3 Identification of plausible non-use scenarios

Discussions were held with OEMs and applicators/MROs to establish what the most likely non-use scenarios would be due to the non-authorisation of slurry coatings. These included discussions surrounding the subsequent effects from the loss of coatings, how activities could otherwise be organised and what options could be available to the companies.

The identification of a single plausible non-use scenario covering all of the different actors in the supply chain is challenging. As previously described, it is the OEMs who typically define the coating product(s) that should be applied to components. It is also typical that OEMs also hold service contracts with their downstream customers. It is therefore unlikely that an industrial gas turbine customer will specifically choose how to recoat their turbine.

As described in the substitution plan (section 4.2.3), OEMs are likely to be at different stages of R&D and their timelines for implementing alternatives and the impacts of the non-use scenarios are also likely to be different. Therefore, a blend of both non-use scenarios may occur and a summary of the impacts under these scenarios is shown in the following tables.

Table 4-19: "Relocating application activities outside the EEA and UK" for the industrial gas turbine supply chain – timeline

Year number	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12
Formulator (IP)	Continue to formulate, export more products to non-UK and non-EEA markets. Sales may have reduced due to lack of capacity in the applicator supply chain.				Formulation continues but sales may begin to fall due to the implementation of alternatives for some turbines.				For some of the more challenging turbine sectors, alternatives may have been identified, if so, these are likely to begin to be implemented leading to a steady reduction in the demand of chromium trioxide products.			
Suppliers of other raw materials and components	Potential disruption due to market changes may see a fallen in demand for raw materials and components.			Markets changes may lead to more business activities being relocated outside of the EU/UK and the supplier and component market may also relocate over time.								
OEMs	Highly disruptive market changes. Significantly impacting industrial gas turbine manufacturing operations and existing orders and contracts. OEMs would be dependent on new applicators (not in the EEA/UK) being able to fulfil their existing demands, this is unlikely to be achieved for at least three years. Currently there is insufficient capacity available in the applicator market. New applicators are typically required to complete several certification stages where the coating is applied to several different components to ensure the coating is applied aligned with the OEMs specifications. This could take at least two years to complete before any jobs could be placed with the applicator. If a lack of capacity remains in the market the OEMs components may not be treated for several months. The components would have to be inspected prior to the completion of the turbine manufacturing or servicing, if the quality of the coating is insufficient the components would need to be recoated. These challenges are likely to involve large fines and liquidated damages claims being made against OEMs which would pose a risk to their business operations.				EEA/UK based OEMs would continue to face challenges for several years due to the additional complications and supply chain complexities. OEMs may take the business decision to move some of their existing UK/EU operations closer to the new application and MRO sites.				When alternatives have successfully be identified, OEMs will switch to these within the UK/EU where this demand can be fulfilled by UK/EU applicators. If some OEM operations have permanently move outside the UK/EU, these OEMs will have the ability to choose between chromate solutions or alternative solutions.			
Applicators and MROs (main	Significant loss of business activity for those applicators where their main business activities are connected to slurry coating activities. These applicators						In the longer term the UK and EU MRO sector might be more widely impacted from the loss of large applicators and changes to the MRO					

Table 4-19: “Relocating application activities outside the EEA and UK” for the industrial gas turbine supply chain – timeline

Year number	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12
users of chromium trioxide)	may need to change their business activities if they are to remain operational. Applicators with smaller business activities connected to slurry coating activities would be less impacted. Transportation costs and environmental impacts would also increase due to sending turbines to non-UK/non-EEA applicators. Export controls in place for some countries will likely impact supply chains.						market. The closing of UK and EU MRO businesses for several years may mean the UK and EU are more reliant on MRO activities in other parts of the world.					
Industrial gas turbine users	New industrial gas turbines and those needing maintenance in the following three years will faces significant disruption due to lack of capacity and quality control issues in the supply chain. Businesses would face significantly extended downtime putting pressure on their operations leading some to go out of business.			Some of the applicator supply chain challenges may start to be resolved. However, the additional supply chain complexity leads to extended lead times in the supply chain. Businesses would still face extended downtime putting pressure on their operations.					Supply chains would have become more efficient. Some users may have made alternative business investments to cope during the extended down time or switch to an alternative industrial gas turbine manufacturer.			
Society impacts	Disruption due to impacts on industrial gas turbine users. Impacts would involve some job losses, the disruption to some services and the potential for price increases for certain finished goods and services.			Disruption is likely to continue during this period, but the impacts might be less significant than in previous years as supply chains have readjusted.					The development and implementation of alternatives along with the continued development of supply chains should mean the impacts continue to reduce.			

Table 4-20: “Switching to an unproven alternative” for the industrial gas turbine supply chain – timeline

Year number	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12
Formulator (IP)	Continue to formulate, export products to non-UK and non-EEA markets. Sales of chromium trioxide products may significantly reduce due to the loss of UK and EU sales.				Formulation continues but sales may begin to fall due to the implementation of alternatives for some turbines.				For some of the more challenging turbine sectors, alternatives may have been identified, if so, these are likely to begin to be implemented leading to a steady reduction in the demand of chromium trioxide products.			
Suppliers of other raw materials and components	If the unproven alternative is less effective, demand for raw materials and components may increase for new gas turbines and existing gas turbines due their decreased service life and the need for them to be maintained more frequently.								The demand for raw materials and components may decrease over time following further R&D and refinement of an alternative(s).			
OEMs	For several years there will be a period of high risk for the OEMs and this may also impact industrial gas turbine users. Switching to an unproven alternative will require additional monitoring of turbines and additional servicing in the short term while the alternative(s) is effectively being tested in real-time by several different customers. If the unproven alternative is less effective, then the operational running hours between MRO activities may significantly reduce and there is increased likelihood of turbine damage and destruction. There are likely to be challenges associated with a lack of capacity at applicator sites to cope with the additional MRO demand. Existing contractual requirements are likely to lead to large fines and liquidated damage claims being made against OEMs which would pose a risk to their business operations. OEMs may need to conduct ongoing R&D over several years if the unproven alternative is not suitable. If the unproven alternative is identified as being successful (i.e. it offers a similar level of performance as the existing solutions), it will be fully implemented and operations will continue as normal.											
Applicators and MROs (main users of chromium trioxide)	If the unproven alternative is less effective, demand for applicator services may increase for coating new gas turbines components and recoating of existing gas turbines components due to their decreased service life and the need for them to be maintained more frequently. However, the increased need for applicator services is built on the basis that OEMs survive the period of high risk, if OEMs leave the market (or move the application outside of the UK/EU) the demand for some related applicator services may reduce significantly.									The demand for applicator services may plateau over time following further R&D and refinement of an alternative(s).		
Industrial gas turbine users	The impacts on industrial gas turbine users will depend on the success of the alternative. There are several risks for users, shorter running time and the increased need and cost for MRO activities will result in more downtime. A lack of capacity in the applicator supply chain may exacerbate this situation. This will likely have an effect on several industries and services. The damage or destruction of turbines may have significant impacts on the business/service. Implementing alternative solutions or backup solutions is likely to be				The impacts on industrial gas turbine users will depend on the success of the alternative and any other alternatives being investigated. Although this risk may continue for several years (shorter running time and the increased need and cost for MRO activities, the risk of damage or destruction of turbines, and the costly implementation of alternative solutions or backup solutions) the applicator market may have grown to reflect the increase in market demand for these services. If the unproven alternative is identified as being successful,					Some users may have made alternative business investments to cope during the extended down time or switch to an alternative industrial gas turbine manufacturer. If the unproven alternative is not identified as being successful, ongoing R&D by OEMs may have identified a successful alternative		

Table 4-20: “Switching to an unproven alternative” for the industrial gas turbine supply chain – timeline

Year number	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**	**Y6**	**Y7**	**Y8**	**Y9**	**Y10**	**Y11**	**Y12**
	costly. If the unproven alternative is identified as being successful, then operations will continue as normal.				then operations will continue as normal.					which will be implemented over a number of years.		
Society impacts	Disruption due to impacts on industrial gas turbine users. Impacts would involve some job losses, the disruption to some services could be significant and there is the potential for price increases for certain finished goods and services. If the unproven alternative is identified as being successful, then there are unlikely to be any significant impacts to society.									Disruption is likely to continue during this period, but the impacts might be less significant than in previous years as supply chains have readjusted.		

4.4.3.1 Alternative non-use scenarios

In addition to the main two non-use scenarios set out above, the following non-use scenarios were considered in case of a non-granted authorisation for the use of IP's chromium trioxide products for DUs:

1. OEMs removing from their product portfolios industrial gas turbines coated with IP's chromium trioxide-based formulations;
2. Leaving key components of industrial gas turbines uncoated;
3. Discontinuation of industrial gas turbine production activities within the EEA/UK and buying finished turbines from outside the EEA/UK to sell them to their customers;
4. Permanent discontinuation of the whole turbines business activities (complete closure of the business); and
5. Buy chromium trioxide formulations from outside the EEA/UK

These four non-use scenarios (NUS) were discarded for the reasons set out below.

Alternative NUS 1 – Removal of turbines coated with chromium trioxide-based formulations from the product portfolios of OEMs would lead to the complete and potentially permanent closure of the business operations of relevant OEMs as all turbines are presently coated with chromate solutions.

Alternative NUS 2 – Leaving key components uncoated within the industrial gas turbine is seen as presenting an unacceptable business risk to the OEMs and their customers. Leaving these components uncoated is not possible as it would mean that these components will suffer corrosion issues that would completely reduce the performance, service life and overhaul capabilities of the industrial gas turbine. In challenging environments, the complete replacement of industrial gas turbines would need to take place on a more regular basis, the cost for the costumer would be significant and the risk to business operations from the failure of the turbine would be significantly higher than turbines with coated components.

Alternative NUS 3 – Permanent discontinuation of turbine OEM production activities within the EEA/UK and buying finished turbines from outside the EEA/UK was ruled out as in this scenario the OEMs would simply become resellers and the downstream customers will prefer to buy directly from the manufacturers located outside of the EEA/UK.

Alternative NUS 4 – Permanent discontinuation of the whole turbines business activities is not an option as a complete closure of the business would entail major socioeconomic impacts all along the supply chains with massive profit losses and dismissals.

Alternative NUS 5 – Buying formulations containing chromium trioxide from outside the EEA and UK was ruled out, the use of imported SVHC's by downstream users within the EEA[39] and UK[40] would still require authorisation.

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[39] https://echa.europa.eu/support/getting-started/importer

[40] https://www.hse.gov.uk/reach/svhc-overview.htm

4.4.4 Conclusion on the most likely non-use scenario

The assessment of the most likely non-use scenario is driven by the responses of the OEMs to the non-use scenario. They are the key stakeholders that carry out the R&D and testing (sometimes in collaboration with chemical formulators) to determine whether an alternative is technically feasible, qualify and gain internal approvals for components to use the alternative(s) and then certify their existing (and any new) applicators/MROs against its use. In some cases, OEMs also assist their customers install, run and maintain the industrial gas turbines as part of a service package.

As a result, the most plausible non-use scenario for OEMs will drive the most likely non-use scenario for the sector as a whole. The most likely scenario is therefore a mix of the following two scenarios:

1. NUS 1: OEMs would relocate some of their coating activities conducted by applicators/MROs outside the EEA and UK.
2. NUS 2: Due to supply chain challenges associated with the scenario above, OEMs may consider implementing an unproven Cr(VI)-free alternative that is currently being tested as part of R&D programmes.

In the short term at least, i.e. 2 – 4 years, the challenges and disruption would result in a loss of revenues and profits from sales in the EEA and UK. Over the longer term, some of the market may return to the EEA and UK but it is also likely that a significant proportion will have relocated more permanently. Using an unproven alternative will entail all the functional issues described in the paragraph on the socio-economic impacts on turbines' manufacturers and their customers.

1. Any OEMs directly involved in onsite slurry coatings would move, at least in the short term, the coating operations outside of the EEA/UK. In the short to medium term a significant proportion of their manufacturing operations with move outside the EEA and UK, with the consequent loss of significant levels of turnover and employment. In particular, they will be moving those manufacturing activities reliant on the use of slurry coatings where there is no qualified alternative or where implementation across suppliers after qualification and certification have been achieved is expected to require several years after the end of the current review period.

2. OEMs who do not carry out slurry coatings themselves, i.e. those who using an existing EEA and/or UK applicator, may still move some of their manufacturing operations outside the EEA and UK due to the desire to have certain treatment, production and assembly activities co-located within a region (i.e. to form clusters). This would facilitate the integration of manufacturing activities and associated coating and MRO activities. As a result, there would be losses in turnover and employment associated with these companies also relocating.

3. As OEMs shift their own manufacturing activities outside the EEA and UK, they will have to carry out technical and industrial qualification of new applicators/MROs (and other suppliers) or of any EEA and UK suppliers moving to a new location, to ensure they have the capability to deliver coatings and other services to stringent internal certification requirements. This would then be followed by a ramping up of services in order to meet the manufacturing and applicator/MRO objectives.

4. In some cases, these newly located supply chains may have been developed using applicators who have moved operations from the EEA and/or UK to new countries in order to continue supplying the OEMs. Those applicators/MROs that undertake surface treatments for sectors other than industrial gas turbines, and also those using non-chromate-based alternatives, are less likely to cease activities in the EEA and UK and hence as a group these would be associated with a reduced level of profit losses. It must be recognised that this level of turnover loss implies that some companies losing a high percentage of turnover would still be able to cover their fixed costs and to remain financially viable.

5. MRO sites that carry out slurry coatings as part of their services will also be severely hit and the larger operators indicated that they will most like cease trading, the prospect of moving operations outside the EEA and UK is possible but unlikely. This will likely have a big impact due to the need to maintain vertical integration of all MRO activities that are carried out.

6. The re-location of MRO activities will have consequent impacts for the customers of OEMs, [redacted] #C, D, E and other sectors who are dependent on the MRO operators for other activities.

7. There is the prospect of significant impacts to industrial and non-industrial users of gas turbines as well as impacts to society [redacted] #C, D, E.

8. If costumers of OEMs are impacted, for example due to delays in their orders, longer turbine downtime, a shortening in the life expectancy of the turbine or the failure of the turbine, customers may seek financial compensation from the OEMs in the form of fines, penalties or liquated damages. These additional costs may be exacerbated by impacts along the supply chains and may result in significant losses for the OEMs. Although this activity may involve customers within the EEA and UK being compensated, which would result in a redistribution of finances internally, several OEMs are likely to have a significant number of customers located outside the EEA and UK, therefore in several situations any compensation would be redistributed outside the EEA and UK.

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

The justification for this NUS takes into account the following factors. Although OEMs are working on substitution of chromium trioxide slurry coatings, the R&D is ongoing and not all components will have completed the R&D programmes, alternatives will not have been certified with existing applicators across the supply chains and neither will alternatives have been implemented by September 2024. Many will require a further 12 years to have fully implemented alternatives across all components/final products in their EEA and UK supply chains. Although alternatives for some uses of industrial gas turbines may be implementable in a shorter timeline, a suitable or "generally available"[41] alternative is not available for those industrial gas turbines operating in the more challenging environments.

As noted previously, because of the complexity of the supply chain, and the close working partnerships that exist, a decision by an OEM to relocate parts of their manufacturing activities will likely result in the supply chain relocating to keep proximity. Such relocation would involve not just applicators, but the associated pre- and post-treatment activities due to the potential for corrosion of unprotected surfaces during transport to another place. The impacted operations and socio-economic impacts to industry under the non-use scenario are therefore likely to go far beyond production of just the specific components that require slurry coatings.

Applicators/MROs will be similarly affected. It is technically not possible (or economically feasible) to carry out repairs to large components outside the EEA and UK, and then ship it back for reassembly into a final product in the EEA and UK. Apart from the fact that the surface of the component could be damaged during transport, adding to the technical infeasibility of this situation, the very tight turnaround times and budgets are impossible to hold in such a scenario.

Finally, although this is considered the most plausible scenario, OEMs note that the obstacles that would have to be overcome may make it overly optimistic. The infrastructure of the sector is based in part around manufacturing clusters or hubs, with smaller suppliers located around the sites operated by the larger OEMs or larger applicator/MRO sites. Not all of these smaller sites, including those of critical suppliers, would be able to shift their activities outside the EEA and UK, leading to OEMs having to create entirely new supply chains outside the EEA and UK. This scenario also implies a huge economic investment would be carried out by the OEMs as well as their EEA and UK suppliers. This level of investment is unlikely to be feasible and hence the OEMs would be likely to cease manufacturing activities until the new industrial facilities were in place and ready to operate outside the EEA and UK.

4.5 Societal costs associated with non-use

4.5.1 Economic impacts on applicants

Under the non-use scenario, IP (the formulator of the slurry coating products) would be impacted by the loss of sales of their chromium trioxide formulations (these impacts are described in the UK formulation application). Under the non-use scenario, OEMs and applicators/MROs will be the main parties that are directly impacted. At the specific supplier level, these impacts may vary in their significance, as the importance of the coatings contacted with the business activities and their revenues varies across the suppliers.

In the short term (i.e. first 2 years under the non-use scenario), the losses will be in the order of tens to hundreds of €/£ millions per annum for the supply chain.

Over time, as consumption of the chromium trioxide formulations reduces in line with companies' substitution plans, sales and hence revenues associated with these chromium trioxide formulations

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

will continue to decrease. However, the formulators producing the chromate-based slurry coatings formulations may also be the same companies that will produce the chosen alternative(s) formulation(s). As a result, sales of alternative formulations, once R&D is complete and they are certified and implemented across value chains, would be expected to offset profit losses from declining demand for the chromate-based formulations.

Economic impacts on some of the main downstream users are described below.

4.5.1.1 Economic impacts on OEMs

4.5.1.1.1 Introduction

The use of protective coatings in has two distinct function/benefits, firstly they provide enhanced protection against corrosion and oxidisation and secondly, they provide performance benefits when applied to components related to the gas flow i.e. blades. As such the impact of removing coatings from an industrial gas turbine, specifically from the compressor, results in a balancing act between maintaining current performance levels, both in terms of efficiency and emission, versus maintenance/service/repair intervals and cost.

Coatings are also used to provide a smoother finish to components, this helps reduce the build-up of contaminants that would otherwise impact gas flow that in turn degrades turbine performance. Options to mitigate this affect at a manufacturing level would be the application of enhanced polishing techniques but these are costly, difficult to perform and provide no protection from corrosion (which is critical for several operational environments). Incremental mitigations could be gained through greater filtration techniques at the point of air intake, however based on the current efficiency of high-efficiency particulate absorbing (HEPA) filtration the performance gains would be marginal and these would be greatly influenced by geographical and environmental conditions.

Another mitigation could include greater wash cycle requirements, however these interventions are known to work best on coated components (where a coating provides a smoother surface which is easier to clean than a rough one). Therefore, this mitigation is unlikely to yield significant results. This mitigation activity would also have a direct cost impact to the customer, a significant impact would be the associated lost operational time. A wash cycle is likely to last up to 8 hours per wash, additional costs to the business would include staff time, increased supplies of cleaning solutions and demineralised water. The disposal of grey water would also need to be considered.

In addition to coatings protecting components from corrosion, they help to extend servicing timelines. The service timeline varies between different OEMs and several factors such a geographical and environmental conditions will be factored into the suggested servicing timeline. For some OEMs the typical expectation between a significant overhaul is around 8 years. With inferior coating solutions the service life might be cut to 4 years or less. This service could result in the requirement to replace blades and other components much earlier than normal. Given that any overhaul activity relating to major items inevitably leads to the replacement of associated components, due to single use and or damage due to physical disturbance of parts, this could lead to significantly increased costs due to scrappage.

Given that service life could be at least halved, it can therefore be expected that inspection intervals, typically carried out at around at 8,000 hours / annually, could also be halved to 4,000 hours. It is highly unlikely that these costs could be fully absorbed by those OEMs that offer service packages with their turbines, therefore these costs would likely have to be passed on to the turbine customer. Although this could be viewed as an improved revenue stream for an OEM, the perception of decreased reliability, poorer turbine performance and additional costs for downstream users would not be a benefit.

If the time between compressor overhauls was maintained at the current intervals, but the turbine was fitted with poor coating solutions to compressor components, then the turbine would have to be run with more corrosion damage and blade fouling than is currently acceptable. This leads to compressor efficiency loss and increased fuel burn.

In order to reduce the risk of oxidisation to hot components running in a turbine without optimal coatings, whilst aiming to maintain the existing service life, this may be achieved by reducing the combustion and turbine entry temperatures. The impact of this would be a lower power output from the turbine, decreased turbine efficiency and increased fuel burn. It is also highly likely that this would result in significantly increased emissions from the gas turbine. This is explained further in section 4.7.4.

Due to current legislative drivers to reduce emissions within the EEA and UK (also globally) via penalties, this will likely remain a key market driver for existing gas turbine operations and new gas turbine sales, therefore the service life of the turbine is more likely to be sacrificed to meet these expectations despite the increased operating costs to the customer.

It would theoretically be possible to move slurry coating activities outside the EEA and UK due to already existing supply chain sites in other countries and to outsource manufacturing as the supply chain is spread around the world. However, there are several obstacles to such a scenario which would make this economically unattractive even if it is part of the most plausible scenarios. Firstly, the due diligence principle will continue to the apply to supply chain and would be exacerbated in case of relocation outside of the EEA and UK. Secondly, when activities are shifted to another site, there is an inevitable phase of technical and industrial preparation (site design, capital procurement and installation, worker training, pilot trials etc.) and qualification to ensure the sustainability of these activities, including an assessment of the technical capability to deliver coatings to stringent internal certification requirements [redacted] #C, D If coatings are applied insufficiently and fail OEM quality checks the components will need to be recoated as they would otherwise not offer the same level of protection. If industrial gas turbines use insufficiently coated components the performance of the turbine is impacted. These impacts are described in more detail in the following sections.

Moreover, once the qualification phase is over, it is essential to get the right ramp up in order to meet the manufacturing rate objectives.

In the remaining time before the end of the initial review period, even if R&D was to identify a suitable alternative(s), it is not realistic that these will be qualified and certified across all applicators in the remaining time available for all of the components/products. It would require a huge economic investment and there is unlikely to be enough capacity at applicators/MROs to complete the work in such short amount of time, therefore this would significantly affect businesses with detrimental economic impacts. As a result, OEMs have indicated that they probably would be forced to stop application activities within the EEA and UK. In place they would need to use applicators outside of the EEA and UK, if not enough capacity existed, OEMs may need to stop taking new orders and concentrate efforts on servicing their existing customers and contracts until such a time that the new industrial facilities and infrastructure is in place and ready to operate outside of the EEA and UK, with consequent impacts on the entire value chain. Given the current levels of industrial gas turbines in operation and anticipated growth in the sector, this is likely to be catastrophic for industrial gas turbine operations in the EEA and UK (and globally).

4.5.1.1.2 Export controls

In the non-use scenario where applicator/MRO activity is required to continue using chromium trioxide products, this would have to take place outside of the EEA and UK. However, OEMs may be at risk of product export controls that prevent the OEM from being able to continue to supply some of their existing customers.

For example, if coatings took place in the USA, Export Control Classification Number (ECCN) and Export Administration Regulation 99 (EAR99)[42] will apply.

Suppliers of EAR99 items need to perform careful due diligence to ensure the item is not going to an embargoed or sanctioned country, a prohibited end-user, or used in a prohibited end-use. If the proposed export of an EAR99 item is to an embargoed country, to an end-user of concern, or in support of a prohibited end-use, companies may be required to obtain a license.

ECCN is a designation that an item, which can be a tangible or intangible (i.e., software or an industrial gas turbine), is controlled because of its specific performance characteristics, qualities, or designed-end use. Unlike an EAR99 designation, which is a broad basket category, an ECCN is much more narrowly defined and are focused on product categories.

Several OEMs are global companies, their turbines are therefore widely used across the world. Both EAR99 and ECCN have the potential to create additional logistical challenges and delays in a sector where quick turnaround times for the majority of customers is critical. If proprietary coatings are used, this may also complicate the ability to export turbines.

4.5.1.1.3 The impact of coatings failing to meet quality checks and the impact of coating delays

In the event that coatings fail to meet quality checks these will be sent back to an applicator for recoating, this present a challenge and potential cost to the OEM if the delivery of the industrial gas turbine is delayed.

If there is a lack of capacity in the supply chain, this may also cause delays where OEMs are manufacturing new turbines and for those turbines which are undergoing MRO activity. If the MRO timelines for industrial gas turbines is reduced (potentially halving as described above), this potential

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[42] https://www.trade.gov/eccn-and-export-administration-regulation-ear99

change would have a significant impact on the existing MRO supply chain. Although this may have a positive economic impact on increasing the demand for applicator and MRO services, the demand is likely to be higher than the available supply, this will likely lead to price rises and in the short term there may not be enough available capacity to fulfil the demand.

There is therefore a risk of fines, liquidated damages and reputational impacts for OEMs. These are described in more detail in section 4.7.1.1.

4.5.1.1.4 The numbers of new turbines manufactured a year

Over several years supply chains have adjusted to customers industrial gas turbine demands. There are several factors which influence this demand and market growth, expansion and development of industrial and non-industrial uses has increased demand. For example, paper companies have been increasingly using industrial gas turbines in recent years due to several reasons, including:

- Energy efficiency: Industrial gas turbines are more energy efficient than traditional steam boilers (and other forms of energy) and can help reduce energy costs for paper companies;
- Reliability: Industrial gas turbines are known for their reliability and can operate continuously for extended periods of time, reducing downtime and maintenance costs;
- Flexibility: Industrial gas turbines can be quickly ramped up or down to respond to changes in demand, providing more flexibility in the manufacturing process; and
- Sustainability: Industrial gas turbines emit fewer pollutants and other gases compared to steam boilers, helping paper companies meet environmental regulations and reduce their carbon footprints.

The use of industrial gas turbines has enabled some businesses to change their working practises and allowed them to become more efficient and increase production. Overall, the adoption of industrial gas turbines in other sectors for similar reasons reflects a more general trend.

The technical manufacturing capacity of all producers worldwide is estimated to be around 400 turbines a year.[43] The industrial gas turbine market is expected to expand over the next several years.

The additional of new gas turbines adds to the number of existing turbines that will require an initial coating and MRO activity at a later date. Some of the existing older turbines are expected to leave the market over the next several years, but in many situations scrapped turbines will be replace by a new industrial gas turbine.

4.5.1.2 Economic impacts on applicators/MROs

The roles of applicators and MROs are closely related. Applicator use relates specifically to the activity of coating industrial gas turbine components. MRO activity extends beyond coating to other maintenance, repair and overhaul activities. MROs will undertake work either as part of a service plan with an OEM or they are contracted directly by industrial gas turbine customers to undertake MRO activity. MROs take care of the major maintenance requirements within their facilities, these activities

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[43] https://www.turbomachinerymag.com/view/worldwide-gas-turbine-forecast-2

start with disassembling the turbine to assess its condition and create a scope of work that is aligned with the intended future operation of the turbine.

MROs will typically have full, unrestricted access to the latest OEM repair and overhaul procedures, including repair schemes, safety bulletins, build specifications and modifications. A standard overhaul includes refurbishment of all components, from air intakes and compressors, through the combustion section, to the turbine. If a full overhaul is not required or desired, MROs can tailor services to the condition of the turbine, as well as the future operating requirements and length of service period. These options allow customers an opportunity to consider all OEM recommendations, including modifications and service bulletins. This also allows for cyclic life evaluations to be performed, based on comprehensive historical records of similar turbines that are in service.

MROs (and OEMs are part of service plans) are also able to send field specialists and engineers to customers sites to resolve unscheduled repairs. If the turbine cannot be repaired onsite, emergency repair work at can normally be scheduled at an MRO facility.

MROs with full access to all modifications released by the OEM are able to offer approved upgrades and modifications which are expected to enhance performance, reliability, durability, safety, service life and the environmental impact of the turbine. Some MROs are also able to offer turbine testing facilities so that the turbine can be fully tested before it is returned to service.

However, applicators and MROs are highly dependent on the upstream actions taken by OEMs, this includes the R&D being undertaken, decisions on the substitution of an alternative coating product or whether components should continue to be coated with existing chromium trioxide solutions at an applicator/MRO facility outside of the EEA/UK.

OEMs also set their own internal certification and quality criteria for the coating of components and these must be achieved before the alternative is widely implemented. This process can take more than 18 months to three years complete.

The inability to undertake slurry coatings to the requirements set out in maintenance manuals may make application, repair and overhaul services unviable for MROs. There is often no scope for MROs to operate outside the requirements detailed in the OEMs’ service manuals, which are based on the qualified and approved uses of substances and mixtures for coatings. Where these requirements mandate the use of chromium trioxide containing products, then the MRO must use the product as instructed unless the manuals also list a qualified alternative.

If the application of coatings takes places outside the EEA and UK, it is likely that MRO operations will relocate to the same location. This will reduce lead times, logistically and transporting challenges and ultimately it will reduce costs. In turn the OEMs may also relocate some of their sites to these countries.

As a result, those MRO sites which offer the full range of services, including slurry coatings, would no longer be viable and would have to cease operations in the EEA/UK. This is the case for at least three applicators/MROs, which would cease their EEA/UK operations, as a partial service would not be practical or feasible at their sites for the industrial gas turbine customers. Of these companies, one indicated that they would potentially move these operations to North America or elsewhere. At least three applicators/MROs suggested that they could continue to operate as only part of their total turnover comes from industrial gas turbines activities. However, some of these applicators/MROs also offer services for the aerospace sector and these services may also be subject to authorisation.

Large applicators/MROs sites are able to process around 100 turbines per year, medium sites 50 turbines and small/micro companies around 1-10 turbines a year. However, the supply chain is complex, some sites are able to coat specific components rather than perform complete MRO activities, some sites specialise in specific turbines and as the components vary between turbines, therefore some sites keep a stock hold of OEM parts in new and used conditions to minimise customer downtime.

As previously indicated, the technical manufacturing capacity of all producers worldwide is estimated to be around 400 turbines a year[44], a significant proportion of this capacity is expected to take place within the EEA and UK. There are also several thousand industrial turbines currently in use (this also excludes those used in the aerospace and defence sectors), the majority of these are likely to have chromate coatings, while it is unclear how many of these new and existing turbines requiring initial coating and recoating as part of MRO activities each year. The number is likely to be at least 200-400 per year.

The EEA/UK has an establish applicator/MRO supply chain, the non-use scenario will remove this supply chain from the market, it is highly unlikely that enough capacity currently exists in the global applicator/MRO market to replace the combined existing EEA and UK capacity.

4.5.2 Approach to assessing economic impacts

As noted in Section 1, IP are covering the use of their chromium trioxide formulations by downstream users. The downstream OEMs, applicators, MROs, distributors and suppliers of raw materials and other industrial turbine components are likely to be competitors. These interlinkages have been taken into account in the estimation of economic impacts, which have been calculated for the OEMs, and applicators/MROs.

Two separate approaches have been used to estimate the magnitude of the potential economic impacts. Both are based on responses to the SEA questionnaire, with one taking as its starting point the number of jobs that would be lost while the other considers losses in turnover and what these imply in terms of losses in profits.

1. **Estimates based on loss of jobs**: The first approach takes as its starting point the number of jobs that would be lost at the sites of SEA questionnaire respondents, based on their most likely response to the non-use scenarios. This includes loss of jobs directly linked to use of the chromates and losses in jobs at the OEM, applicator and MRO site reliant upon the continuation of their use, i.e. jobs in related manufacturing, assembly, coating and MRO activities. Importantly, it excludes losses in employment at local sub-contractors providing support services. The numbers of jobs lost are multiplied by the average Gross Value Added (GVA) - per job (taking into account variations by role) to provide an estimate of total GVA lost. Personnel costs associated with this GVA are then subtracted to derive the implied losses in operating surpluses per annum.

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[44] https://www.turbomachinerymag.com/view/worldwide-gas-turbine-forecast-2

2. **Estimates based on loss of turnover**: The second approach takes as its starting point the anticipated losses in terms of percentage of turnover reported by the respondents to the SEA questionnaire. Lost operating surplus is then calculated as an average per company based on role in the supply chain and Eurostat data on Gross operating surplus (GOS) as a percentage of turnover[45].

Both of these approaches provide proxy estimates of profit losses based on current levels of employment and turnover. They do not account for foregone future turnover under the continued use scenario due to the inability of the EEA/UK industrial turbine sector to respond to growth in the global demand for turbines as a result of either a cessation in manufacturing activities or their relocating outside the EEA/UK.

The two approaches have been applied to account for uncertainty in the data available from the SEA questionnaire responses. Together they provide an interval, with one estimate acting as an upper bound and the other as a lower bound to the economic impacts.

4.6 Estimates based on loss of jobs (and GVA lost)

The SEA questionnaire collected data on the number of employees who would lose their jobs under the NUS. This includes both those whose jobs directly involve use of the chromates, and those whose jobs would be affected due to a cessation of activities or due to companies moving outside the EEA/UK. To develop conservative estimates, where no response was received an estimate was made (as indicated in **Table 2-3**). There are a wide number of downstream users of IP's chromium trioxide formulations, this includes several aerospace companies (covered by the aerospace application) and this also includes several industrial OEMs, applicators/MROs). The resulting figures collected for the 11 sites are presented in **Table 4-21** below.

The job losses reported by respondents, which range from a few per site where only slurry coatings would cease to all employees in the event of closure are significant:

- Extrapolated out to the total 33 sites expected to be carrying out slurry coatings across the EEA and UK: 20,522 jobs (around 14,545 in the EEA and 5,977 in the UK) due to the cessation of slurry coatings and linked to manufacturing activities across product lines or to the cessation of application and MRO services, including as a result of companies moving operations outside the EEA/UK; and
- In the non-use scenario where an unproven coating is applied, the direct job losses at applicator/MRO sites are unlikely to occur in the short term, however, this option presents a higher risk to OEMs which risks their business activities and may lead to a delay to job losses.

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[45] https://ec.europa.eu/eurostat/databrowser/view/sbs_na_ind_r2/default/table?lang=en

Table 4-21: SEA survey responses and extrapolations on numbers of jobs lost under the non-use scenario

	No. Company Responses		Direct job losses – workers undertaking processes linked slurry (diffusion) coatings		Additional direct job losses – due to a cessation of manufacturing / applicator / MRO activities	
From SEA Survey	**EEA**	**UK**	**EEA**	**UK**	**EEA****	**UK****
Applicator/MROs (7 sites)*	1	6	10	74	20	585
OEMs (4 sites)	2	2	0	0	2,600	2,000
Total (11 sites)	**3**	**8**	10	74	2,620	2,585
Job losses - Extrapolation of job losses under the non-use scenario to the estimated 47 sites undertaking slurry coatings treatments						
Applicator/MROs (33 sites)	15	18	150	222	1,395	1,755
OEMs (14 sites)	10	4	0***	0***	13,000	4,000
Total sites (47)	**25**	**22**	150	222	14,395	5,755
Total EEA direct and indirect across 25 sites			**14,545**			
Total UK direct and indirect across 22 sites			**5,977**			

*Some of the applicator/MRO sites also conduct spraying activities for the aerospace sector

**A UK company applies coatings to new components and applies new coatings to existing turbine components. Directly related to the coating business activity, the company also offers a large range of other MRO services. The extrapolation made for EEA indirect job losses is based on the situation in the UK

***It is assumed that no OEMs conducted spraying operations on site and there would be no job losses associated with manual touch up activities at OEM sites

Table 4-22: GVA losses per annum under the non-use scenario

By role	GVA per worker assumed by role		GVA lost due to direct job losses € million		Additional GVA lost due to a cessation of manufacturing / MRO activities - € million	
	EEA	UK	EEA	UK	EEA	UK
Applicator/MROs (7 sites)	82,200	82,200	0.82	6.08	1.64	48.09
OEMs (4 sites)	73,550	73,550	-	-	191.23	147.10
Total (11 sites)	-	-	0.82	6.08	192.87	195.19
		Total EEA	**€ 193.70 million per annum**			
		Total UK	**€ 201.27 million per annum**			
GVA losses - Extrapolation to the estimated 47 sites undertaking slurry coatings treatments						
Applicator/MROs (33 sites)	82,200	82,200	12.33	18.25	114.42	144.26
OEMs (14 sites)	73,550	73,550	-	-	956.15	294.20
Total sites (47)	-	-	12.33	18.25	1,070.57	438.46
		Total EEA	**€ 1,082.90 million per annum**			
		Total UK	**€ 456.71 million per annum**			
MRO and OEM GVA figures from Eurostat (2019). Numbers may vary due to rounding.						

Table 4-23: Implied GVA-based gross operating surplus losses under the Non-Use Scenario

By role	Total GVA losses - € millions per annum		Total personnel costs associated with lost jobs - € millions per annum*		Implied operating surplus losses € millions per annum	
	EEA	UK	EEA	UK	EEA	UK
Applicator/MROs (7 sites)	2.5	54.2	1.7	37.9	0.7	16.3
OEMs (4 sites)	191.2	147.1	161.3	124.1	29.9	23.0
Total (11 sites)	193.7	201.3	163.1	162.0	30.6	39.3
Operating surplus losses - Extrapolation to the estimated 47 sites undertaking slurry coatings treatments						
Applicator/MROs (33 sites)	126.8	162.5	88.7	113.7	38.1	48.8
OEMs (14 sites)	956.2	294.2	806.7	248.2	149.5	46.0
Total sites (47)	1,082.9	456.7	895.3	361.9	187.6	94.8
MRO and OEM GVA figures direct from Eurostat (2019) for EU / UK as available. Numbers may vary due to rounding.						

The estimated losses in GVA equate to:

- €1,082.9 million per annum across the EEA and €456.7 million per annum for the UK, extrapolated out to the 25 EEA and 22 UK downstream user sites.

For comparison, turnover for the EU A&D industry is around €259 billion[46] per annum, while that for the UK A&D sector is around €57 billion (£50 billion) in 2020.[47] Thus, although these figures appear high for the industrial gas turbine sector, they are considerably lower than the aerospace sector.

In order to convert these GVA losses to an estimate of lost operating surplus (profits), personnel costs for each lost job are subtracted. The results of this calculation are given in **Table 4-23**. Personnel costs are based on Eurostat data for the relevant NACE codes, the average personnel costs by NACE code from Eurostat for OEMs and MROs are adopted in these cases. The estimated (implied) values of lost operating surpluses generated by this GVA-based approach equate to:

- €187.6million per annum across the EEA and €94.8 million per annum for the UK, extrapolated out to the 25 EU and 22 UK downstream user sites.

4.6.1.1 Estimates based on lost turnover

The SEA questionnaire also asked companies to provide information on the impacts that a refused authorisation would have on turnover/revenues. Most companies who responded to the consultation answered this question and the responses provided by the OEMs (as the end customer) and applicators/MROs enable estimates of the likely percentages of turnover lost by role to be developed. These estimates take into account the number of companies indicating that they also carry out activities other than chromate-based slurry coatings for the industrial gas turbine sector, as well as surface treatment and other processes for other sectors. They also account for potential loss in turnover from subsequent manufacturing and assembly activities.

Estimates of lost revenues per site are based on Eurostat data by NACE code specific data for OEMs and MROs. Note that the weighted averages exclude micro-enterprises as few suppliers within the sector will fall into this size category. Gross operating surplus losses are then calculated by applying GOS rate data for the different NACE codes from Eurostat for 2019. The resulting losses are given in **Table 4-24**.

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

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

Table 4-24: Turnover and GOS losses under the Non-Use Scenario – (avg. 10.7% losses across all roles)

	Turnover lost per annum millions		GOS losses per annum millions per annum	
	EEA (€)	UK (£)	EEA (€)	UK (£)
Applicator/MROs (7 sites)	0.3	25	0.03	13.86
OEMs (4 sites)	100	1,000	4.65	46.50
Total (11 sites)	**100.3**	**1,025**	**4.68**	**60.36**
Extrapolation of turnover and GOS losses to the estimated 47 sites undertaking slurry (diffusion) coatings treatments				
Applicator/MROs (33 sites)	70	495	5.91	41.58
OEMs (14 sites)	500	1,200	23.25	55.80
Total sites (47)	**570**	**1,695**	**29.16**	**97.38**

MRO and OEM figures direct from Eurostat (2019) for EU / UK as available.
Some MRO activities are dependent on the application of coatings continuing in the EEA/UK so this business would mostly likely also be lost.

4.7 Comparison of the profit loss estimates

The figures presented in **Table 4-24** are higher than those given in **Table 4-23** for both the EEA and UK. This is considered to be due to the turnover-based estimates taking better account of the loss in associated manufacturing, applicators/MROs, given the importance of chromate-based slurry coatings to both of these sets of companies.

- GVA based approach estimates of lost operating surplus:
  - Losses of €187.6 million per annum for the EEA
  - Losses of €94.8 million per annum for the UK

- Turnover based approach of lost operating surplus:
  - Losses of €29.2 million per annum for the EEA
  - Losses of €97.4 million per annum for the UK

These two sets of figures are used in this SEA to provide lower and upper bound estimates of losses in producer surplus, with the ratios between the two sets of estimates for the different roles shown in **Table 4-25**. It is important to note that these losses apply to commercial enterprises only. No data was provided by any of the raw material providers, industrial gas turbine component providers, [redacted] #C, D, transport & logistic companies or customers of OEMs that are reliant upon the continued use of chromate-based slurry (diffusion) coatings which could be used in this analysis.

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[48] [redacted] #C, D, E

Table 4-25: Comparison of profit loss estimates from the two methods

	Ratio of lost profits based on turnover to lost operating surplus based on jobs (based on €billions lost)	
	EU	UK
Applicator/MROs	0.16	0.85
OEMs	0.16	1.21
Total	0.16	1.03

Offsetting profit losses and impacts on rival firms

The losses in operating surplus given above would result not only from a cessation of manufacturing activities, but also from the premature retirement of existing capital equipment. Some of this capital equipment would be replaced in any event as part of substitution, over the next 4 - 12 years, with any such investment in new equipment would be focused on facilitating substitution (while the capital equipment associated with the continued use of the chromates over the next 7 - 12 years would not be expected to be replaced).

As there are no suitable alternatives which are generally available, following SEAC's latest guidance, consideration has been given to the need to offset the profit losses for downstream users against the potential resale or scrappage value of the sector's tangible EU and UK assets. However, given the potential scale of the impacts of a refused authorisation for the sector as a whole, any possible market for redundant equipment is likely to be overwhelmed by the number of sites ceasing activities, including related processes. As a result, it is not possible to estimate the potential scrappage value of equipment (e.g. spray booths, spraying equipment).

Because this is a sectoral application and the ability to shift to alternatives is driven by qualification by OEMs and obtaining supply chain certification, the issue of potential losses incurred by rival businesses undertaking slurry coatings using alternatives is not relevant. The OEMs determine whether or not there are alternatives that can be used, it is highly unlikely individual downstream users will make their own decisions on alternatives. Furthermore, as previously indicated, IP are applying for use covering their downstream users (OEMs, applicators/MROs) with known suppliers appearing in **Table 2-3**. Within this supply chain competitor OEMs are likely to use similar applicators/MROs. OEMs may also source similar raw materials and other industrial gas turbine components from similar suppliers. Therefore, an overlap is expected between suppliers and service companies. Relationships between the OEMs, suppliers and applicators/OEMs are developed over time and often reflect long-term commitments given the need for OEMs to certify their suppliers and applicators/OEMs in the manufacturing of components. As a result, rival suppliers cannot readily step in and replace their activities.

The economic losses are therefore based on consideration of losses in operating surplus / profits only. These have been estimated over three time periods in line with SEAC's new guidance for those cases where there are not suitable alternatives available in general. Discounted losses over 1, 2, 4, 7 and 12 years are given in **Table 4-26**.

As discussed earlier, these losses are based on Eurostat turnover figures for 2018 (most recently available by company size). They therefore represent an underestimate of the losses in turnover that would arise over the review period under the Non-Use scenario, given the anticipated level of future growth in turnover for the sector due to the importance of the EEA and UK in the global manufacture, maintenance and repair of industrial gas turbines.

Table 4-26: Discounted profit /operating surplus losses under the Non-Use Scenario – Discounted at 4%, year 1 = 2025

	Lost EBITDA/Profit - millions		GVA-based Operating Surplus Losses - millions	
	EU €	UK £	EU €	UK £
1 year profit losses (2025)	29	97	188	95
2 year profit losses (2026)	55	184	354	179
4 year profit losses (2028)	106	353	681	344
7 year profit losses (2031)	175	584	1,126	569
12 year profit losses (2036)	274	914	1,761	890

4.7.1 Other impacts on industrial gas turbines companies

Under the non-use scenario there would be an enormous impact on the industrial gas turbine sector in the EEA and UK, leading to a second wave of negative impacts on the EU market. These impacts have not been quantified here but would include as a minimum:

- Cancelled future orders and loss of contracts for new products if supplies are significantly interrupted;
- Extended durations of MRO activity for products in service leading to increased durations in which industrial gas turbines are out-of-service, with consequent penalties and additional impacts on turnover;
- Increased logistical costs;
- Reputational damages due to late delivery or cancelled orders;
- Labour reduction at suppliers; and
- Availability of spare parts

4.7.1.1 Fines, penalties and liquidated damages

The potential for delays in delivery and servicing can result in fines, penalties and liquated damage claims. In response to the SEA questionnaire, two OEMs shared examples of compensation claims. Due to confidentiality, details of the claims are redacted in the two examples presented below, both claims are in the €/£ 1 - 10 million range. The duration of the delay will impact the total compensation claimed.

Example 1

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Example 2

[redacted]

[redacted]

[redacted]

[redacted]

The two examples above highlight how supply chain risks can have an economic impact on OEMs. OEMs are the companies who hold contracts with their customers, and they are exposed to upstream (formulators, raw materials and component suppliers) and downstream supply chain risks (applicators/MROs, logistics and transport). OEMs typically take several orders for industrial gas turbines which may be delivered over the next 1-4 years (some industrial gas turbines for power generation may have been ordered years in advance for delivery towards the end of the sites construction).

Section 4.5.1.2 describes the impacts on applicators/MROs and the potential capacity within the UK and EEA market.

In the non-use scenarios, applicators/MROs outside of the EEA/UK may need to fill the existing market demand from chromium trioxide coatings or the unproven alternative will likely half (or more) the current operating duration of several turbines causing greater demand for applicators/MROs services.

Table 4-27 sets out different theoretical scenarios and estimate damage claims that OEMs could experience. Some basis assumptions are made in the scenarios, the claims are at the low end of the €/£ 1 - 10 million range (some sectors may have higher penalties written into contracts). The non-use scenarios have similar outcomes, these being a lack of capacity outside the EEA/UK causes delays (logistically and transport delays may also occur, but for simplicity OEM certification and quality delays are excluded) and a switch to an unproven alternative cause an increase in the demand for applicator/MRO services. The scenarios are focused on the estimated cost to the OEM and not the customers, it is assumed that customers do not go out of business or completely switch to an alternative form of power/heat or mechanical drive.

The scenarios can be applicable to individual OEMs as well as the sector as a whole, they are described as follows:

- Scenario 1: This sets out a baseline that might occasionally occur. The occasional complication and supply chain delay may lead to damage claims;

- Scenario 2: This sets out a bad year. This scenario could be experience in the run up to and shortly after the beginning of the non-use scenario;

- Scenario 3-5: These describe increasing challenges. The loss of the EEA/UK applicator/MRO market is unlikely to be quickly replaced by the existing non-UK/non-EEA market, these applicators/MROs are already likely to have existing orders, therefore delays would be expected. The scenarios may happen within the first year of a non-use scenario where OEMs use non-UK/non-EEA applicators/MROs. These scenarios may also represent the non-use scenario after 2-3 years where an unproven alternative is used. In this non-use scenario those existing turbines coated with chromium trioxide formulations would be coming up for MRO activities that were booked in as part of business as usual, while newly coated turbines with the alternative may come back in for MRO activity (particularly those used in challenging environments); and

- Scenarios 6-7: These represent situations where the demand for applicator/MRO services completely outstretches the capacity available causing significant supply chain challenges and in turn risking extended lead times and economic impacts. This scenario may occur 2-5 years after the non-use scenario and the impacts may last for several years.

Table 4-27: The potential for liquidated damages and compensation due to delays

Scenario	Delayed turbine operations			Enough capacity in the market	Delayed lead time (months)	Lead time delay costs (million)	Estimated cost (million)
	New	MRO	Total				
1	5	10	15	Yes	3	1	15
2	10	20	30	Yes	4	1.33	40
3	20	40	60	Challenging	6	2	120
4	40	80	120	Challenging	9	3	360
5	80	160	240	Challenging	12	4	960
6	160	320	480	No	24	8	3,840
7	320	640	960	No	36	16	15,360

Although the scenarios in **Table 4-27** are theoretical, along with the potential liquated damage costs, the scenarios highlight the risks to the existing supply chain. As indicated in section 4.5.1.2, the technical manufacturing capacity of all producers worldwide is estimated to be around 400 turbines a year[49], with a significant proportion of this is expected to take place within the EEA/UK. There are also several thousand industrial turbines currently in use (excluding the aerospace and defence sectors), and at least 200-300 turbines per year are likely to undergoing MRO activity in the UK/EU. Delays in the first year will likely impact the available capacity for applicator and MRO activity the following year which may cause additional impacts and delays for the subsequent years.

It is also important to note that some of the potential alternative solutions described in section 3 may take significantly longer to apply to components than the existing products being used. For example, all of the alternatives in **Table 3-5** would require three coats to be applied to components, it would therefore increase the time to fully coat products and reduce the efficiency of applicators/MROs. This would also reduce the capacity of applicators/MROs which in turn would add to any pressures in the supply chain. In addition to increasing the coating duration and complexity, there will be a related increase in coating costs that will have to be absorbed by OEMs or the supply chain.

To mitigate these challenges industrial gas turbines could be run for longer than typical operating cycles, this would however increase the likelihood of turbine failure or scrappage. If turbines fail, then the liquated damages for OEMs could be larger as would the impact to customers and potentially wider society. Furthermore, the lack of capacity in the market may impact the lead delivery time of new turbines replacing those that have been scrapped. To extend the lifetime of turbines they could be run less efficiently. Although this would extend lifetime and reduce maintenance, this would reduce the power output of the turbine and increase emissions from the turbine.

Annex 3 contains information about industrial gas turbine OEMs that are known to be downstream users, of IP products, and Annex 4 contains information about other industrial gas turbine manufacturers who are likely to continue to use Cr(VI). Although industrial gas turbines with a higher power output (i.e. those used for power generation) may be able to implement alternatives in the shorter term, there are many turbines that are used in more challenging environments where an alternative will take longer to identify and to implement. If there are ongoing impacts to the applicator and MRO supply chain, these impacts will also likely impact the services related to larger turbines.

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[49] https://www.turbomachinerymag.com/view/worldwide-gas-turbine-forecast-2

Other external events and factors may also impact the supply chain and increase the lead time of OEMs. For example, in December 2022 a large fire broke out at an applicators site located in the UK.[50] The fire caused a large amount of damage and operations are unlikely to resume at the site in the short term. [redacted] Although the services of the site are unlikely to be directly relevant to the industrial gas turbine sector covered in this application, the impact of the fire may impact the applicator/MRO supply chain in other ways. Aerospace & Defence companies and industrial users previously relying on this site may need the services of other applicator/MRO sites. [redacted]

Overtime the applicator/MRO market outside of the EEA/UK may grow in capacity to reduce the impact of waiting for an alternative with suitable technical performance to be identified and implemented.

4.7.1.2 Producer surplus loss

As described in the AoA, the applicant considers that this application for authorisation has to be considered as a No-SAGA case. In In line with SEACs guidance note for calculating producer surplus[51], to account for the loss of profit during the requested review period of 12 years, the recommended 4-year period for no-SAGA cases was used in the assessment of the socio-economic impacts.

The following comments are provided in support of a longer timeline for profit losses.

Competition: It is noted that the EU industrial gas turbine market consists of several companies [redacted]. This includes OEMs that are known downstream users of IP, see **Table 2-3**, and OEMs, including some of those in **Table 2-5**, which may need chromium trioxide solutions in the future (see section 4.7.2.6). Applicators/MROs have been applying protective coatings based on OEM's guidance for many years and several of these companies are supporting the application.

Without these OEMs and applicators/MROs, the EEA/UK manufacturing of industrial gas turbines would be significantly negatively impacted. Any new industrial gas turbine manufacturers and applicators/MROs within the UK/EU would need to set up from scratch which would take time in securing the investment required and building the required production facilities.

Market share: As previously indicated, the application is intending to cover the use of IP's products by downstream users in the industrial gas turbine sector. This includes OEMs that are known existing downstream users of IP, see **Table 2-3**, which make up a significant market share and this does not include other OEMs which may need to use the products in the future due to formulators leaving the market.

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[50] https://www.bbc.co.uk/news/uk-england-somerset-64101294

[51] See SEAC/52/2021/03

Therefore, this would mean that a significant market would need to be “reallocated” in the non-use scenario, although there might be some rival firms within the EU who could take on the additional volumes, it is very unlikely this market share could be replaced for several years.

Location: In the event of refused authorisations for IP’s downstream users, for a couple of years a significant number of new and existing industrial gas turbines already in operation would be sent to competitors outside of the EEA/UK for applicator coating and MRO activities. This may also result in some OEMs relocating activities outside of the EEA/UK. Alternatively, if unproven coatings were used, the additional MRO costs and potentially lower technical performance may mean a greater number of industrial gas turbines are imported into the UK/EU by competitors located outside the UK/EU. Refusal of the application covering downstream users would likely mean the UK/EEA is dependent on services/imports for a couple of years or risk the implementation of an unproven alternative. This would involve the UK/Europe being dependent on stakeholders outside of the EEA/UK or risking an unproven alternative for critical national infrastructure and wider industrial and societal uses. This would also increase the level of societal loss as there would be limited alternative suppliers (OEMs and applicators/MROs) that would be readily available within the EEA/UK. In the long-term downstream users may be able to regain some of the market lost.

4.7.2 Economic impacts on the supply chain

4.7.2.1 Introduction

The impacts of the non-use scenario on different EEA/UK companies along their supply chain are expected to be substantial. These companies include the IP’s suppliers of chemicals, raw materials and services, IP’s direct customers (OEMs, coating applicators and MRO activity), IP’s upstream customers and their customers (such as power generators and different industrial and non-industrial actors).

The economic impacts on the supply chain are likely to be significant, these impacts will not only be experienced in the UK/EU, but they will be global.

4.7.2.2 OEMs and applicators/MROs

The impacts along the immediate supply chain have been discussed in sections 4.5.1, 4.6, and 4.7.1.

Any impacts resulting from the need to use applicators/MROs outside of the EEA/UK are likely to increase lead times and the downstream users may not be able to quickly adjust to this demand. Using an unproven alternative may result in negative impacts for the customers using industrial turbines. At a minimum, the initial operational running time of industrial gas turbines will be reduced, and this may also interrupt the existing supply chains. The additional MRO activity would also increase the non-operational down-time of affected turbines and result in unexpected additional MRO costs for the customers.

4.7.2.3 Upstream suppliers and other service providers

There are likely to be negative economic impacts for upstream suppliers of raw materials and other components for industrial gas turbines in the non-use scenario involving the application of chromium trioxide formulations on components outside of the EEA/UK. In this non-use scenario it is highly likely that MRO activity will also relocate to countries where the application/MRO activity is taking place. Over time manufacturing and assembly of turbines may also relocate to these countries. In addition, raw material and suppliers of other industrial gas turbine components in the EEA/UK will lose the turnover and profits related to these existing sales. Logistics, transport companies and other service providers may also lose business due to the changes to the supply chain.

In the non-use scenario where the unproven alternative is implemented, and applicator/MRO activity continues to take place within the EEA/UK, raw material and component and service suppliers may benefit economically from shorter operational running time and extra turbine wear if the unproven alternative does not offer similar technical performance to Cr(VI). In this scenario, logistics, transport companies and other service providers may benefit from additional business due to the extra MRO activity required for a period of several years until an alternative with similar technical performance is identified and implemented.

4.7.2.4 Customer uses

There are several reasons why industrial gas turbines are used. They provide a mechanical drive, simple cycle power generation, combined heat and power generation and combined cycle gas turbines. The latter are designed for maximum efficiency as the waste heat from the gas turbine is recovered and used to drive an additional steam turbine, generating additional electricity.

Gas turbines can be used in different configurations (alone or combined) to produce flexible, reliable and stable production of power and heat. Both the power and/or heat can be produced day or night at any time of the year and in any weather conditions. There are typically four main uses of industrial gas turbines[52]:

1. Stable power, providing steady and efficient power supply as needed. Gas power plants, with the gas turbine at the core, in both simple and combined cycle configuration provide flexible and stable power;
2. Back-up and peak demand power, ensuring the stability of the grid and security of supply thanks to the flexibility and fast response of turbine-based power plants;
3. Storage and security of supply, combining thermal or chemical storage with gas turbines to guarantee the provision of power also in the medium and long-term; and
4. Combined heat and power, achieving maximum fuel utilisation through the simultaneous provision of power and heat – may be with a gas turbine alone or in a combined configuration. The waste heat of the gas turbine is directly used for industrial processes or after driving a turbine to produce additional power, distributed to district heating networks.

Industrial gas turbines can operate with a wide variety of gases and gas qualities. OEMs have also prepared and continue to improve their turbines for the future, this includes of the progressive replacement of natural gas by low-carbon, renewable gases and hydrogen. Both the UK Government and European Commission have set out strategies involving hydrogen, these are the Hydrogen Strategy (HM Government, 2021) and REPowerEU Plan (European Commission, 2022).

Some challenges are associated to the use of hydrogen due to its higher reactivity, which results in increased flame speed, higher autoignition risk due to lower ignition delay time and higher flame

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[52] https://www.euturbines.eu/things-to-know/turbine-applications/power-generation/

temperatures. However, despite these challenges, a number of OEM turbines are hydrogen ready, and some can already use up to 100% hydrogen (ANNEX 3 – Industrial gas turbines).

4.7.2.5 Customer impacts

Industrial gas turbines manufactured by OEMs in the EEA/UK are used by many different customers operating in several different sectors. The OEMs produce a range of different turbines. The customers of EEA/UK OEMs also extend beyond those customers within the EEA/UK, although the turnover and profits of OEMs and applicators/MROs are captured in EEA/UK, this section will focus on those customers within the EEA/UK.

In response to the SEA questionnaire, three OEMs provided examples of the industries their industrial gas turbines are used in. In particular, one these OEM provided detailed information about who their customers are, the countries the turbines are used in, the purpose of the turbine and specific information about the industry sector the turbine in used in.

In the non-use scenarios the impacts on customers are likely to include the extended maintenance periods where they are unable to operate the turbine due to the extra lead times associated with using applicators/MROs outside the EEA/UK. These impacts could be highly significant if supply chains are unable to meet the market demand and quality requirements set by OEMs.

The scenario may involve the application of an unproven alternative which may not offer the same technical performance which may risk the operability of the turbine and shorten the duration of the turbines operational running cycle, at least in the short term (until a proven alternative is identified) this will result in additional maintenance costs and periods where the turbine is not operational. A shortening of the turbine’s operational running cycles will also increase the demand for applicator/MRO services and the additional market demand may exceed existing capacity. Particularly in more challenging environments, the use of an unproven alternative creates enhanced risks for customers using the alternative. Although tested in short term laboratory studies, the use of the alternative for extended periods in the service environment may result in unexpectedly poor performance resulting in increased wear, corrosion and damage which would reduce performance of the turbine. This may significantly reduce the service life of the turbine and may require its complete replacement. There would be an increased risk of complete turbine failure or destruction from wear, corrosion and resulting damage.

4.7.2.5.1 Critical infrastructure

The European Commission (EC) defines critical infrastructure as an asset or system which is essential for the maintenance of vital societal functions and wellbeing of EU citizens. Within Europe, critical infrastructure encompasses 11 sectors including power grids, transportation, and information and communication systems.[53]

The UK government’s definition of a Critical National Infrastructure (CNI) sector is similar to that of the EC. The UK focuses on the impact that could result if the sector was lost or compromised. If this

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[53] EC (Nd): Critical infrastructure protection. Webpage from the European Commission website. Available at: https://joint-research-centre.ec.europa.eu/scientific-activities-z/critical-infrastructure-protection_en accessed on 01 February 2023.

could result in a detrimental impact to essential services, significant economic or social impacts and/or significantly impair national security, defence, or the functioning of the state.[54]

Several customer's uses and sectors would fit the definition of being part of critical national infrastructure.

Sectors

Based on information provided by OEMs, the following sectors listed in **Table 4-28** may be impacted are a minimum.

Table 4-28: Sectors likely be impacted in the non-use scenario

Sector	EU critical sector	UK critical sector
Aerospace manufacturing		
Agrochemical fertilizers		Yes
Airports		
Asphalt refineries		
Automotive manufacturing		
Banking/commerce		
Bottle manufacturing		
Buildings and institutes		
Cement		
Ceramics		
Chemical industry		Yes
Data centres	Yes	Yes
District heating (residential, universities, hospitals etc.)		
Electronics		
Engineering and heavy engineering		
Exhibition centres		
Film processing		
Food and drink sector		Yes
General manufacturing		
Glass manufacture		
Heating/air conditioning manufacturing		
Hospitals		Yes
Housing/construction		
Incineration		
Industrial zones		
Landfill		
Medical equipment manufactures		
Mineral industry		
Nuclear industry	Yes	Yes
Oil and gas industry	Yes	Yes

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[54] CPNI (2021): Critical National Infrastructure. Webpage from the website of the Centre for the Protection of National Infrastructure. Available at: https://www.cpni.gov.uk/critical-national-infrastructure-0 accessed on 01 February 2023.

Table 4-28: Sectors likely be impacted in the non-use scenario

Sector	EU critical sector	UK critical sector
Optical film		
Paper and cardboard manufacture		
Petrochemical		Yes
Pharmaceutical		Yes
Plastics		
Power generation	Yes	Yes
Printing		
Rubber/tyres manufacturers		
Semiconductor manufactures		
Steel works		
Textiles		
Wallboard manufacture		
Water companies, utilities & sewage treatment		Yes
Wood		

The sectors (**Table 4-28**) where industrial gas turbines are used employed thousands of people across the EEA/UK, relevant sectoral information is provided in ANNEX 5 – Enterprises, employees, salaries, turnover, GOS, GVA and profit margins of sectors in the EU and UK where industrial gas turbines are known to be used (**Table A5-1** (EU) and **Table A5-2** (UK)). The information in these tables is used to illustrate the different sectors that industrial gas turbines are known to be used. Industrial gas turbines will not be used by all enterprises within sectors, however, in several sectors the supply chains are likely to be complex and any challenges and price rises in one part of the supply chain are like to result in downstream challenges and price rises in other parts of the supply chain. Impacts in one sector may also result in impacts across several other sectors.

Some of the sectors provide vital services and industrial gas turbines are an effective solution in these sectors either as the primary source of heat and power or as an effective backup solution.

A high-level description of the sectors and the potential impacts are described for these sectors below.

Oil and gas

The oil and gas sector can be considered part of ‘Critical Infrastructure’ in both the EU and UK context. Information received from one OEM shows that industrial gas turbines are in operation within the oil and gas industry, across the EU and the UK. The turbines are used within a number of different operations within the oil and gas sector, including but not limited to; onshore and offshore oil and gas exportation, onshore and offshore oil and gas production platforms (including crewed fixed platforms and Floating Production Storage and Offloading (FPSO)), onshore and offshore oil and gas processing and distribution networks (boosting, compression, pumping, storage, separation and transmission), liquid natural gas (LNG) and other terminals, and refineries.

If a crewed offshore oil and gas platform loses electrical power, the following consequences could occur:

- Emergency shutdown systems may activate, leading to a cessation of production and the sealing of wellheads to prevent the release of oil or gas;
- The platform's control systems, including those for fire and gas detection and suppression, may become inoperative, increasing the risk of an accident;
- The platform's communications systems may also be affected, making it difficult to call for help in an emergency; and
- The platform's living quarters and safety systems, such as lighting, heating, and air conditioning, may become inoperative, affecting the comfort and safety of personnel on board.

Some offshore platforms may have more than one industrial gas turbine available to provide power as part of backup systems for occasions where a turbine needs to be inspected or undergo maintenance. There may also be other emergency backup power systems that could provide temporary power to critical systems. However, in general, the loss of electrical power on an offshore platform can have significant consequences for both the environment and the personnel on board, making it a critical issue that must be addressed promptly and effectively. There have several occasions where loss of power has occurred on platforms leading to evacuation of non-essential personnel[55] [56] [57] [58] and other accidents involving turbines and power loss have been captured.[59] [60]

Restarting production at oil & gas fields following the pausing or cessation of production can be a complex and time-consuming process. Disruption can also impact the production flow of oil & gas through pipelines, causing the oil or gas to become stagnant and form deposits within the pipeline. This can cause corrosion and other damage to the pipeline which could become blocked. The non-use scenarios are likely to impact the ability of the grid to operate efficiently, this include the provision of gas to power stations and the wider gas network. A key factor for the oil and gas industry uses of industrial gas turbines produced by OEMs is their reliability.

These examples highlight the importance of the oil and gas sector and although the non-use scenario will impact the use of industrial gas turbines, the impact is unlikely to result in the collapse of the sector, it could result in a period of downtime which could have large economic and social impacts across both the EU and UK. As has been seen within the past year the natural gas market can be very volatile, the European gas price index has increased from 87 points in January 2021 to 341 points in October 2022, before falling slightly to 314 points in November 2022.[61] A proportion of this price increase can be attributed to cutting off gas supply from Russia (following the invasion of the Ukraine, both the EU[62] and UK[63] have introduced sanctions against Russia), any further or future disruption to

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[55] https://www.offshore-energy.biz/shell-removes-135-workers-from-north-sea-platform-after-power-outage/

[56] https://www.scotsman.com/news/148-flown-oil-platform-after-power-outage-1528547

[57] https://www.offshore-energy.biz/over-100-offshore-workers-evacuated-after-power-loss-on-north-sea-platform/

[58] https://www.tnp.no/norway/economy/3895-statoils-platform-closed-after-power-outage/

[59] HSE: Accidents on fixed offshore units on the UK continental shelf 1980-2001, available at: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.hse.gov.uk%2Fresearch%2Frrpdf%2Frr096.xls&wdOrigin=BROWSELINK

[60] HSE: Accidents on floating offshore units on the UK continental shelf 1980-2003, available at: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fwww.hse.gov.uk%2Fresearch%2Frrpdf%2Frr353.xls&wdOrigin=BROWSELINK

[61] HEPI (2022): Household Energy Price Index for Europe. Report by the Household energy price index. Available at https://www.energypriceindex.com/price-data on 02 February.

[62] https://eu-solidarity-ukraine.ec.europa.eu/eu-sanctions-against-russia-following-invasion-ukraine_en

[63] https://commonslibrary.parliament.uk/research-briefings/cbp-9523/

the supply of gas to Europe could lead to further price inflation. The EU[64] and UK[65] also both have measures in place to protect energy security.

Increased oil and gas prices, which could occur from impacts to industrial gas turbines in the oil and gas supply chain in the non-use scenarios, has the potential to impact many other sectors of the wider economy. With higher energy costs, input costs are increased this can lead to supply in multiple sectors falling and/or higher costs being passed onto consumers.

Power generation

The non-use scenarios have the potential to impact the operators of power stations where electricity is generated by industrial gas turbines, this may occur due to delays in the turbines being delivered to new power stations or delays in the maintenance schedule of those turbines undergoing maintenance. In these situations, it is complex undertaking to install a different type of turbine (manufactured by the same OEM or a different OEM) in the place of the turbine undergoing maintenance. As described in the oil and gas example above, extended downtime of power stations has the potential to cause wider economic and social impacts.

Where industrial gas turbines are used by companies, including the other sectors described below, they will also have the ability to sell power back to the grid or store excess power in battery energy storage solution. The capability to sell or store energy is practical and financially beneficial for companies.

Food and drink

It has also been highlighted that industrial gas turbines are in use within areas of the food and drink industry. This includes industrial gas turbines within corn processing plants and breweries as well as turbines in operation supporting the dairy, sugar, and starch manufacture supply lines.

If these manufacturers are not able to continue to use these turbines it could lead to a period of time where these products are not produced or at least supply is restricted. In some cases these industries may be able to put temporary measures in place to allow operations to continue. Dairy, sugar and starch are key ingredients used in a significant number of food products, a contraction in the supply of these key ingredients would most likely lead to high inflation across the food and drink industry.

Food and non-alcoholic drink inflation rose by 16%[66] in the 12 months to November 2022, across the EU, and 16.5%[67] in the same period within the UK. This inflation has been caused by a number of factors including increasing input costs from rising fuel prices, and Russia's invasion of Ukraine leading to a drop in global supply levels. Rising food prices has a larger impact on the most economically vulnerable countries and individuals and can lead to growing inequality. Food banks across Europe,

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[64] https://energy.ec.europa.eu/topics/energy-security/secure-gas-supplies_en

[65] https://www.gov.uk/guidance/preparing-for-and-responding-to-energy-emergencies

[66] ECB (2023): Measuring inflation – the Harmonised Index of Consumer Prices (HICP). Webpage on the website of the European Central Bank. Available at https://www.ecb.europa.eu/stats/macroeconomic_and_sectoral/hicp/html/index.en.html on 02 February 2023.

[67] ONS (2022): Rising cost of pasta, bread and other everyday foods leaves most vulnerable the worst off. Webpage on the website of the Office National Statistics. Available at https://www.ons.gov.uk/economy/inflationandpriceindices/articles/risingcostofpastabreadandothereverydayfoodsleavesmostvulnerabletheworstoff/2022-12-22 on 02 February 2023.

including in some of the wealthier such as Germany and France, have seen increases in demand between 20-50%, with many having to turn away new applicants[68]. Any further rises in food prices, that could be caused by supply contractions, if the removal of industrial gas turbines leads to periods of downtime, could be damaging to both the EU and UK economy and place an increased burden on the citizens in both of these areas that are already struggling with inflated prices.

The profit margins of some food and drink (**Table A5-1** and **Table A5-2**) entities is shown to be low, although any rising costs could be passed onto consumers, these low profits, loss operational time and increased costs could put the business at risk.

Steel

Further data received suggest that industrial gas turbines are in operation within the steel industry. As can be seen in **Table A5-1**, in 2020, enterprises involved in the manufacture of basic iron and steel and of ferroalloys (under NACE code C24.10) across the EU had an average profit margin of 1.6%. Within the UK, enterprises within the same sector had an average profit margin of 2.2% across the same time period. These low profit margins could suggest that enterprises with this sector may struggle if there is a period of time where manufacturing was impacted by the non-use scenarios.

Waste

Industrial gas turbines are in action at sewage treatment plants both in the UK and the EU, industrial gas turbines are also at incineration plants and at some landfills. Sewage treatment is an essential activity that is required for society to function smoothly. Any disruption to sewage treatment plants could result in negative economic (e.g. increase costs to these companies which are passed onto consumers) social and environmental impacts (e.g. the possibility that sewage works may discharge untreated sewage into the environment).

Utilities/Water companies

In some cases, utility companies may use industrial gas turbines to generate onsite electricity to power their operations.

Automotive

Supply information shows that industrial gas turbines are also used within the automotive industry. Turbines are typically used for two main purposes, the generate electricity that helps to power the operations on site, the heat energy generated is also used along parts of the production line. The automotive industry is a key industry for the EU and is a sector that is expected to grow substantially in the coming years. The EU is looking to lead in the transition to electric vehicles and the automotive industry has an important role to play in the EU reaching its environmental and net zero targets. In 2020, enterprises across the EU, within the NACE code C29.10 (manufacture of motor vehicles) had an average profit margin of 4.4%, this low percentage may be attributable to COVID-19 and the lower demand for vehicles as a result of the pandemic.

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[68] FT (2022): On the breadline: inflation overwhelms Europe's food banks. Article by Martin Arnold and Alexander Vladkov for the Financial Times. Available at https://www.ft.com/content/bb098ccd-c74b-4c7e-8baa-e90546030fa5 on 02 February 2023.

The non-use scenarios have the potential to impact the effectiveness and efficiency of automotive manufactures that use industrial gas turbines. Extended inoperability of the industrial gas turbine may impact the manufacturing operations. The cost of several days of lost production can be significant, although alternative measures could be implemented to mitigate against any downtime, the cost of these alternative measures may be high.

Transport

Industrial gas turbines and related coated parts are also used in different parts of transport networks and on trains, industrial gas turbines are also known to power some existing airports. In Europe, the OEM (#C) made turbines for use in the production of some trains.[69]

Pharmaceutical

Industrial gas turbines are in operation within the pharmaceutical industry, both in the EU and the UK. The Pharmaceutical Group of the European Union (PGEU) conducts a yearly survey among its members to map medicine shortages across Europe. The 2022 survey was conducted between November and December 2022. The survey concluded that there continued to be a high incidence of medicine shortages in most European countries and that the impact of medicine shortages on patients and pharmacy practices across Europe is worsening.[70] If it is the case that industrial gas turbines are required in, or impact the manufacture of pharmaceuticals, and under the non-use scenario the pharmaceutical industry was not able to use turbines, medicine shortages and the accompanying issues could intensify.

Other manufacturing

As described above, the non-use scenarios have the potential to impact the effectiveness and efficiency of manufacturers (including those described in **Table 4-28**) who use industrial gas turbines. Extended inoperability of the industrial gas turbine may impact the manufacturing operations on site and lead to lost production. Lost production can be significant as the companies will still incur several costs (including overheads and staff) and companies may also experience:

- Revenue loss: from the businesses inability to produce products or deliver services;
- Customer dissatisfaction: The lost production can lead to delays in fulfilling customer orders, which can result in customer dissatisfaction and may lead to lost business and decreased business reputation;
- Supply chain disruptions: where a business experiences lost production, it can also disrupt its supply chain, leading to decreased efficiency and increased costs. This can cause further delays and reduce profitability;
- Increased costs: Lost production can often result in increased costs, such as overtime pay for employees, expedited shipping costs, and the cost of hiring temporary workers. Missing

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[69] #C, D

[70] PGEU (2022): Medicine Shortages, PGEU Survey 2022 Results. Report by the Pharmaceutical Group of the European Union. Available at https://www.pgeu.eu/wp-content/uploads/2023/01/Medicine-Shortages-PGEU-Survey-2022-Results-1.pdf on 02 February 2023.

contract deadlines can also result in penalties, liquated damages and compensation claims; and

- Loss of market share: Lost production can also result in the loss of market share to competitors, as other business and consumers switch to other providers who can meet their needs more effectively.

Although alternative measures could be implemented to mitigate against any downtime, the cost of these alternative measures may be high.

District heating

In both the EEA[71] and UK[72], there are many examples of district heating and cooling systems that provide heat/cooling to multiple buildings and businesses. District heating systems are particularly prevalent in Nordic countries. They are becoming increasingly popular as a way to achieve energy efficiency (by achieving economies of scale and achieve higher levels of energy efficiency by using efficient industrial gas turbines), cost savings (by spreading the cost amongst many users) and reducing overall carbon emissions.

Hospitals

Several hospitals, along with other venues like conference facilities and large offices, benefit from the combined heat and power of industrial gas turbines. The turbines allow these sites to gain significant cost savings by avoiding the cost of purchasing power from national grids where it can be more expensive. The sites also benefit from the combined power and heat production from the turbines.

Commerce and data centres

Similar to the hospital (above) and backup power (below) examples, commerce and data centres benefit from the security of supply and backup power should it be required. #C, D.

Backup Power

Industrial gas turbines provide emergency power for airports, subways #C, D and hospitals. In some cases, it is critical that these systems be robust and effective when needed.

Another example of industrial gas turbines providing backup power is Sellafield Ltd, a nuclear decommissioning site. Here two industrial gas turbines provide security of electrical supply and fast start up in the event of power grid failure.

4.7.2.6 Potential impacts of natural gas supply disruption

As indicated in the previous section, industrial gas turbines are important for supporting several different sectors with mechanical power generation and heat energy. Industrial gas turbines play a

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[71] Overview of District Heating and Cooling Markets and Regulatory Frameworks under the Revised Renewable Energy Directive: available at: https://op.europa.eu/en/publication-detail/-/publication/4e28b0c8-eac1-11ec-a534-01aa75ed71a1/language-en

[72] Market Report: Heat Networks in the UK, available at: https://www.theade.co.uk/assets/docs/resources/Heat%20Networks%20in%20the%20UK_v5%20web%20single%20pages.pdf

critical role in the ongoing extraction of oil and gas from European sources (e.g. the North Sea and Irish Sea) and receiving, processing and transporting oil and gas around the grid. Industrial gas turbines built and maintained by EEA/UK OEMs are also critical to the extraction, production and supply of oil and gas outside of the EEA/UK, this includes the supply of oil and gas to the UK and EEA.

The importance of gas to Europe is recognised by the European Central Bank[73] (ECB) who highlighted in 2022 that natural gas is the second most important primary energy resource in the euro area, after petroleum-based products. It is the most important source of energy in the manufacturing sector, and more than 90% of the gas consumed in the euro area is imported. It is also recognised that gas acts as the key marginal energy resource in electricity generation, given the flexibility of gas-fired power plants and the overall gas infrastructure (e.g. network interconnections, storage capacity and liquified natural gas terminals) in responding to fluctuations in electricity demand.

Any significant increases in natural gas prices are understood to dampen economic activity through both the consumption channel and the intermediate goods channel. In the case of the consumption channel, higher gas and electricity prices have the impact of reducing households' real disposable income and purchasing power (as a result of the deterioration in terms of trade due to the increased cost of imported energy), and thus private consumption.

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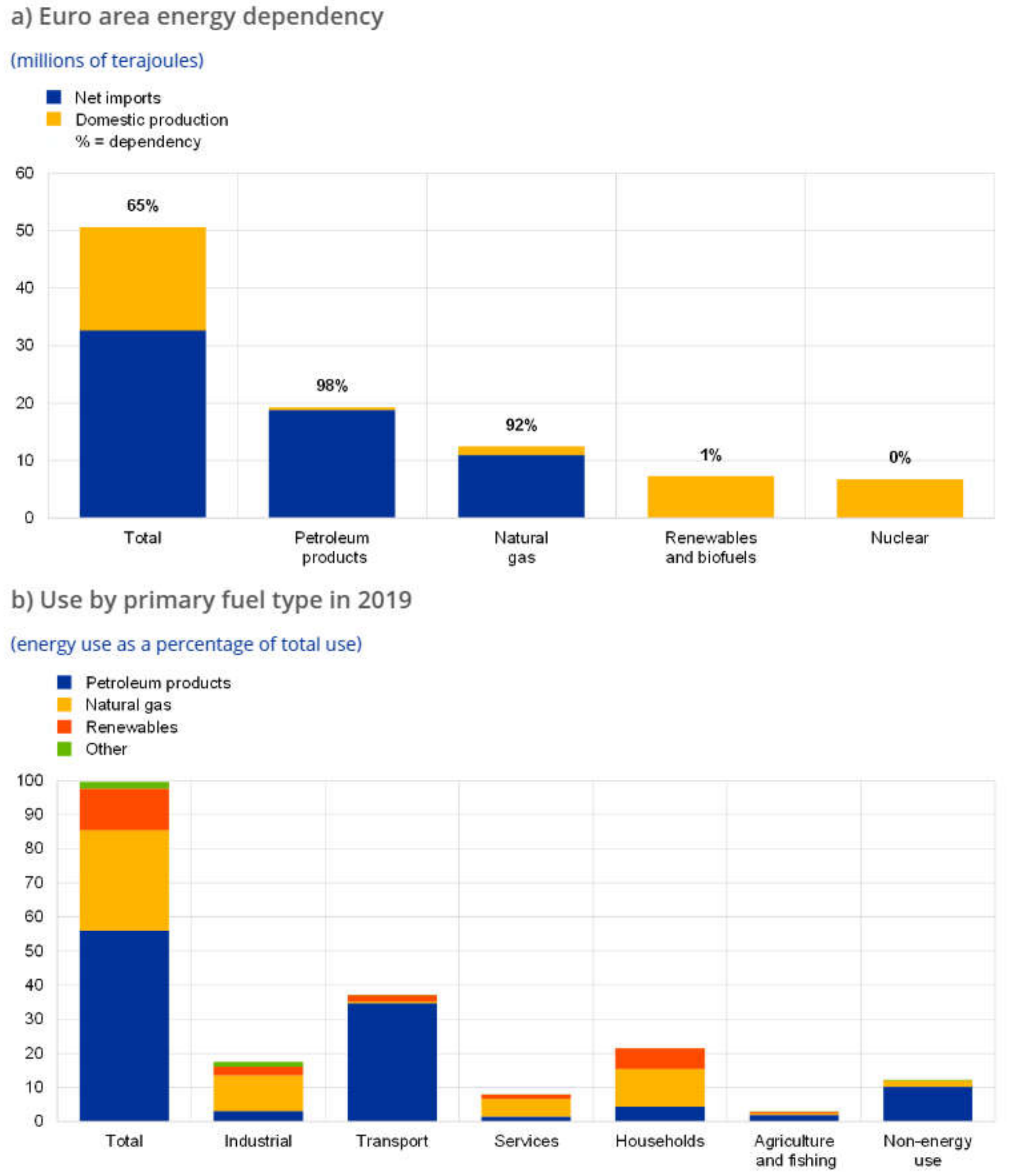
[73] Natural gas dependence and risks to euro area activity, available at: https://www.ecb.europa.eu/pub/economic-bulletin/focus/2022/html/ecb.ebbox202201_04~63d8786255.en.html accessed 2 February 2023.



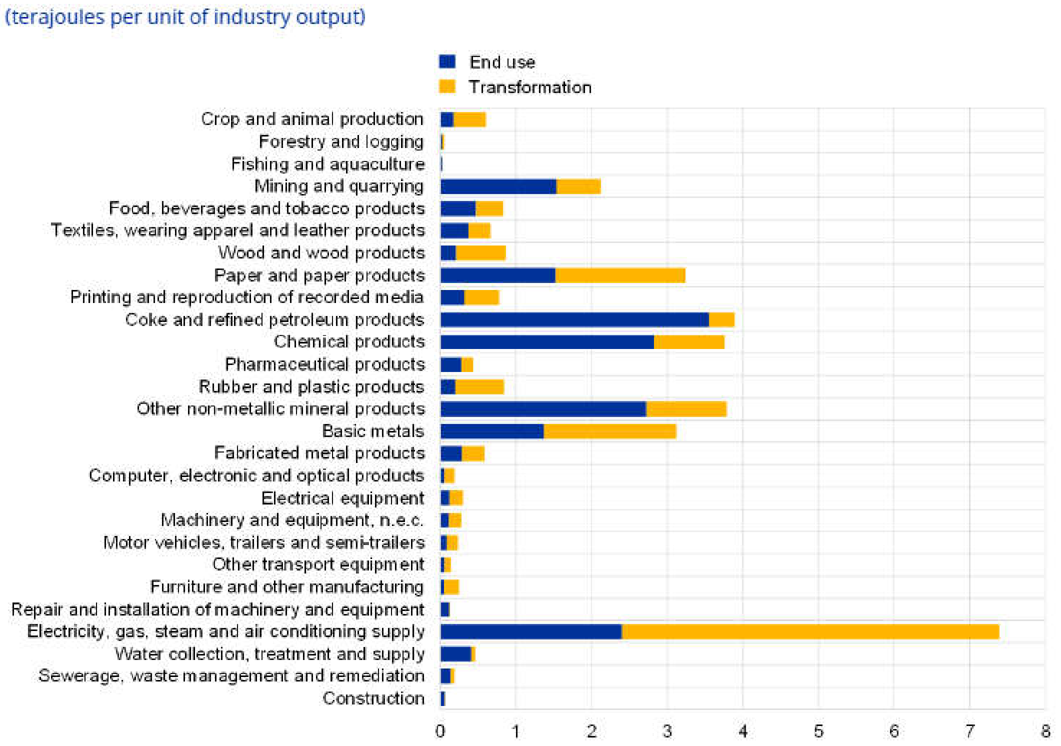
Source: Eurostat (energy balances).

Notes: Dependency refers to the ratio of net imports to gross available energy. Intra-euro area trade is not included.

Figure 4-7: Energy dependency and energy use by primary fuel type in the euro area

Source: ECB

For the intermediate goods channel, gas is an input in the production processes of many firms.



Sources: Eurostat (energy supply and use tables) and ECB staff calculations. The sectors are classified according to the Statistical classification of economic activities in the European Community (NACE Rev. 2).

Figure 4-8: Gas use by industrial sector in 2019
Source: ECB

The ECB also indicated that supply chain linkages amplify the reaction of goods producers and services providers to gas price increases. Amplification occurs because more than two-thirds of energy consumption is attributable to indirect use embedded in the earlier stages of production.

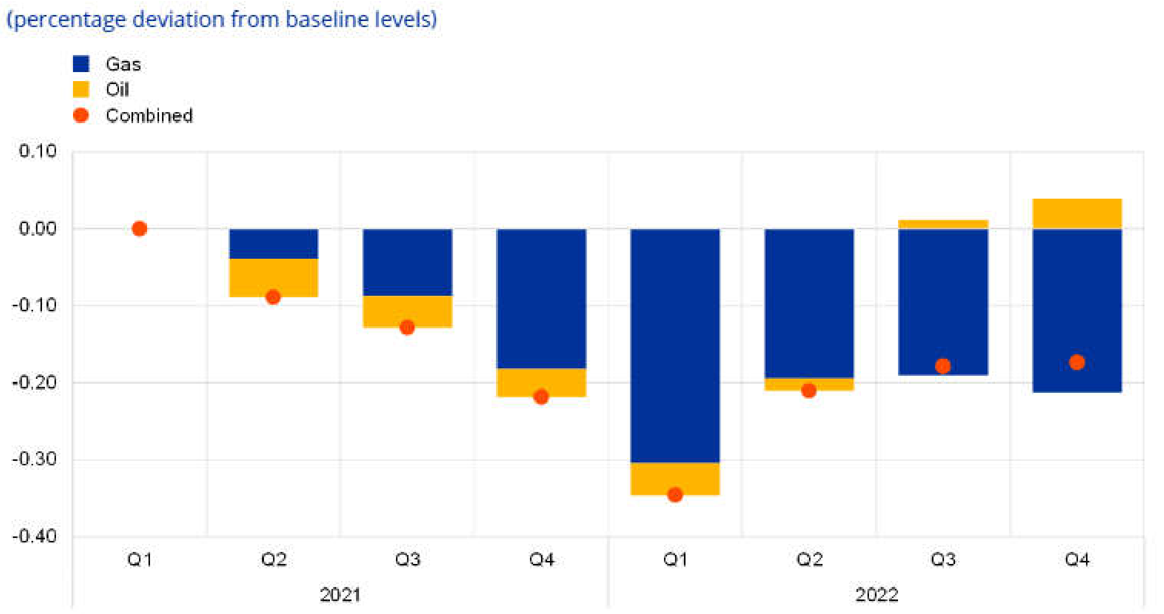
Regarding supply disruptions, the ECB estimated that the direct and indirect impact of a hypothetical 10% gas rationing shock on the corporate sector could reduce euro area gross value added by about 0.7%.

Furthermore, the ECB considered:

> *"An alternative framework for assessing the macroeconomic impact of gas price increases is to use general equilibrium models with a rich energy representation. The rich energy block of the National Institute Global Econometric Model (NIGEM) permits an illustrative assessment of the impact of the ongoing surge in gas (and oil) prices on euro area activity. NIGEM distinguishes between four types of energy: oil, gas, coal and renewables. While there is no mechanism for direct quantity rationing, simulated impacts for activity are possible by imposing shocks to global energy prices using current profiles from spot and futures prices. NIGEM-based estimates suggest that a permanent one standard deviation increase in natural gas prices from the first quarter of 2021 would result in a deviation in euro area GDP of around*

0.2% from baseline levels over the standard three-year projection horizon (in the absence of policy and exchange rate effects)."

"Illustrative counterfactual simulations based on the surge in oil and gas prices since the start of 2021 suggest a significant negative impact on euro area activity in 2022, peaking in the first quarter. At the data cut-off date for the December 2021 Eurosystem staff projections, euro area oil and gas spot prices and futures suggested that euro area natural gas prices would likely peak in the first quarter of 2022 at almost 600% above their first quarter 2021 levels, before declining significantly thereafter.[74] *Conditioning on these paths*[75]*, and under standard simulation assumptions excluding exchange rate and policy feedback, mechanical simulations using NIGEM suggest that the current surge in oil and gas prices could reduce euro area output by around 0.2%, compared with baseline levels of GDP (***Figure 4-9***), by the end of 2022. While the proportional impact of increases in gas prices is typically substantially lower than the impact associated with rising oil prices, the extraordinary magnitude of the gas price increases seen in energy futures makes gas prices the main driver of the adverse impact on euro area GDP this time."*



Sources: Bloomberg, National Institute Global Econometric Model (NIGEM) and ECB staff calculations.
Note: The chart shows the simulated impact of deviations in energy prices from first quarter 2021 levels on euro area GDP, net of exchange rate and policy effects.

Figure 4-9: Simulated impacts of ongoing energy price developments on euro area GDP
Source: ECB

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[74] While the increases in oil prices compared with their level in the first quarter of 2021 (which is broadly equivalent to the nominal averages seen over the course of 2017-19) are in line with historical patterns (as last seen in the run-up to and wake of the global financial crisis), the surge in recent gas prices is well outside earlier deviations. At the time of drafting, gas prices remained highly volatile, despite spot prices in January falling to around half of their December futures values.

[75] The profiles used in these simulations reflect the quarterly averages of the profiles shown in Chart A of Box 3 entitled "Developments in energy commodity prices and their implications for HICP energy price projections" in the December 2021 Eurosystem staff macroeconomic projections for the euro area, published on the ECB's website on 16 December 2021.

The International Monetary Fund (IMF) also analysed the potential impact of natural gas supply disruption in Europe due to the invasion of Ukraine. With natural gas being an important input in production, it was suggested that the capacity of the economy would shrink. Di Bella et al., (2022) suggests that in the short term, the most vulnerable countries in Central and Eastern Europe — Hungary, Slovak Republic and Czechia — face a risk of shortages of as much as 40 percent of gas consumption and of gross domestic product shrinking by up to 6 percent. The effects on Austria, Germany and Italy would also be significant, but would depend on the exact nature of remaining bottlenecks at the time of the shutoff and consequently the ability of the market to adjust. Many other countries are unlikely to face such constraints and the impact on GDP would be moderate—possibly under 1 percent.

Disruption to the industrial gas turbine industry may cause similar supply chain disruption.

4.7.3 Economic impacts on competitors

4.7.3.1 Chromium trioxide formulations

IP are one of the main formulators and providers of chromium trioxide formulations to the UK and EEA markets. There is at least one existing competitor, #C. The competitor restricts sales of their products and only allows them to be used at their applicators' facilities. The competitor has already closed #C. IP believes that this competitor is preparing to leave the chromium trioxide formulation market and that they will market an alternative chrome free coating.

As part of the AoA-SEA questionnaire and consultation, OEMs were asked about their use of existing and alternative products. All four OEMs confirmed they use chromium trioxide products. An OEM that produces large industry gas turbines (where more expensive blades are used, where the environmental conditions are much more controlled, where fewer turbines are manufactured and maintained) suggested some progress towards identifying and implementing an alternative is being made. Three out of the four OEMs confirmed that they currently use #C.[76]

At present, IP estimate they make up #C, D (range 10-40%) of the existing market.[77] However, as indicated in **Table 2-5**, there are several other large manufacturers of turbines in the EU and there are also likely to be other manufacturers including some of those in **Table 2-3** that may use #C.

It is anticipated that no new chromium trioxide formulators will enter the market, to do this a business investment would be required and an AfA would need to be granted. Before any new products could be implemented, OEMs would typically require that the new coating formulation is certified amongst their applicators/MROs prior to the coating of any on turbine components. Although the final plans of

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[76] #C

[77] #C, D

the competitor (and any other competitors) are unclear, it is expected that IPs main competitor will leave the market.[78]

Although IP produce alternative formulations, the key technical criteria, R&D decisions, choosing of an alternative(s), pursuing with internal certification and industrialisation are decisions that will be taken by downstream users, principally OEMs.

In the non-use scenario, it is unclear whether any competitors would gain the market share and profits lost by IP as all companies may have left the market. This may result in significant impacts as it is unclear whether there would still be any producers of chromium trioxide formulations.

4.7.3.2 OEMs

Those OEMs that are known to be downstream users of IP (**Table 2-3**) may over time lose their market share to other OEMs, however, this may only be the case if the other OEMs are not also dependent on chromium trioxide formulations to protect key components of industrial gas turbines.

As indicated previously, a significant majority of industrial gas turbine manufacturers are expected to apply protective coatings to turbine components, especially those turbines that are used in more challenging environments. OEMs located outside of the EEA/UK will still be able to coat components with chromate coatings. It is unclear how successful the industrial gas turbine sector has progressed with identifying and implementing alternatives with a similar or greater technical performance. The implementation of alternatives with a lower technical performance will reduce the reliability and operational time of the turbine, there will also be a greater risk of turbine wear with may lead to premature scrapping or failure of the turbine. These possibilities will likely generate greater waste and costs for the customers of OEMs.

A number of the known OEMs in IP's supply chain are recognised as having a significant market share, this may mean that a significant proportion of the market may need to be "reallocated" in a non-use scenario (especially if OEMs still require chromium trioxide formulations and no formulations are available).

4.7.3.3 Applicators/MROs

Applicators/MROs are dependent on the decision taken by OEMs, those applicators/MROs who a large proportion of their business operations are related to the application of new coatings and as part of MRO activity will be more impacted positively or negatively than other businesses.

In the non-use scenario where applicator/MRO activity takes place outside of the UK/EU these existing businesses may need to diversify their servicing offerings if they are to stay in business. However, there is likely to be more supply than there is demand.

In the non-use scenario where an unproven alternative is used, all applicators may benefit from additional business in the short term, especially those who already conduct these activities regularly.

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[78] [redacted]

4.7.3.4 Conclusion

As a result of a competitor also leaving the market, the economic impacts may be greater than described in this application as additional OEMs, applicators/MROs, supply chain members, and industrial gas turbine customers may be negatively impacted and this would subsequently have greater impacts on society.

4.7.4 Environmental impacts under non-use

As a result of the most likely non-use scenarios, the following environmental impacts can be expected:

- CO_2 emissions from more frequent and longer transportation routes for chrome-plated turbines' components;
- increased volumes of waste generated by the need of packaging to reduce the risks related to transportation of parts to be coated or repaired outside the EEA/UK;
- Reduced thermal efficiency and subsequent increased emissions of nitrogen oxides (NOX), carbon monoxide (CO), volatile organic compounds (VOC) and other hazardous pollutants;
- Reduced positive environmental impacts related to a timely transfer to hydrogen turbines

In both of the non-use scenarios (i.e. NUS 1 - the continuation of the chromium trioxide coating activities outside of the EEA/UK and NUS 2 - the use of an unproven alternative) more frequent transportation of turbines and components will be necessary, leading to environmental impacts.

In the non-use scenario where chromium trioxide coating activity continues outside of the EEA/UK, all existing industrial gas turbines that are operating in EEA/UK (numbers are in the thousands) will need to be transported greater distances to an applicator/MRO company. These huge logistics and transport related requirements would have dramatic impacts on the industrial gas turbines environmental footprint.

In the non-use scenario where an unproven alternative coating is used (NUS 2), the existing industrial gas turbines operating in the EEA/UK would highly likely have a shorter operating duration before a servicing and overhaul is required. This reduced operating time would mean more frequent transportation of turbines and components by plane and overland transport leading to increases in fuel consumption and CO_2 emissions.

The frequent and long transportation routes entail a significant risk of breaks or defaults of parts to be coated or repaired outside the EEA/UK. To avoid such risk from transportation, most likely packaging should be changed or increased to make the contained components more resistant to shocks. This would bring to the generation of additional volumes of waste and environmental impacts associated to their disposal.

Decreasing the operating efficiency of industrial gas turbines to prolong the running cycle of the turbine and as part of an attempt to reduce wear on components will increase emissions from the turbine.

To help reduce turbine wear[79] and increase the operating duration, the industrial gas turbine could be run less efficiently, however, this would increase the emissions from operating the turbine.

A key contributing factor to the emissions generated is the fuel being used and thermal efficiency. As identified by Pirro et al., (2016), gas turbine engine pollutants include nitrogen oxides (NOX), carbon monoxide (CO), and volatile organic compounds (VOC). Particulates are also a primary pollutant for engines using liquid fuel. Nitrogen oxide formation is strongly reliant on the high temperatures developed in the combustor. Carbon monoxide, VOC, hazardous air pollutants (HAP), and particulate matter (PM) result from incomplete combustion. Trace to low levels of HAP and sulphur dioxide (SO_2) are emitted from gas turbines. Ash and metallic additives in the fuel may also contribute to PM emissions. Oxides of sulphur (SOX) will only appear in significant amounts if heavy oils are used in the turbine. Emissions of sulphur compounds, mainly SO_2, are directly related to the sulphur content of the fuel.

Available emissions data point to a significant impact on emission levels that a gas turbine's operating load has. Gas turbines are typically operated at high loads (greater than or equal to 80 percent of their rated capacity) in order to achieve maximum thermal efficiency and peak flame temperatures. With reduced loads (below 80 percent), or during frequent load changes, the combustor zone temperature is expected to be lower than when operating at high loads. This will result in lower thermal efficiencies and more incomplete combustion.

Although the formation of CO acts to reduce CO_2 emissions, the amount of CO produced is insignificant compared to the amount of CO_2 produced. The majority of the fuel carbon not converted to CO_2 is due to incomplete combustion. The formation of N_2O during the combustion process is governed by a complex series of reactions and its formation is dependent upon many factors. However, the formation of N_2O is minimized when combustion temperatures are kept high and excess air is kept to a minimum (less than 1 percent). Similar to the CO emissions, HAP emissions increase with reduced operating loads. Typically, combustion turbines operate under full loads for greater fuel efficiency, thereby minimising the amount of CO and HAP emissions.

Both of the most plausible non-use scenarios, in the event of a refused authorisation would not be practical and they would involve significant levels of investment.

Today, the industrial gas turbine industry is striving to develop new technologies or adapt existing turbines to run more efficiently and reduce emissions. Presently, a number of new turbines and existing industrial gas turbines are hydrogen ready, meaning that should the UK Hydrogen Strategy (HM Government, 2021) and REPowerEU Plan (European Commission, 2022) be developed as planned, industrial gas turbines will be ready for this transition.

As part of the non-use scenario where chromium trioxide coatings are applied to the industrial gas turbines outside of the EEA/UK, OEMs may move parts of their existing assembly and production

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[79] Additional wear and damage to turbine components from using an unproven and potentially unsuitable alternative may result in the premature scrapping of parts and turbines. This would go against the principles underlying the Circular Economy and the sustainable use of raw materials, by limiting the ability of the sector to recoat, repair and re-use parts and assemblies.

activities outside of the EEA/UK to reduce supply chain complexity. The relocation of OEMs may impact the implementation of UK Hydrogen Strategy and REPowerEU Plan.[80]

Although existing industrial gas turbines coated using chromium trioxide formulations are hydrogen ready, a technical challenge using hydrogen are the higher flow rate and flame temperatures. The alternatives in development are focused on achieving the same technical criteria for cyclic heat-corrosion resistance and dry heat resistance, although the alternatives may be suitable, there could be some difference at the very limits of the coating capability and the higher flame temperatures produced using hydrogen may require additional research and development, reformulation and testing. The inability to continue use chromium trioxide in the EEA/UK due to non-authorisation may also impact the implementation of UK Hydrogen Strategy and REPowerEU Plan.

As discussed above, under both most likely non-use scenarios, the environmental impacts would be real and the effects would be significant. However, due to uncertainty related to the locations of applicators and MROs outside the EEA/UK, to the packaging that will be requested by the customers and about the consequences in terms of use of hydrogen turbines, these environmental impacts have not been quantified.

4.7.5 Wider socio-economic impacts

Potentially, a non-use scenario would have wide-ranging negative impacts on wider non-industrial actors such as districts, hospitals, communication networks, water utilities, etc. that currently use turbines coated with IP's chromium trioxide formulations or buy power generated from these turbines. As for certain industrial sectors, some of these actors can be considered as critical national infrastructures.

In fact, a number of district heating schemes in the UK, EEA and rest of the world are powered by these gas turbines, as the main source of power generation or as the backup source. In case of prolonged power cuts and failures in district heating schemes during extremely cold winter events, it can be expected that the end users (residents of the served communities) will suffer a loss of comfort at least temporarily.

Even if they are mainly powered by gas turbines, hospitals have backup power sources such as generators. Therefore, for hospitals, aside the inconvenience of having to switch to these backup sources, no major impacts in terms of human health of patients can be expected.

Non-authorisation would have other wider economic impacts:

- **Loss of competitiveness for the EEA/UK industry**: as previously noted, non-authorisation would impact upon the ability of the EEA/UK industrial gas turbine industry to use these formulations as part of their business activities. For non-EEA/non-UK competitors of IP's customers this would create a competitive advantage that could help these non-European/non-British companies to step into the market. Examples of such an effect would be:
  - Downstream users located outside the EEA/UK may have easier access to chromium trioxide formulations and therefore gain an advantage over EEA/UK downstream users.

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[80] https://etn.global/wp-content/uploads/2020/02/ETN-Hydrogen-Gas-Turbines-report.pdf

This situation may be exacerbated in markets where alternatives have not yet been identified or cannot yet be fully implemented. The end result would be that EEA/UK exports of relevant products/services would decline while non-UK and non-EEA products/service providers could have easier access onto the UK and EEA markets. In addition, the uncertainty of the sustainability of the chromium trioxide market in terms of securing an extended sunset date as part of a REACH Authorisation, could lead to lower investment in the EEA/UK, production relocation outside the EEA/UK until downstream users/services are satisfied that alternatives are available, offer a similar technical performance and have been implemented.

- **Changes in trade flows**: EEA/UK industries such as the industrial gas turbine sector have a strong exporting element. Curtailing the use of chromium trioxide formulations to the various downstream users could result in changes to trade flows with more applicator, final turbine assembly and MRO activity being imported from outside the EEA/UK.

- **Impacts on the government revenues**: in the event of a non-authorisation for the continued use of chromium trioxides coatings by downstream users, and hence the loss of income from these related operations, would cause a loss in income for the various national governments. These would include losses in corporation taxes, social insurance contributions, etc. Although these losses are not insignificant, they may be orders of magnitude greater if the uses and operations of industrial gas turbines by the OEMs customers were impacted.

The potential impacts on OEMs customers are described in section 4.7.2.5.

4.7.5.1 Social impacts

4.7.5.1.1 Estimated level of job losses

The main social costs expected are the redundancies that would be expected to result from the cessation of coating activities (all or some) and the closure and relocation of sites. The non-use scenarios of coating taking place outside of the EEA/UK or the use of an unproven alternative are both likely to result in job losses. Because the risk of using an unproven alternative is likely be an unacceptable risk until a proven alternative is identified, relocation of coating activities is the mostly likely outcome. Over time it will likely become more cost effective for OEMs to relocate some of their existing manufacturing activity to countries where applicator and MRO services are being conducted, therefore job losses are also expected at OEMs.

Direct job losses will impact on workers at the sites involved in coatings of new components and those involved in recoating existing turbine components as part of MRO activity. Direct job losses will also involve those in subsequent steps and related activities (e.g., laboratory workers, quality control, logistics etc.). These are all referred to here as direct job losses (for avoidance with confusion of multiplier effects).

As indicated in the assessment of economic costs, the estimated reduction in job losses is based on responses to the SEA questionnaires covering 7 applicators (1 based in the EEA and 6 in the UK) and 4 OEMs (2 in each the EEA and UK) sites in total.

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

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

Estimates of the direct job losses that would arise at downstream users' sites under the NUS were presented above. For ease of reference, the totals are repeated in **Table 4-29** below. The magnitude of these figures reflects the importance of coatings to the production of industrial gas turbines within the EEA/UK, as well as to maintenance and repairs of such parts at a subset of MRO facilities. No consideration is given to job losses at those companies providing services that are contracted to provide cleaning, transportation and other services to OEMs and applicators/MROs.

As context, these numbers are lower than the civil aeronautics industry which alone employees around 405,000 people in the EU, with the defence sector employing more than 500,000 and supporting a further 1.2 million.[81]

Table 4-29: Predicted job losses in aerospace companies under the NUS		
Role	**Total job losses due to cessation of manufacturing activities or relocation under the NUS**	
From SEA Survey	**EEA**	**UK**
Applicators/MROs (7 sites)	30	659
OEMs (4 sites)	2,600	2,000
Total (11 sites)	2,630	2,659
Job losses - Extrapolation of job losses under the non-use scenario to the estimated 47 sites undertaking slurry (diffusion) coatings treatments		
Applicators/MROs (33 sites)	1,545	1,977
OEMs (14 sites)	13,000	4,000
Total sites (47)	14,545	5,977

The figures in **Table 4-29** indicate that approximately 20,522 of these jobs related to the industrial gas turbine industry could be in jeopardy under the non-use scenario. This number may underestimate the impact due to the supply chain complexities and authorisation decisions that may or may not be taken by competitors of IP.

4.7.5.1.2 Monetary valuation of job losses

The method for estimating the social costs of unemployment follows that recommended by ECHA Dubourg (2016).[82]

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

[82] Dubourg, R (2016): Valuing the social costs of job losses in applications for authorisation. Available at: https://echa.europa.eu/documents/10162/13555/unemployment_report_en.pdf/e0e5b4c2-66e9-4bb8-b125-29a460720554

Costs of unemployment can be calculated by adding up lost output which is equivalent to the pre-displacement gross salary throughout the period out of work, search costs, rehiring costs for employers and scarring effects. Considering that individuals place positive value on their time out of work ("leisure time"), having more leisure time at their disposal partially offsets the negative value of unemployment. Such value should be deducted from the estimation of the costs of unemployment.

Dubourg (2016) estimated different ratios of the social cost per job loss over the annual pre-displacement wage for European countries and the EU-28 as a whole that varies according to the mean duration of unemployment. These vary by country, with the mean duration of unemployment weighted by the number of employees for each country relevant to the industrial turbine sector varying from 7 months to 1.9 years.

These figures are combined with the ratio of social costs per job loss provided in Dubourg (2016) and annual wages to calculate the social costs per lost job. For the purposes of these calculations, a figure of €40k / £35k has been adopted and applied across all locations and job losses. This figure is based on the NACE code data provided by companies.

The resulting estimates of the social costs of unemployment are given in **Table 4-30** based on consideration of the geographic distribution where the known location of SEA respondents, the location of applicators/MROs as well as other members of the supply chains. The estimated social costs under the non-use scenario are around €1.5 billion for the EEA and £437 million for the UK due to the cessation of the slurry coatings and linked manufacturing activities.

Table 4-30: Social Cost of Unemployment – Job losses at companies under the NUS

Country	Employment losses due to cessation or relocation of manufacturing	Social costs of unemployment (€)
EEA		
Belgium	1,265	153,318,000
Denmark	632	44,240,000
Finland	632	54,352,000
France	3,162	400,941,600
Germany	1,897	197,288,000
Hungary	632	69,520,000
Ireland	632	61,936,000
Italy	632	76,598,400
Netherlands	1,265	118,910,000
Norway	632	68,761,600
Poland	1,265	118,910,000
Spain	632	70,784,000
Sweden	1,265	112,838,000
Total EEA	**14,545**	**€ 1,548,397,600**
UK		
United Kingdom	**5,977**	**£ 437,217,550**
Grand total		
Grand Total	**20,522**	**€ 2,048,074,800**

4.7.5.2 Wider indirect and induced job losses

4.7.5.2.1 Industrial gas turbine sector related multiplier effects

Employment in one sector is often the input to employment in another sector, so that fluctuations in employment of the former will inevitably affect the latter. It is clear that, under the NUS, there could be significant wider impacts on jobs given the likelihood that some of the largest European and British players in the industrial turbine sector would at least partially cease their activities in the EEA / UK and relocate elsewhere with a partial cessation of some manufacturing elements in the EEA / UK.

In the context of the present analysis, job preservation for OEMs, applicators and MROs would also mean the indirect preservation of jobs both within the UK and wider EEA area.

A 2012 study by Stehrer & Ward for the European Commission provided tables from a research project (WIOD) which collects input-output data for 40 countries (including all EU Member States) which are consistent with National Accounts and are linked across countries so that one can also take account of domestic versus foreign effects (Stehrer & Ward, 2012). This study developed employment multipliers for the year 2005. The multipliers most closely related to the present application are those for the machinery & equipment sector. For the machinery & equipment sector a domestic employment multiplier of 1.6 is suggested for the EU-27 with an interregional multiplier of 1.7 (this is smaller than the chemicals sector (employment multiplier of 2.3 interregional multiplier of 3.6), but larger than business services (employment multiplier of 1.5 interregional multiplier of 0.5))

Using multipliers relevant to the machinery & equipment sector may underestimates the impacts on the industrial gas turbine sector along with the downstream users of the turbines. However, these estimates are only used to provide an illustrative overview.

Estimates on the number of jobs indirectly sustained under the applied for use scenario are provided in the following table.

Table 4-31: Estimation of indirect jobs preserved in the EEA and UK economies under the applied for use scenario

Site	Direct jobs losses	Domestic indirect jobs		Interregional indirect jobs	
		Multiplier	Jobs	Multiplier	Jobs
EU sites	14,545	1.6	23,272	1.7	9,563
UK sites	5,977	1.6	24,727	1.7	10,161

Total indirect and induced job losses would be spread across many different economic sectors. Therefore, a weighted average salary taken from Eurostat and updated to 2021 prices (€35,650), related to the Industry, Construction and Services sector (except public administration, defence, compulsory social security), has been used for the purpose of monetisation. The average duration of unemployment in the individual EU Member States (ECHA, 2016a) is that the welfare cost of one job lost is about 2.7 times the annual pre-displacement wages (excluding taxes paid by the employer) of this job. The estimated losses are €6.52 billion for the most likely non-use scenario.

Table 4-32: Monetisation of social costs of indirect unemployment

NUS	Number of indirect/induced job losses	Weighted average salary (Euros)	Ratio of social costs to annual gross salary	Total costs (billion Euros)
Ceasing of chromium trioxide coating activity	67,723	€ 35,650	2.7	€ 6.52

4.7.6 Summary of social impacts

In summary, the social impacts that would arise under the NUS include the following:

- Direct job losses:
    - Around 14,545 jobs in the EEA due to the loss of slurry coatings and linked assembly and/or manufacturing activities and MRO activity, and
    - Over 5,977 jobs in the UK due to the loss of slurry coatings and linked assembly and/or manufacturing activities and MRO activity.

- Social costs of unemployment:
    - €1,548 million for the EEA associated with direct job losses and
    - £437 million for the UK associated with direct job losses; and

- Indirect and induced unemployment at the regional and national level due to direct job losses.

It should also be recognised that the shift of jobs outside the EEA / UK may also give rise to negative consequences for workers in the benefitting countries. The level of worker health and safety regulation outside the EEA / UK is not necessarily as strict as it is in the EEA / UK, with the shift of production activities potentially leading to increased levels of health effects compared to chromium trioxide-based slurry coatings and related manufacturing remaining in the EEA / UK.

4.8 Combined impact assessment

Table 4-33 sets out a summary of the societal costs associated with the non-use scenario. Figures are provided as annualised values, with costs also presented as a present value (PV) over a 4-year and 2-year period as per ECHA's latest guidance; note that restricting losses to only those occurring over the first four and two years of non-use will significantly underestimate the profit losses to the industrial gas turbine and applicator/MRO companies. The OEMs of larger industrial gas turbines (in particular those large turbines used in less challenging conditions) may be able to switch to an alternative in the near future, however a significant number of OEMs of small to medium industrial gas turbines will require more time to identify and implement an alternative. Most companies would incur losses for at least a 4-year period, with a significant proportion likely to incur losses for the full 12-year period as work continues towards development, testing, qualification, validation, certification and industrialisation of alternatives.

Table 4-33: Summary of societal costs associated with the non-use scenario

Description of major impacts	Monetised / quantitatively assessed / qualitatively assessed impacts		
1. Monetised impacts	**PV @ 4%, 4 years**	**PV @ 4%, 2 years**	**€ annualised values**
Lost producer surplus[1]: Impacts on applicants - Lost profits EEA - Lost profits UK Impacts on industrial gas turbine, applicator and MRO companies[1]: - Lost profits EEA - Lost profits UK	Applicants: Monetised value not included in the EEA application Downstream user companies: EEA: €106 – 681 million UK: £344 – 353 million	Applicants: Monetised value not included in the EEA application Downstream user companies: EEA: €55 – 354 million UK: £179 – 184 million	Applicants: Monetised value not included in the EEA application Downstream user companies: EEA: €29 – 188 million UK: £95 – 97 million
Lost profits for suppliers of raw materials, components, transportation, logistics etc.	Not monetised	Not monetised	Not monetised
Lost profits for downstream users of industrial gas turbines	Not monetised	Not monetised	Not monetised
Relocation or closure costs	Not monetised	Not monetised	Not monetised
Loss of residual value of capital	Not quantifiable	Not quantifiable	Not quantifiable
Social cost of unemployment: workers in industrial gas turbine sector only[2]	EEA: €1,548 million UK: £437 million		EEA: €774 million UK: £219 million
Wider indirect and induced job losses	Monetised value not included	Monetised value not included	Monetised value not included
Spill-over impact on surplus of alternative producers	Not assessed due to sector level impacts	Not assessed due to sector level impacts	Not assessed due to sector level impacts
Sum of monetised impacts	EEA: €1,654 – 2,229 million UK: £781 – 790 million	EEA: €1,603 – 1,902 million UK: £616 – 621 million	EEA: €773 – 962 million UK: £314 – 316 million
2. Additional qualitatively assessed impacts	**PV @ 4%, 4 years**	**PV @ 4%, 2 years**	**€ annualised values**

Table 4-33: Summary of societal costs associated with the non-use scenario

Description of major impacts	Monetised / quantitatively assessed / qualitatively assessed impacts	
Impacts on industrial gas turbine sector	Impacts on R&D by the industrial gas turbine sector, impacts on supply chain, impacts on technological innovation.	
Supply chains	The non-use scenarios are likely to have a significant impact on supply chains, in particular applicators and MROs who may not have the available capacity to meet the additional demand. The need to qualify applicators/MROs for coating the products on components may also take 1.5 to 3 years to complete.	
[redacted]	#C, D, E [redacted]	
Other sectors in the EEA / UK	Loss of jobs due to indirect and induced effects; loss of turnover due to changes in demand for goods and services and associated multiplier effects. Loss of jobs in other sectors reliant on the use of industrial gas turbines. Societal impacts due to the loss of productivity, services and business that are reliant on industrial gas turbines. Impacts on logistics and cargo transport.	
Workers outside the EEA / UK	Potential shift in the use of chromates to countries with lower levels of regulation and enforcement, leading to increased risks to workers health.	
Excess risks associated with continued use		
Human health impacts	150 EEA and 180 UK directly exposed workers based on extrapolation and 10 exposed worker per site	EEA €137,420 UK €164,904 (£146,594)
	188,600 EEA and 226,320 indirectly exposed at the local level based on extrapolation Indirectly exposed populations at the regional level are not monetised	EEA €696,991 UK €836,390 (£743,634)
Impacts on downstream applicants	R&D into alternatives	Not monetised
Aggregated present value costs of continued use	Impacts including excess risks and costs to downstream applicants	EEA €834,411 UK £890,228

1) Lower bound figures represent lost EBITDA estimates, upper bound lost operating surpluses.
2) Estimated using the approach set out by Dubourg

Overall, the benefits of continued chromium trioxide coating activity by downstream users of IP, without fully estimating the impacts on all potential downstream users, significantly outweigh the residual risks from continued use. The human health risks are low due to the low number of workers exposed and the risk management measures in place at applicator/MROs sites. The benefit risks ratios would still be >1 if only those companies answering the SEA are survey were to be considered.

Table 4-34: Benefit/risk summary

	Region	Impacts including all benefits and costs – lower bound	Impacts not including social or environmental impacts – lower bound
Benefit of continued use / costs of continued use (including costs of residual risks)	EEA	926 - annualised 1,921 - 2 years 1,982 - 4 years	35 - annualised 66 - 2 years 127 - 4 years
	UK	353 - annualised 692 - 2 years 877 - 4 years	107 - annualised 201 - 2 years 386 - 4 years

4.8.1 Distributional impacts

The above estimates for the net present value of impacts under the non-use scenario do not take into account a range of other impacts, including those on downstream users and some which would relate to transfers such as redundancy costs, corporation taxes, income tax and other social payments that would arise. The distribution of impacts is summarised in **Table 4-35** below.

Table 4-35: Distributional impacts from the continued coating of components with chromium trioxide formulations in the applied for use scenario

Affected group	Economic impact	Health impact
Economic operators		
Supplier of chromium trioxide	Continued sales of chromium trioxide to IP – profits made likely to be small, given the relatively low turnovers made by IP	N/A
EEA/UK suppliers to IP	Continued sales of materials and consumables to IP – profits made are uncertain	N/A
Non-EEA and Non-UK suppliers to IP		N/A
IP (UK site)	Continued formulation of chromium trioxide formulations – profits made from impacted products lost	Low worker exposure and low local releases
EEA/UK suppliers to downstream users	Continued sales of materials and consumables to downstream users – profits made are uncertain	N/A
Non-EEA and Non-UK suppliers to downstream users		N/A
IP – other EEA and UK based sales	Continued operations at IP site, these are likely in both the applied for use and non-use scenarios	N/A
Downstream user – other EEA and UK based sales and services	Continued operations at sites, these are likely in both the applied for use and non-use scenarios but there are like to be significant impacts in the non-use scenarios	N/A

Table 4-35: Distributional impacts from the continued coating of components with chromium trioxide formulations in the applied for use scenario

Affected group	Economic impact	Health impact
DU competitors	No opportunity to expand their operations by filling the market share left by the downstream users of IP. However, it is unclear whether competitors would also require chromium trioxide coatings for their components or whether they have identified alternatives. It is likely that the market will reduce in the future once downstream users implement alternatives. The theoretical profit competitors would not be making due to the continued use is estimated at around €29 – 188 million EEA and £95 – 97 million UK annualised values (2 years EEA: €55 – 354 million/UK: £179 – 184 million. 4 years EEA: €106 – 681 million/UK: £344 – 353 million). It has been assumed that beneficiaries would be EEA/UK based companies and those based outside of the EEA and UK.	Unknown
General public in the EEA, UK and rest of the world	The public will continue to benefit from the products and services produced by downstream users.	N/A
Geographic scope		
Downstream user sites	The local economy would be supported by the retaining of jobs. Jobs would also be supported more widely.	Releases of low levels of chromium trioxide in the local area
EEA and UK	National state authorities will continue to collect corporation tax, social and health insurance contributions, associated the formulation and downstream users' activities	
Within the applicant's business		
Employees/owners	Preservation of 20,522 jobs, Total EEA direct and indirect across 25 sites: 14,545 Total UK direct and indirect across 22 sites: 5,977	N/A
Exposed workers	N/A	Low exposure to 5 workers per site
Non-exposed employees	N/A	N/A

4.9 Uncertainty analysis

The ECHA Guidance on SEA proposes an approach to conduct an uncertainty analysis. This approach provides three levels of assessment of uncertainties: qualitative, deterministic and probabilistic. The ECHA Guidance further indicates that the level of detail and dedicated resources to the assessment of uncertainties should be proportionate to the scope of the SEA.

Given the complexity of this application and as the socio-economic impacts outweigh the health impacts of the continued use by a large factor, performing a systematic (but qualitative) analysis of uncertainties seems sufficient. This analysis of the key parameters that might potentially challenge the quantitative results of the socio-economic analysis and of the human health assessment helps to determine the key uncertainties, their level of magnitude (low, medium, high) as well as their direction (under- or over-estimation). In those cases, in which the variability and quality of the available input data, given the associated uncertainties, required to make some assumptions, the applicant has applied a conservative approach by overestimating human health impacts of the continued use scenario and by underestimating the socio-economic impacts of the non-use scenario.

Table 4-36: Table Uncertainties on human health impacts and socio-economic impacts

	Details	Level of uncertainty (low, medium, high)	Direction of the uncertainties (Underestimation and overestimation)
Human health impacts	Exposure levels	Medium	Potential overestimation since holidays, bank holidays and illnesses are not taken into account
	Number of people exposed at local level	Medium	Potential overestimation for the total local exposure calculation (PEClocal in a distance only 100 m from the point source)
Socio-economic impacts	Quantities used	Low	
	Market/EBITDA growth	Medium	Underestimation as higher production volume and associated profits might occur if unforeseen contracts will be placed in the future (from instance due to the main competitor exiting the market)
	Costs of raw materials	High	Conservative estimation of costs is based on previous experience however the war in Ukraine is affecting business as Russia is a key supplier of gas and oil
Substitution plan timelines	Phase 1 - Reformulation of the alternatives	Medium	Currently undergoing
	Phase 2 - Laboratory testing	Low	
	Phase 3 - Site-based engine testing	Medium to High	Timelines (1,000 hours) have been based on the best-estimated scenario
	Phase 4 - In-field rainbow engine testing	High	Timelines (64,000 hours) estimates for this phase (that includes determining the degradation of the coating and assessing its performance integrity) could be highly underestimated
	Phase 5 - Analysis and assessment of results	Low	Timeline expected to be well estimated
	Phase 6 - Internal certification	High	Timelines take into consideration the time for applicators to coat all the different turbine components with the new alternative coating. These will then be inspected before final turbine assembly, if inadequate it will be returned to the applicator to be re-coated.

4.10 Information to support the review period

4.10.1 Introduction

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

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

In the context of this application, it is assumed that applicants have demonstrated that research and development efforts have already been made but these did not lead to the development of an alternative than can be implemented successfully in the normal review period, criterion 3. Furthermore, internal OEM certification requirements and several offshore health and safety requirements are in place to protect the health and safety of workers and reduce the risks of incidents causing environmental harm. Using an unproven alternative that has not been fully tested creates risks which are similar to the requirements under criterion 4 above.

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

1. *As evaluated by the RAC, the risk assessment for the use concerned should not contain any deficiencies or significant uncertainties related to the exposure to humans (directly or via the environment) or to the emissions to the environment that would have led the RAC to recommend additional conditions for the authorisation. In the case of applications for threshold substances, the appropriateness and effectiveness of the applied risk management measures and operational conditions should clearly demonstrate that risks are adequately controlled, and that the risk characterisation ratio is below the value of one. For applications for non-threshold substances, the applied risk management measures and operational conditions should be appropriate and effective in limiting the risks and it should be clearly demonstrated that the level of excess lifetime cancer risk is below* $1x10^{-5}$ *for workers and* $1x10^{-6}$ *for the general population. For substances for which the risk cannot be quantified, a review period longer than 12 years should normally not be considered, due to the uncertainties relating to the assessment of the risk.*
2. *As evaluated by the SEAC, the analysis of alternatives and the third party consultation on alternatives should demonstrate without any significant uncertainties that there are no*

> *suitable alternatives for any of the utilisations under the scope of the use applied for and that it is highly unlikely that suitable alternatives will be available and can be implemented for the use concerned within a given period (that is longer than 12 years)" (CARACAL, 2017).*

As far as the second criterion above is concerned, the same document provides some relevant examples, one of which (Example (d)) reads as follows:

> "(…) *the use of the substance has been authorised in accordance with other EU legislation (e.g. marketing authorisation, certification, type-approval), the substance being specifically referred to in the authorisation/certification granted and substitution, including the time needed for modification of the authorisation/certification/type-approval, would not be feasible within 12 years and would involve costs that would jeopardise the operations with regard to the use of the substance*".

4.10.2 Criterion 1: Demonstrably Long Investment Cycle

The industrial gas turbine industry is driven by long design and investment cycles, as well as very long in-service time of their products, which are required to meet high safety standards and a key criteria for several customers is reliability. As noted in Section 4, the average life of industrial gas turbines is typically 30-40 years.

Examples of long investment cycles and long product lives have been recognised in the FWC Sector 26 study on the Competitiveness of the EU aerospace industry[83], a sector where there is a similar use of turbines. They are a key driver underlying the difficulties facing the sector in substituting the use of the chromium trioxide in coatings across all components within the final products. The long service life of industrial gas turbines and other products makes it difficult to undertake all of the tests required to internally qualify and certify components with the substitute(s), due to the level of investment and costs that would be involved in such an activity. OEMs may need to certify components and the substitute at more than one site and the existing (and future) demands on the supply chains combined with the number of unique components in different turbines means this activity may take up to three years to complete.

The industrial gas turbine sector would emphasise the crucial role every single component within a turbine plays with respect to the reliability, safety and extended lifetime of the turbine. For example, industrial gas turbines are complex machines involving not only design of the turbine itself, but also its use and maintenance history in varied climates and challenging environments, including highly corrosive environments. Industrial gas turbines are exposed to large forces and extremely high stress levels due to heat generated and compressional forces. Therefore, every single component needs to be designed and manufactured with serious attention and care.

In a complex system, change introduces new forms of failure. Any change will bring failures that can be anticipated – and some that are unanticipated. The components in an industrial gas turbine need to be adjusted to each other very precisely on the design as well as on the manufacturing level. When in the early design phase for completely new turbines, for example, there is an opportunity to consider

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[83] Ecorys et al (2009): FWC Sector Competitiveness Studies – Competitiveness of the EU Industry with focus on Aeronautics Industry, Final Report, ENTR/06/054, DG Enterprise & Industry, European Commission. Available at: http://www.decision.eu/wp-content/uploads/2016/11/FWC-Sector-Competitiveness-Studies-Competitiveness-of-the-EU-Aerospace-Industry-with-focus-on-Aeronautics-Industry.pdf

introducing a material change. Mostly such a material change will be a step improvement on a previous design, in line with the principle of proven engineering. Very rarely is a substantial design change introduced into an existing product, as this would involve substantial cost and risk.

Even where such a small change is considered feasible in principle, the implications are significant and highly complex; time consuming, systematic technology readiness levels (TRL)-style implementation is required to minimise the impact of unanticipated failures and the serious repercussions they might cause. Even when an OEM has been able to undertake the required testing and is in the process of gaining qualifications and certifications of components with a substitute, it may take up to 7 years to implement the use of a substitute across the value chain due to the scale of investment required and the need for OEMs to undertake their own qualification of different suppliers.

[redacted] most MROs in the industrial gas turbine field are only allowed to carry out maintenance and repairs in line with OEMs' requirements as set out in Maintenance Manuals. Long service lives therefore translate to on-going requirements for the use of the chromium trioxide in the production of spare parts and in the maintenance of those spare components and the final products.

As such, a review period of at least 12 years is warranted and requested for the highly complex systems used in the industrial gas turbine sector of this application. A 12-year review period in itself may not be sufficient for the industrial gas turbine sector to fully replace all chromium trioxide use in all slurry coatings if the current and ongoing research and development is unsuccessful. However, the industry is committed to the goal of substitution and this is highly likely to be achieved for several components. A 12-year review period will enable the implementation of the significant (additional) investment in R&D, qualification and certification of design/drawing changes and industrialisation required across the various OEMs and the relevant applicators/MROs.

4.10.3 Criterion 2: Cost of moving to substitutes

Cr(VI) coatings were validated/certified for use in the aerospace sector in the 1950s and 1960s and extensive in-service performance has demonstrated the performance of chromated materials. Around the same time chromates were used to protect industrial gas turbines. Chromium trioxide based slurry coatings, due to their extensive performance history, represent the baseline that alternatives must match to demonstrate equivalence.

For example, modern industrial gas turbines many constantly be in operations for 40,000 hours or more before undergoing maintenance and overhaul. Industrial gas turbines have collectively billions of hours' experience of operation time with components protected from corrosion by chromium trioxide based slurry coatings. Conversely, there is still limited experience with Cr(VI)-free alternatives on components. It is critical that components coated using a Cr(VI)-free alternative are demonstrably every bit as safe as they had been when coated using a Cr(VI) product. The performance of Cr(VI)-free products can sometimes be demonstrated at the laboratory step but then fails at industrial scale, as it is impossible to replicate all in-service conditions in a laboratory. As a result, the time taken to progress through the TRL process may be increased until it is possible for the performance of the alternative to be demonstrated as equivalent to the existing chromium trioxide solution operating under real life conditions.

Turbine reliability and safety are of paramount concern and cannot be diminished. Take, for example, a compressor blade that is located in the middle of an engine. If that blade can only survive for a portion of the life of an engine due to service life (and hence maintenance requirement) limitations on a new coating, the engine would need to be disassembled to be able to access the blades. That means disconnecting the turbine, sending it to an MRO center, disassembling the turbine and replacing the components at much shorter intervals than previously needed for the remainder of the turbines life. This would add inherent maintenance time and costs to the manufacturers; MRO operators; and eventually end-use customers.

Where possible, and for specific components and final products, some alternatives might be able to be utilised that do not contain a Cr(VI)-based coating, however an alternative has not be identified for several other turbine components. Although the use and worker risk may therefore be reduced due to the implementation of an alternative(s), use of chromium trioxide coatings will still be required for other components for at least several years.

These technical hurdles are a fundamental reason why the industrial gas turbine industry requests a review period of at least 12 years.

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

Research into the substitution of the chromium trioxide has been on-going for several years in several different sectors (including industrial gas turbines and the aerospace sector). Although there have collectively been achievements by companies in reducing the amount of chromates being used, research is ongoing for challenging components and operating conditions.

Industrial gas turbine companies cannot easily apply a less effective corrosion protection process as this will likely increases risks and have significant impacts. If such equal or better performance is not achieved, then the alternatives are unlikely to be used. The implications for repair, replacement and overhaul must also be understood before moving to an alternative. In particular, it must be recognised that the performance delivered by one component is dependent upon the performance of other components; thus, the performance delivered by a final product is dependent upon the components used. The number of configurations of components and final products is immense and each configuration may differ from the next in terms of its behaviour with a Cr(VI) alternative.

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

4.10.5 Criterion 4: Legislative measures for alternatives

As discussed in detail in section 3, the identification of a technically feasible Cr(VI)-free formulation is only the first stage of an extensive multi-phase substitution process leading to implementation of the alternative. This process, illustrated below, requires that all components, materials and processes incorporated into an industrial gas turbine system to be qualified, validated, internally certified and industrialised before production and applicator/MRO activity can commence.

From start to finish, significantly more than 12 years is required to move from Phase 1 to Phase 5 (i.e. to identify, qualify, validate, certify and industrialise alternatives) for all critical industrial gas turbine components. The industrial gas turbine OEMs are design owners are currently working through this process with the aim of implementing one or more chromium trioxide free coatings by 2036; their current substitution plans are designed to ensure they achieve industrialisation within the next 12 years or sooner. This includes completing internal certification with applicators and MROs for all relevant industrial has turbine components, which can take up to three years to complete.

[redacted]

[redacted]

[redacted]

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

IP has highlighted the importance of worker protection to the customers by providing information on business practices and the relevant authorisation numbers are clearly indicated on their products. As demonstrated by the information collected by the SEA questionnaire, applicators and MRO companies have invested in monitoring and the installation of additional risk management measures in response to the conditions placed on the continued use of the chromates under the initial authorisations. These measures have resulted in reduced exposures for both workers and reduced emissions to the environment. As substitution progresses, consumption of chromium trioxide will decrease and exposures and emissions will be further reduced over the requested 12-year review period. As a result, the excess lifetime risks derived in the CSR for both workers and humans via the environment will decrease over the review period. These risks will also be controlled through introduction in 2017 of the binding occupational exposure limit value on worker exposures to Cr(VI) at the EU level under the Carcinogens and Mutagens Directive[84].

As described in section 4, the socio-economic benefits of retaining several key manufacturing bases in the EEA and UK industrial gas turbine industry is clearly significant. As demonstrated in the socio-economic analysis presented here, even without accounting for any such growth in demand under the continued use scenario (for example by demand for industrial gas turbines increasing) the socio-economic benefits clearly outweigh the associated risks to human health at social costs to risk ratios of over 60 for both the EEA and UK (PV @ 4%, 2 years).

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

As the AoA shows, some alternatives are shown to be potentially technically feasible for some components/turbines – on a component-by-component/turbine-by-turbine basis – they are currently in the process of completing R&D and will then be implemented. However, there are still many cases where components do not have technically feasible alternatives available yet. **Figure 4-2** highlights the actions that are being taken by industrial gas turbine OEMs to develop, qualify, validate, internally certify and industrialise alternatives for individual components.

This work will continue over the requested review period with the aim of phasing out all uses of chromium trioxide-based slurry coatings. As highlighted previously, on-going substitution is expected to result in decreases in the volumes of the chromium trioxide used in slurry coatings within the next 7 years for larger industrial gas turbines used in more controlled and less challenging environments. However, technically feasible alternatives are still at the development phase for some components of other turbines, where alternatives have not been found to meet performance requirements of more challenging environments.

4.12 Links to other Authorisation activities under REACH

This application is similar to the series of applications for the re-authorisation of the use of chromium trioxide in surface treatments carried out by the aerospace and defence industry.

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[84] Directive 2004/37/EC of the European Parliament and of the Council of 29 April 2004 on the protection of workers from the risks related to exposure to carcinogens or mutagens at work (Sixth individual Directive within the meaning of Article 16(1) of Council Directive 89/391/EEC), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32004L0037

5 CONCLUSION

IP produces Cr(VI)-based formulations that are then applied by European/British specialised applicators to protect the components of several different turbines. Subsequently, the coated components are used to produce gas turbines that are finally utilised by several of IP's downstream users such as companies in various industrial sectors and different non-industrial actors. During their whole service life, gas turbines work under challenging technical stress, heat and corrosive conditions and are in contact with chemical agents (i.e. salts, hydrogen sulphide, hydraulic fluids, engine oils, fuel). Chromium trioxide coatings provide protection to enhance the durability the turbines' components enabling a high level of corrosion protection, high temperature resistance, smooth surface finish, chemical resistance, as well as excellent scratch and abrasion resistance.

Since 2014, R&D has been conducted into the substitution of chromium trioxide-based slurry coatings, substantial efforts have been made by IP on its own and in collaboration with its key downstream users. Four Metallic Ceramic Aluminium Coatings (MCAC) and two alternative diffusion coatings have been identified and are currently undergoing further development. However, at present, none of these coatings free of Cr(VI) are technically ready having only been tested at laboratory scale and as part of short turbine tests. Site-based and in-field engine testing of these coatings are still needed to ensure that the gas turbines meet all the above-mentioned technical requirements required by the OEMs. As described in detail in the substitution plan, completing these tests under typical operational conditions during the real running time of industrial gas turbines will take several years.

In terms of the health risks from the continued use scenario, the implementation of risk management measures and protective personal equipment allow risks to be reduced. The residual risks to human health of continued use of Cr(VI) amount to <€1 million for the EEA and <£1 million for the UK when the assumed number of sites has been extrapolated.

Among several potential non-use scenarios, two were selected as being the most likely.

The first one considers the continued use of chromium trioxide formulations outside the EEA/UK

The second one considers the implementation of an unproven alternative coating technology. However, this non-use scenario does not come without risk, as significantly increased turbine downtime, more frequent recoating and higher maintenance would be needed.

Huge socio-economic impacts are expected for IP and other actors along the supply chains that depend on the use of chromium trioxide. These DUs are European/British companies applying the coatings and/or conducting maintenance, repair and operations (MRO), turbine manufacturers, different industries and non-industrial actors for mechanical or electrical power as well as the end users of the final industrial products that required heat energy produced by the gas turbines. Overall, in case an authorisation was not granted to IP for the use of Cr(VI) slurry coatings for downstream users in industrial gas turbines and associated components, the total socio-economic costs per year (NPV 4% base year 2022) incurred by IP and all other actors along the supply chains would amount to approximately €773 – 962 million for the EEA and £314 – 316 million for the UK.

Combining all impacts, socio-economic benefits of a granted authorisation outweigh the monetized health risks related to the continued use of chromium trioxide by factors significantly greater than 1, ratios of 66:1 and 1,982:1 (lower and upper bound respectively).

In summary, as demonstrated in the analysis of alternative and in the substitution plan, due to the technical requirements and the complexity of the substitution of Cr(VI)-based slurry coatings for industrial gas turbines, at least 12 years (long review period) will be needed. The length of the requested review period includes the time still needed for research and development, for testing on site and under real situations, as well as for allowing a successful implementation of the alternative and get new certifications. The substitution plan takes into consideration all potential overlaps between the different phases to shorten the substitution timeline period as much as possible. This includes the likelihood that larger turbines (which make up a minority of all turbines) may be able to substitute to an alternative earlier in the review period.

As demonstrated by the socio-economic analysis, a long review period would prevent power and heat losses due to a lack of turbine downtime, this is especially important for those sectors which are critical national infrastructure and to avoid profit and job losses all along the affected supply chains.

In conclusion, a non-authorisation or an authorisation granted for a review period shorter than 12 years would significantly affect the European/British society. The requested review period is expected to start at the end of 2024 and run until the end of 2036.

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ANNEX 1 – Instructions on how to document confidential and public information

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Table A1-1: Justifications for confidentiality claims

Reference type	Commercial Interest	Potential Harm	Limitation to Validity of Claim
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

Table A1-1: Justifications for confidentiality claims

Reference type	Commercial Interest	Potential Harm	Limitation to Validity of Claim
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

Table A1-1: Justifications for confidentiality claims

Reference type	Commercial Interest	Potential Harm	Limitation to Validity of Claim
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

ANNEX 2 – Laboratory testing of chrome free alternatives

Table A2-1: Laboratory testing of chrome free alternative [redacted]			
Criteria	**Requirement**	**Testing result**	**Image**
Initial testing carried out in 2018			
Corrosion resistance **“Override criteria”**	*1000+ hours of neutral salt spray resistance* *ECM-LAB-0046 – no corrosion creep > 1mm from scribe and no breakdown of coating*	Failure of the [redacted] with [redacted] [redacted]. [redacted]. Poor result.	[redacted] #F (whole table)
Water solubility **“Override criteria”**	*Resistance to water at 80°C for 100 hours* *After examination, subjected to bend and adhesion testing.*	Failure of the [redacted]. Poor result, unable to perform subsequent adhesion and bend tests.	

Table A2-1: Laboratory testing of chrome free alternative [redacted]

Criteria	Requirement	Testing result	Image
Candidate testing in 2020			
Corrosion resistance **“Override criteria”**	*1000+ hours of neutral salt spray resistance* *ECM-LAB-0046 – no corrosion creep > 1mm from scribe and no breakdown of coating*	[redacted] [redacted] in scribe and some [redacted] from blistering.	[redacted]
Water solubility **“Override criteria”**	*Resistance to water at 80°C for 100 hours* *After examination, subjected to bend and adhesion testing.*	Major loss of [redacted] on one side of panel, but no damage to [redacted]. Bend test and adhesion test was done on the side of the panel with the topcoat still intact. Bend test – small chipping within [redacted] of the edge. Considered as a pass.	

Table A2-1: Laboratory testing of chrome free alternative [redacted]

Criteria	Requirement	Testing result	Image
		Adhesion test – After scoring the surface, it was lightly brushed removing the [redacted]	[redacted]
Overspeed erosion test	*Coated blades fitted to a dummy [redacted] [redacted] and exposed to 3 overspeed cycles.* *The average depth of material loss was taken as the average of three measurements*	2 overspeed cycles were performed. There was a [redacted] and showed [redacted]. Maximum erosion – [redacted] up aerofoil	

Table A2-2: Laboratory testing of chrome free alternative [redacted]			
Criteria	**Requirement**	**Testing result**	**Image**
Initial testing carried out in 2018			
Corrosion resistance **"Override criteria"**	*1000+ hours of neutral salt spray resistance* *ECM-LAB-0046 – no corrosion creep > 1mm from scribe and no breakdown of coating*	No [redacted] present in the scribe or ball drop, [redacted] and [redacted] was observed.	[redacted] #F (whole table)
Water solubility **"Override criteria"**	*Resistance to water at 80°C for 100 hours* *After examination, subjected to bend and adhesion testing.*	Small blisters across the panel. Panels subjected to bend and adhesion testing showed [redacted]. As well the water appears to have blistered the coating influencing the [redacted] on the adhesion test	

Table A2-2: Laboratory testing of chrome free alternative [redacted]

Criteria	Requirement	Testing result	Image
			[redacted]
Candidate testing in 2020			
Corrosion resistance **“Override criteria”**	*1000+ hours of neutral salt spray resistance* *ECM-LAB-0046 – no corrosion creep > 1mm from scribe and no breakdown of coating*	[redacted] in the scribe and on ball drop panels. Some [redacted] upon receipt of returned panels but not visible in the photographs.	[redacted]

Table A2-2: Laboratory testing of chrome free alternative [redacted]

Criteria	Requirement	Testing result	Image
			[redacted]
Water solubility **“Override criteria”**	*Resistance to water at 80°C for 100 hours* *After examination, subjected to bend and adhesion testing.*	A pair of panels were coated by separate applicators. One of the panels had no blisters and passed both bend and adhesion tests. The other panel had blistering after water exposure and delamination was observed after adhesion testing.	[redacted]

Table A2-2: Laboratory testing of chrome free alternative [redacted]

Criteria	Requirement	Testing result	Image
Overspeed erosion test	*Coated blades fitted to a dummy [redacted] [redacted] and exposed to 3 overspeed cycles.* *The average depth of material loss was taken as the average of three measurements*	2 overspeed cycles were performed. Small defects observed but nothing significant. Maximum erosion – [redacted] mm	[redacted]

Table A2-3: Laboratory testing of chrome free alternative [redacted]

Criteria	**Requirement**	**Testing result**	**Image**
Initial testing carried out in 2018			
Corrosion resistance **“Override criteria”**	*1000+ hours of neutral salt spray resistance* *ECM-LAB-0046 – no corrosion creep > 1mm from scribe and no breakdown of coating*	Before re-formulation, known as [redacted] Formation of [redacted] on the scribe and on the ball drop. Slight breakdown of the [redacted].	[redacted] #F (whole table)
Water solubility **“Override criteria”**	*Resistance to water at 80°C for 100 hours* *After examination, subjected to bend and adhesion testing.*	Before re-formulation, known as [redacted] There was a small amount of white deposit and blistering in one area of the panel.	

Table A2-3: Laboratory testing of chrome free alternative [redacted]

Criteria	Requirement	Testing result	Image
Candidate testing in 2020			
Corrosion resistance **“Override criteria”**	*1000+ hours of neutral salt spray resistance* *ECM-LAB-0046 – no corrosion creep > 1mm from scribe and no breakdown of coating*	After re-formulation and name change. Some [redacted] product present in the scribe.	[redacted]

Table A2-3: Laboratory testing of chrome free alternative [redacted]

Criteria	Requirement	Testing result	Image
Water solubility **"Override criteria"**	*Resistance to water at 80°C for 100 hours* *After examination, subjected to bend and adhesion testing.*	After water exposure the coating did not have any blistering and passed both adhesion and bend tests with no decrease in performance.	[redacted]
Overspeed erosion test	*Coated blades fitted to a dummy [redacted] [redacted] and exposed to 3 overspeed cycles.* *The average depth of material loss was taken as the average of three measurements*	2 overspeed cycles were performed. Small defects observed but nothing significant. Topcoat peeled off slightly. Maximum erosion – [redacted] mm	[redacted]

Table A2-4: Laboratory testing of chrome free alternative [redacted]

Criteria	**Requirement**	**Testing result**	**Image**
Initial testing carried out in 2018			
Corrosion resistance **“Override criteria”**	*1000+ hours of neutral salt spray resistance* *ECM-LAB-0046 – no corrosion creep > 1mm from scribe and no breakdown of coating*	Before reformulation, known as [redacted] [redacted]. No [redacted] on the scribe, but a small amount on the convex side of the ball drop.	[redacted] #F (whole table)

Table A2-4: Laboratory testing of chrome free alternative [redacted]

Criteria	Requirement	Testing result	Image
Water solubility **“Override criteria”**	*Resistance to water at 80°C for 100 hours* *After examination, subjected to bend and adhesion testing.*	Before reformulation, known as [redacted] [redacted]. [redacted] on the centre of the panel, however, this did not impact the subsequent adhesion and bend tests.	[redacted]
Candidate testing in 2020			
Corrosion resistance **“Override criteria”**	*1000+ hours of neutral salt spray resistance* *ECM-LAB-0046 – no corrosion creep > 1mm from scribe and no breakdown of coating*	[redacted] product in the cross score and protrusions under the coating. [redacted]. This was considered as a failure.	[redacted]

Table A2-4: Laboratory testing of chrome free alternative [redacted]

Criteria	Requirement	Testing result	Image
			[redacted]
Water solubility **“Override criteria”**	*Resistance to water at 80°C for 100 hours* *After examination, subjected to bend and adhesion testing.*	Adhesion to mild steel panels demonstrated decreased performance and failures in subsequent adhesion tests. The coating applied to stainless steel panels was better.	

Table A2-4: Laboratory testing of chrome free alternative [redacted]

Criteria	Requirement	Testing result	Image
Overspeed erosion test	*Coated blades fitted to a dummy* [redacted] [redacted] *and exposed to 3 overspeed cycles.* *The average depth of material loss was taken as the average of three measurements*	2 overspeed cycles were performed. [redacted] Maximum erosion – [redacted] mm	[redacted]

ANNEX 3 – Industrial gas turbines

This Annex sets out some information about the industrial gas turbines of companies known to be downstream users of IP. The downstream users are claimed as being confidential and therefore all information is redacted. Some of the largest industrial gas turbine manufactures are however set out in **Table 2-5** and additional information about these is set out in ANNEX 4.

[redacted]

Table A3-1: [redacted]

Turbine	Number of turbines produce	Power generation (MW)	Mechanical drive gross output (MW)	Hydrogen ready
[redacted]	#C, D, E (whole table)	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Source: [redacted]

[redacted]

Table A3-2: [redacted]

Turbine	Number of turbines produce	Power generation (MW)	Mechanical drive gross output (MW)	Hydrogen ready
[redacted]	#C, D, E (whole table)	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Source: [redacted]

[redacted]

Table A3-3: [redacted]

Turbine	Number of turbines produce	Power generation (MW)	Mechanical drive gross output (MW)	Hydrogen ready
[redacted]	#C, D, E (whole table) [redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Source: [redacted]

[redacted]

Table A3-4: [redacted]

Turbine	Number of turbines produce	Power generation (MW)	Mechanical drive gross output (MW)	Hydrogen ready
[redacted]	#C, D, E (whole table) [redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Source: [redacted]

[redacted]

Table A3-5: [redacted]

Turbine	Number of turbines produce	Power generation (MW)	Mechanical drive gross output (MW)	Hydrogen ready
[redacted]	#C, D, E (whole table) [redacted]	[redacted]	[redacted]	[redacted]

Source: [redacted]

[redacted]

[redacted]

Table A3-6: [redacted]

Turbine	Number of turbines produce	Simple cycle power generation - gross power output (MW)	Combined cycle power generation - gross power output (MW)	Mechanical drive gross output (MW)	Hydrogen ready
[redacted]	#C, D, E (whole table) [redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table A3-6: [redacted]

Turbine	Number of turbines produce	Simple cycle power generation - gross power output (MW)	Combined cycle power generation - gross power output (MW)	Mechanical drive gross output (MW)	Hydrogen ready
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Source: [redacted]

[redacted]

[redacted]

[redacted]

Table A2-7: [redacted]

Turbine	Number of turbines produce	Power generation (MW)	Mechanical drive gross output (MW)	Hydrogen ready
[redacted]	#C, D, E (whole table)	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Source: [redacted]

ANNEX 4 – Industrial gas turbines

This Annex sets out information about the industrial gas turbines OEMs that are not currently known to be downstream users of IP, but who may use chromium trioxide protective coatings. The focus in this Annex is only on those other companies in **Table 2-5**, it is not a complete analysis of all turbine OEMs.

[redacted]

Table A3-1: [redacted]

Turbine	Number of turbines produce	Power generation (MW)	Mechanical drive gross output (MW)	Hydrogen ready
[redacted]	#C, D (whole table)	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Total	[redacted]	[redacted]	[redacted]	[redacted]

Source: [redacted]

[redacted]

Table A3-2: [redacted]

Turbine	Number of turbines produce	Power generation (MW)	Mechanical drive gross output (MW)	Hydrogen ready
[redacted]	#C, D (whole table)	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table A3-2: [redacted]

Turbine	Number of turbines produce	Power generation (MW)	Mechanical drive gross output (MW)	Hydrogen ready
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Source: [redacted]

[redacted]

Table A3-3: [redacted]

Turbine	Number of turbines produce	Power generation (MW)	Mechanical drive gross output (MW)	Hydrogen ready
[redacted]	#C, D (whole table)	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table A3-3: [redacted]

Turbine	Number of turbines produce	Power generation (MW)	Mechanical drive gross output (MW)	Hydrogen ready
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Source: [redacted]

[redacted]

Table A3-4: [redacted]

Turbine	Number of turbines produce	Power generation (MW)	Mechanical drive gross output (MW)	Hydrogen ready
[redacted]	#C, D (whole table) [redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Source: [redacted]

[redacted]

Table A3-5: [redacted]

Turbine	Number of turbines produce	Power generation (MW)	Mechanical drive gross output (MW)	Hydrogen ready
[redacted]	#C, D (whole table)	[redacted]	[redacted]	[redacted]

Source: [redacted]

ANNEX 5 – Enterprises, employees, salaries, turnover, GOS, GVA and profit margins of sectors in the EU and UK where industrial gas turbines are known to be used

Profit margins are colour code as follows, less than 5 – red, less than 10 – orange, less than 20 – yellow, more than 20 – green. Information in **Table A5-1** for the EU is taken from 2020 and for the UK in **Table A5-2** it is taken from 2018. Both years predate the COVID-19 pandemic and conflict in Ukraine, the impact of both of these events may have impacted the information captured in these tables including the profit margins.

Table A5-1: Enterprises, employees, salaries, turnover, GOS, GVA and profit margins of sectors in the EU where industrial gas turbines are known to be used

Sector	NACE Code	Number of enterprises	Number of employees	Average salary (thousand €)	Turnover (million €)	GOS (million €)	GVA (million €)	Profit margin (%)
Oil and gas	B06.10 Extraction of crude petroleum	133	7,920	93	5,740	653	1,390	11.4
	B06.20 Extraction of natural gas	68	10,827	77	:	:	:	:
	B09.10 Support activities for petroleum and natural gas extraction	1,040	20,200	67	5,283	1,301	2,658	24.6
Food and drink	C10 Manufacture of food products	260,000	4,000,000	30.0	945,912*	70,000	190,000	7.7
	C10.5 Manufacture of dairy products	12,569	390,326	42	172,878	10,032	26,386	5.8
	C10.61 Manufacture of grain mill products	5,049	84,301	61	34,598	1,991	5,054	5.8
	C10.62 Manufacture of starches and starch products	250	21,624	60.0	13,940	1,149	2,471	8.2
	C10.81 Manufacture of sugar	161	31,086	58	14,005	723	2,537	5.2
	C10.91 Manufacture of prepared feed for farm animals	3,786	88,223	42	62,800	3,356	7,041	5.3
	C11 Manufacture of beverages	31,000	400,000	45	140,000	18,147*	36,152*	14.5

Table A5-1: Enterprises, employees, salaries, turnover, GOS, GVA and profit margins of sectors in the EU where industrial gas turbines are known to be used

Sector	NACE Code	Number of enterprises	Number of employees	Average salary (thousand €)	Turnover (million €)	GOS (million €)	GVA (million €)	Profit margin (%)
	C11.01 Distilling, rectifying and blending of spirits	7,444	41,873	42	17,285	2,619	4,380	15.2
	C11.05 Manufacture of beer	7,205	127,143	48	38,721	5,600	11,748	14.5
	C11.06 Manufacture of malt	123	3,248	48	2,427	225	381	9
Textiles	**C13.10 Preparation and spinning of textile fibres**	2,732	42,147	25	6,281	481	1,531	7.6
	C13.20 Weaving of textiles	4,300	70,045	32	10,572	806	3,020	7.6
	C13.30 Finishing of textiles	9,381	59,353	25	5,160	510	1,985	9.9
	C13.96 Manufacture of other technical and industrial textiles	3648*	64,448	37	10,519	877	3,245	8.3
Paper	**C17.12 Manufacture of paper and paperboard**	1,620	140,566	59	67,364	6,393	14,689	9.5
	C17.21 Manufacture of corrugated paper and paperboard and of containers of paper and paperboard	6,906	260,334	39	53,435	5,889	16,105	11.0
Petrol	**C19.20 Manufacture of refined petroleum products**	821	163,082	69	306,162	2,714	13,953	2.8
Chemicals	**C20 Manufacture of chemicals and chemical products**	29,000	1,092,030*	:	528,931	67,187	142,673	12.7
Plastics	**C20.16 Manufacture of plastics in primary forms**	2,246	129,734	70	79,362	6,714	15,751	8.5
Pesticides	**C20.20 Manufacture of pesticides and other agrochemical products**	618	29,474	66	13,817	1,287	3,238	9.3
Pharma	**C21.10 Manufacture of basic pharmaceutical products**	745*	61,356	59	16,957*	3,153*	6,405*	16

Table A5-1: Enterprises, employees, salaries, turnover, GOS, GVA and profit margins of sectors in the EU where industrial gas turbines are known to be used

Sector	NACE Code	Number of enterprises	Number of employees	Average salary (thousand €)	Turnover (million €)	GOS (million €)	GVA (million €)	Profit margin (%)
	C21.20 Manufacture of pharmaceutical preparations	3,000	572,584	79	321,377	80,344	125,433	25.0
Rubber	C22.11 Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres	1,460	99,248	44	31,411	3,256	7,661	10.4
	C22.19 Manufacture of other rubber products	6,510	209,727	38	31,445	2,688	10,568	8.5
Glass	C23.1 Manufacture of glass and glass products	13,794	290,000	41	50,000	5,000	17,000	10.0
	C23.13 Manufacture of hollow glass	3,137	87,674	40	15,402	2,303	5,845	15.0
Ceramics and cement	C23.20 Manufacture of refractory products	702	23,000	46	4,803	382	1,444	8.0
	C23.31 Manufacture of ceramic tiles and flags	1,071	60,000	39	11,796	1,768	4,098	15.0
	C23.51 Manufacture of cement	300	56,793	58	20,143	4,010	7,314	19.9
Asphalt refinery	C23.99 Manufacture of other non-metallic mineral products n.e.c.	2,360	61,343	46	17,683	2,049	4,878	11.6
Steel	C24.10 Manufacture of basic iron and steel and of ferro-alloys	2,769	315,913	55	125,668	1,953	19,282	1.6
Automo.	C29.10 manufacture of motor vehicles	2,000	1,090,000	72	710,000	31,516	110,000	4.4

Table A5-1: Enterprises, employees, salaries, turnover, GOS, GVA and profit margins of sectors in the EU where industrial gas turbines are known to be used

Sector	NACE Code	Number of enterprises	Number of employees	Average salary (thousand €)	Turnover (million €)	GOS (million €)	GVA (million €)	Profit margin (%)
Elect. & gas	D35.11 Production of electricity	145,912	349135*	58*	458,001	78,838	113,436	17.2
	D35.22 Distribution of gaseous fuels through mains	572	53,013	46	25,846	7,258	9,712	28.1
Water	E36.00 Water collection, treatment and supply	15,000	343,604	35	54,200	14,427	26,328	26.6
Waste	E37.00 Sewerage	11,824	140,999	33*	24,874	3,941*	14,171	26.2
	E38.21 Treatment and disposal of non-hazardous waste	6,700	191,292	43	36,914	6,309	14,562	17.1
	E38.22 Treatment and disposal of hazardous waste	1,000	29,257	49	6,280	1,510	495	24.0
Transport	H49.50 Transport via pipeline	192	26,555	56	14,551	7,173	8,653	49.3
	H52.23 Service activities incidental to air transportation	5,851	249,368	49	24,827	-131	12,170	44.3
Banking	K64.11 Central banking	20*	34087*	:	:	19,576*	22,905*	:
	K64.19 Other monetary intermediation	4857*	1,696,688	:	:	123,483*	260,072*	:
Film	M74.20 Photographic activities	146,684	50,000	24	6,248*	1,800	3,000	25.5

Source: Eurostat

*Where no data was available for EU27, the total/average has been taken from the countries where data was available

GOS = Gross operating surplus, GVA = Gross Value Added

Table A5-2: Enterprises, employees, salaries, turnover, GOS, GVA and profit margins of sectors in the UK where industrial gas turbines are known to be used

Sector	NACE code	Number of enterprises	Number of employees	Average salary (thousand €)	Turnover (million €)	GOS (million €)	GVA (million €)	Profit margin (%)
Oil and gas	B06.10 Extraction of crude petroleum	78	12,745	164	30,798	:	:	:
	B06.20 Extraction of natural gas	77	193	47	181	:	:	:
	B09.10 Support activities for petroleum and natural gas extraction	211	:	:	5,331	1,057	2,737	19.8
Food and drink	C10 Manufacture of food products	8,224	389,957	35	95,551	10,872	24,584	11.4
	C10.5 Manufacture of dairy products	692	28,428	41	10,907	537	1,696	4.9
	C10.61 Manufacture of grain mill products	160	9,407	27	3,924	935	1,391	23.8
	C10.62 Manufacture of starches and starch products	5	1,227	148	1,737	36	69	2.0
	C10.81 Manufacture of sugar	6	1,770	81	1,181	95	238	8.0
	C10.91 Manufacture of prepared feed for farm animals	281	9,600	44	5,526	339	758	6.1
	C11 Manufacture of beverages	:	:	:	:	:	:	:
	C11.01 Distilling, rectifying and blending of spirits	577	14265	62	8,362	3,082	3,967	36.9
	C11.05 Manufacture of beer	1,364	12,768	50	8,351	940	1,575	11.3
	C11.06 Manufacture of malt	9	1,254	52	785	117	181	15
Textiles	C13.10 Preparation and spinning of textile fibres	123	2,875	20	255	31	90	12.0

Table A5-2: Enterprises, employees, salaries, turnover, GOS, GVA and profit margins of sectors in the UK where industrial gas turbines are known to be used

Sector	NACE code	Number of enterprises	Number of employees	Average salary (thousand €)	Turnover (million €)	GOS (million €)	GVA (million €)	Profit margin (%)
	C13.20 Weaving of textiles	188	6,905	27	809	132	321	16.3
	C13.30 Finishing of textiles	1,040	8,133	23	741	162	345	21.9
	C13.96 Manufacture of other technical and industrial textiles	201	3,526	30	446	68	172	15.1
Paper	C17.12 Manufacture of paper and paperboard	:	:	:	:	:	:	:
	C17.21 Manufacture of corrugated paper and paperboard and of containers of paper and paperboard	382	:	:	:	:	:	:
Petrol	C19.20 Manufacture of refined petroleum products	114	11,321	95	84,111	2,354	3,432	:
Chemicals	C20 Manufacture of chemicals and chemical products	2,945	102,224	45	35,628	5,925	10,524	16.6
Plastics	C20.16 Manufacture of plastics in primary forms	373	11,223	46	6,175	1,065	1,583	17.2
Pesticides	C20.20 Manufacture of pesticides and other agrochemical products	69	2,475	39	908	227	323	25.0
Pharmaceutical	C21.10 Manufacture of basic pharmaceutical products	194	6,984	59	1,914	387	799	20.2
	C21.20 Manufacture of pharmaceutical preparations	449	43,117	61	17,562	3,246	5,874	18.5
Rubber	C22.11 Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres	41	:	:	1,684	-0.7	271	0.0

Table A5-2: Enterprises, employees, salaries, turnover, GOS, GVA and profit margins of sectors in the UK where industrial gas turbines are known to be used

Sector	NACE code	Number of enterprises	Number of employees	Average salary (thousand €)	Turnover (million €)	GOS (million €)	GVA (million €)	Profit margin (%)
	C22.19 Manufacture of other rubber products	523	:	:	2,285	423	948	18.5
Glass	C23.1 Manufacture of glass and glass products	736	24,524	29	3,440	719	1,432	20.9
	C23.13 Manufacture of hollow glass	44	5,314	48	1,140	236	488	20.7
Ceramics and cement	C23.20 Manufacture of refractory products	91	2,218	38	466	54	137	11.6
	C23.31 Manufacture of ceramic tiles and flags	56	:	:	123	10	38	7.9
	C23.51 Manufacture of cement	6	:	:	128	10	29	7.8
Asphalt refinery	C23.99 Manufacture of other non-metallic mineral products n.e.c.	160	:	:	3,780	450	877	11.9
Steel	C24.10 Manufacture of basic iron and steel and of ferro-alloys	682	25,765	42	8,953	200	1,276	2.2
Automotive	C29.10 manufacture of motor vehicles	980	84,436	73	71,255	8,107	14,274	11.4
Medical/Dental	C32.50 Manufacture of medical and dental instruments and supplies	2,015	36,738	38	5,479	1,051	2,429	19.2
Electricity and gas supply	D35.11 Production of electricity	4,488	35,798	47	26,252	4,283	5,958	16.3
	D35.22 Distribution of gaseous fuels through mains	:	17,639	:	:	:	:	:

Table A5-2: Enterprises, employees, salaries, turnover, GOS, GVA and profit margins of sectors in the UK where industrial gas turbines are known to be used

Sector	NACE code	Number of enterprises	Number of employees	Average salary (thousand €)	Turnover (million €)	GOS (million €)	GVA (million €)	Profit margin (%)
Water	E36.00 Water collection, treatment and supply	120	41,940	48	14,318	6,637	8,674	46.4
Waste	E37.00 Sewerage	1,053	17,729	39	3,706	2,508	3,198	67.7
	E38.21 Treatment and disposal of non-hazardous waste	1,065	21,015	32	4,191	1,081	1,744	25.8
	E38.22 Treatment and disposal of hazardous waste	115	6,206	57	1,297	143	2,930	11.0
Transport	H49.50 Transport via pipeline	:	:	:	:	:	:	:
	H52.23 Service activities incidental to air transportation	944	57,813	49	11,479	5,084	7,935	-0.5
Banking	K64.11 Central banking	1	4,368	:	:	265	716	:
	K64.19 Other monetary intermediation	368	348,214	:	:	65,636	102,096	:
Film	M74.20 Photographic activities	7,938	17,997	24	1,996	794	1,234	39.8

Source: Eurostat
GOS = Gross operating surplus (GOS); GVA = Gross Value Added

As previously indicated, the sectors (**Table 4-28**) where industrial gas turbines are used employ thousands of people across the EEA/UK and relevant sectoral information is provided in **Table A5-1** (EU) and **Table A5-2** (UK). If the total number of employees is summed across the 46 NACE code sectors that industrial gas turbines have been estimated to be in operation, the total number of employees is estimated to approximately 13.4 million across the EU and a further 1.4 million in the UK. In the situation where industrial gas turbines are not able to be used across all of these different sectors, it is not possible to directly tell what level of impact could be expected on these employee numbers. However, taking a conservative figure of 0.1% unemployment across all of the sectors gives some figures which could be used for the consideration of possible impacts. A 0.1% impact on unemployment would represent almost 13,400 employees across the EU and just 1,400 in the UK. Using the Dubourg (2016) social cost of unemployment model, the below unemployment costs have been calculated and presented by member state as well as a total and UK figure, which can all be seen in the table below. The impacts of 1% unemployment would be ten times larger.

Table A5-3: Social cost of unemployment calculator

Country	Social cost of unemployment (€)
Austria	38,700,000
Belgium	76,600,000
Bulgaria	6,340,000
Croatia	6,040,000
Cyprus	1,560,000
Czechia	22,900,000
Denmark	11,300,000
Estonia	1,980,000
Finland	11,000,000
France	355,000,000
Germany	540,000,000
Greece	21,100,000
Hungary	18,000,000
Ireland	3,240,000
Italy	187,000,000
Latvia	2,010,000
Lithuania	4,260,000
Luxembourg	2,910,000
Malta	615,000
Netherlands	71,300,000
Poland	54,400,000
Portugal	26,500,000
Romania	18,100,000
Slovakia	12,100,000
Slovenia	4,900,000
Spain	163,000,000
Sweden	33,800,000
EU 27	**1,694,655,000**
United Kingdom	154,000,000
Total (All)	**1,848,655,000**