Exemption Request Form – Exemptions #6(a)

Date of submission: 09 October 2020

1. Name and contact details

1) Name and contact details of applicant:

Machining steels:

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On behalf of the Company/Business organisations/Business associations listed below participants in the **RoHS Umbrella Industry Project ("the Umbrella Project")**:

European Automobile Manufacturers Association The European Automobile Manufacturers' Association (ACEA) EU Transparency Register ID number: 0649790813-47	AmCham EU SPEAKING FOR AMERICAN BUSINESS IN EUROPE American Chamber of Commerce to the European Union (AmCham EU) EU Transparency Register ID number: 5265780509-97	ANIE FEDERAZIONE CONFINDUSTRIA ANIE Federation EU Transparency Register ID number: 74070773644-23	CIAJ Communications and Information Network Association of Japan (CIAJ)

Copper Development Association Inc. (CDA)	DIGITALEUROPE (DE) EU Transparency Register ID number: 64270747023-20	European Association of Internal Combustion Engine Manufacturers (EUROMOT) EU Transparency Register ID number: 6284937371-73	European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry (COCIR) EU Transparency Register ID number: 05366537746-69
European Garden Machinery Industry Federation (EGMF) EU Transparency Register ID number: 82669082072-33	European General Galvanizers Association (EGGA) EU Transparency Register ID number: 634416015579-93	European Partnership for Energy and the Environment (EPEE) EU Transparency Register ID number: 22276738915-67	European Passive Components Industry Association (EPCIA) EU Transparency Register ID number: 22092908193-23
The European Semiconductor Industry Association (ESIA) is an industry association working under the umbrella and legal entity of the European Electronic Component Manufacturers Association (EECA) EU Transparency Register ID number: 22092908193-23	The European Steel Association (EUROFER) EU Transparency Register ID number: 93038071152-83	Fédération des Industries Mécaniques (FIM) EU Transparency Register ID number: 42858181373783-89	GAMBICA - The UK Association for Instrumentation, Control, Automation & Laboratory Technology
Information Technology Industry Council (ITI) EU Transparency Register ID number: 061601915428-87	Interconnect Technology Suppliers Association (ITSA)	IPC – Association Connecting Electronics Industries EU Transparency Register ID number: 390331424747-18	Japan Analytical Instruments Manufacturers' Association (JAIMA)
Japan Business Council in Europe (JBCE) EU Transparency Register ID number: 68368571120-55	Japan Business Machine and Information System Industries Association (JBMIA)	Japan Electric Measuring Instruments Manufacturers' Association (JEMIMA)	Japan Electrical Manufacturers' Association (JEMA)

Japan Electronics and Information Technology Industries Association (JEITA)	Japan Federation of Medical Devices Associations (JFMDA)	Japan Inspection Instruments Manufacturers' Association (JIMA)	Japan Land Engine Manufacturers Association (LEMA)
Japan Lighting Manufacturers Association (JLMA)	Japan Measuring Instruments Federation (JMIF)	Japan Medical Imaging and Radiological Systems Industries Association (JIRA)	LightingEurope (LE) EU Transparency Register ID number: 29789243712-03
MedTech Europe EU Transparency Register ID number: 433743725252-26	Nippon Electric Control Equipment Industries Association (NECA)	Orgalim – Europe's Technology Industries EU Transparency Register ID number: 20210641335-88	SPECTARIS - German Hightech Industry Association EU Transparency Register ID number: 55587639351-53
The Japan Auto Parts Industries Association (JAPIA)	Wirtschafts Vereinigung Metalle (WVMetalle) EU Transparency Register ID number: 9002547940-17	Wirtschaftsverband Großhandel Metallhalbzeug e.V. (WGM)	Wirtschaftsverband Industrieller Unternehmen Baden e.V. (wvib)
Wirtschaftsverband Stahl- und Metallverarbeitung e.V. (WSM) EU Transparency Register ID number: 921351835520-23	ZVEI - German Electrical and Electronic Manufacturers´ Association EU Transparency Register ID number: 94770746469-09		

2. Reason for application:

Please indicate where relevant:

☐ Request for new exemption in:

☐ Request for amendment of existing exemption in

☒ Request for extension of existing exemption in

☐ Request for deletion of existing exemption in:

☐ Provision of information referring to an existing specific exemption in:

☒ Annex III ☐ Annex IV

No. of exemption in Annex III or IV where applicable: #6(a)

Proposed or existing wording: *Lead as an alloying element in steel for machining purposes containing up to 0,35 % lead by weight and in batch hot dip galvanised steel components containing up to 0,2 % lead by weight (as wording of Exemption 6a-I).*

Duration where applicable: We apply for renewal of this exemption for the category marked in section 4 further below for the respective maximum validity period foreseen in the RoHS2 Directive, as amended. For this category, the validity of this exemption may be required beyond those timeframes. As specified in separate requests to renew the exemption submitted to the European Commission within the deadline foreseen by the Directive for submission of applications, applications in this exemption renewal request are relevant to other categories not marked in section 4 further below.

☐ Other: _____

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3. Summary of the exemption request / revocation request

Steel containing lead for machining purposes

As of today, no alternatives have been identified that can effectively replace lead as a machinability enhancer in steel in all respects. Lead-free alternatives may show acceptable results in single machinability tests, but the overall performance of the lead-free steels is worse than that of leaded steel. The lack of hot workability of the lead-free alternatives is also an important obstacle towards the substitution.

If a variety of machining operations is required or if deep drilling of material is required, lead is still considered, by far, the best machinability enhancer for industrial production. Customer demand (in the EEE sector) supports the view that leaded steels are required rather than the alternatives which are currently offered by European steel manufacturers.

Batch galvanized steel

The batch hot dip galvanizing process allows the complete coverage of manufactured steel components with a metallurgically-bonded metallic coating that is formed through diffusion of iron and zinc (giving no clear delineation between coating and steel substrate). Lead performs no function in the process or the performance of the coating. Lead has had some influence on the process used to apply the coating but this has largely been addressed by advances in process technology, hardware and other techniques. However, more importantly, the batch galvanizing industry is a significant user of recycled zinc ingots that originate from sources that contain lead at levels that would result in exceeding the 0,1% Pb threshold if applied to the coating according to the RoHS Directive. The existing exemption for up to 0,2 % Pb in the steels that have been hot dip galvanized was lowered from 0,35 % Pb with effect July 2019, following careful examination of Pb levels in recycled zinc. There have been no significant changes to prevailing lead levels in recycled zinc or major technical advances in processing techniques since this reduction in the exemption threshold. The existing exemption therefore remains necessary. The exemption is therefore requested primarily to ensure continued use of recycled zinc in many processing facilities and, secondarily, to satisfy technical functions that cannot be replaced in some processing facilities and product types.

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4. Technical description of the exemption request / revocation request

(A) Description of the concerned application:

1. To which EEE is the exemption request/information relevant?

   Name of applications or products:

   Machining steels are used in a diverse range of final applications within electrical and electronic equipment, including finished products, fixed installations etc.

   Batch galvanized steel is used in a variety of small components (e.g. brackets/fixings) and fasteners used in electrical equipment within the scope of WEEE.

   An exhaustive list of applications is not feasible. Batch galvanized items may include ancillary items such as fasteners and support brackets/fixings for a range of EEE items such as lighting units that require high levels of durability in outdoor or aggressive environments. Specific components include transformer housings and heat exchangers (although some of these items may be outside the current scope of the EEE directive). It must be emphasized that the term 'small' is a relative one and is used in the renewal request in the context of the range of items that are batch galvanized – a range that includes large structural steelwork of up to 25m length. Components that are termed 'small' in this request may not be 'small' in the wider context of EEE components.

a. List of relevant categories: (mark more than one where applicable)

☐ 1	☐ 7
☐ 2	☐ 8
☐ 3	☐ 9
☐ 4	☐ 10
☐ 5	☒ 11
☐ 6	

b. Please specify if application is in use in other categories to which the exemption request does not refer: As specified in separate requests to renew the exemption submitted to the European Commission within the deadline foreseen by the Directive for submission of applications, applications in this exemption renewal request are relevant to categories not marked above and below.

c. Please specify for equipment of category 8 and 9:

   The requested exemption will be applied in

   ☐ Monitoring and control instruments in industry

☐ In-vitro diagnostics

☐ Other medical devices or other monitoring and control instruments than those in industry

2. Which of the six substances is in use in the application/product?

   (Indicate more than one where applicable)

   ☒ Pb ☐ Cd ☐ Hg ☐ Cr-VI ☐ PBB ☐ PBDE

3. Function of the substance:

   Machining steels – Lead improves machinability in machining processes allowing deep drilling and/or high-speed operations. The lead provides a great hot workability as well, which is essential for the production of free cutting steels.

   Batch galvanized steel – Lead is primarily present as an inadvertent impurity in recycled zinc used in the process.

4. Content of substance in homogeneous material (%weight):

   Machining steels – Up to 0,35%

   Batch galvanized steel – Pb levels range from <0,03% up to 0,8%Pb in the coating if this is considered the ‘homogeneous material’. Steel items that have been batch hot dip galvanized would therefore be below the exemption limit of 0,2 % Pb.

5. Amount of substance entering the EU market annually through application for which the exemption is requested: _____

   Machining steels – in 2013 the import of steel products for machining purposes amounted to approximately 73,000 tons. Assuming that the lead content in steel for machining purposes is between 0,2 and 0,35%, this means that the lead annually entering in the EU market through the import of free cutting steels can vary between 146 to 255 tons[1]. However, note that these figures do not correspond solely to steel intended for EEE (which was not possible to estimate) and that also contains the volumes of steel intended for automotive.

   Batch galvanized steel – the amount of Pb metal used intentionally for applications in the scope of WEEE/ROHS is estimated to be less than 1 tonne p.a. The amount of Pb circulating within the recycling loop is difficult to establish, but this volume is not 'entering the EU market' for EEE products (it is already in the wider market).

6. Name of material/component: Steel

7. Environmental Assessment:

   Machining steels:

   The addition of lead into low carbon free cutting steels enhances machinability and can increase the production rate of a component by up to 40% depending upon part and machining process design, and a potential reduction in energy usage of approximately 27% when machining parts using the leaded steel are compared to the non-leaded steel. It is also important to consider the wider environmental implications of material choice. The lower energy consumption of machining leaded steels means that there is a potential benefit of reduced electricity consumption and CO_2 emissions in fabrication. However, to assess the full environmental benefit, a more detailed environmental assessment is required, which covers the full life cycle of the product.

   LCA: ☒ Yes. Please, refer to Annex I for additional information.

   ☐ No

   Galvanized steels: Please, go to section 6 for further information.

   LCA: ☒ Yes

   ☐ No

[1] Source: EUROFER statistics (considering the CN codes related to the free cutting steel semifinhed products)

(B) In which material and/or component is the RoHS-regulated substance used, for which you request the exemption or its revocation? What is the function of this material or component?

Lead is used in a number of steel alloys.

The exemption is for the specific application where individual components require machining as part of their production route. As indicated previously, machining steels are used in a diverse range of final applications within the electrical and electronic equipment, also in finished products and in fixed installations. Further explanation on the function is provided in the following answers.

(C) What are the particular characteristics and functions of the RoHS-regulated substance that require its use in this material or component?

<u>Machining steels:</u> Fundamentally, lead is added to enable improved machinability. The specific function of lead in steel is to provide a lubricant effect from the material itself when that material is being machined into a component. Through this lubricant effect, the steel becomes more machinable.

Machinability can be considered as meaning any of the following: a reduced cutting force when machining steel, appropriate chip formation (length and force), facilitation of a smooth surface finish, facilitation of a good dimensional achievement under commercial production conditions or reduced “tool wear” during the machining operation.

Machining encompasses a number of production operations, including: turning, grinding, rough forming, fine forming, drilling and parting.

<u>Batch Galvanized Steel:</u> Lead has a low solubility in the zinc-iron alloys that are formed during the galvanizing reaction. Hence, the quantity of lead present in the coating is normally significantly lower than the lead present in the process bath – typically half as much. For a given bath composition, the variations of lead concentrations in the coating mainly depend on the steel type (reactivity with molten zinc).

Generally galvanized steel items are used in applications such as fasteners, brackets, lighting supports and many others. Advantages of batch galvanized components include:

- Highly durable corrosion protection,
- Resistance to mechanical damage,
- Increased durability allowing lighter steel sections,
- Recyclable within existing steel recycling circuit.

Lead is present in the zinc coating of galvanised steels. Lead has no beneficial (or adverse) effect on the coated product, but may have a technical influence on the galvanizing process in a small number of plants:

- Fluidity – optimal drainage reduces excess zinc on the product (i.e. better resource efficiency)
- Avoidance of "floating dross" during galvanizing of complex geometries which may lead to adverse surface finishes.

The importance of each of these factors varies according to the nature of the component to be coated, the technical features of the plant (often related to the age of the plant) and the type of work that is required of the plant (range of work). It must be emphasized that the intentional addition of lead to the galvanizing bath for the purposes described above is rapidly declining due to technical innovation. The primary justification for the exemption is the inadvertent presence of Pb as an impurity in recycled zinc.

Recycled zinc may be from two main sources:

• Recovery and remelting of scrap zinc sheets from roofing/gutter applications. Many of these scrap arisings are from roofs of cities such as Paris that have been installed >100 years ago. These roofing sheets/gutters were historically joined with lead-based solders. These solders are impossible to separate from the scrap zinc sheets and enter the recycling circuits – giving rise to lead levels in recycled zinc of 0.3-1.0%

• Recovery and remelting of metallic zinc that is entrained in zinc ash generated during the galvanizing process (through surface oxidation). These residues are fully recyclable and the metallic zinc part is separated and returned to the galvanizing bath. In a particular region, the lead content of the recycled zinc from this route will reflect the lead content of the galvanizing bath(s) that supply residues to a specific recycler. Note that those prevailing levels may be influenced by both intentional use and use of recycled zinc. Levels are therefore variable and can be in the range 0.5 – 1.0%.

In some cases, recycled zinc may be produced from a mix of the above routes. Note that there is not a direct correlation between the lead content of the process bath and the lead content of the galvanized steel component. Typically, the lead content of the coating is lower than the content of the bath from which it is produced.

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5. Information on Possible preparation for reuse or recycling of waste from EEE and on provisions for appropriate treatment of waste

1) **Please indicate if a closed loop system exist for EEE waste of application exists and provide information of its characteristics (method of collection to ensure closed loop, method of treatment, etc.)**

The steel industry has in place the appropriate practice and processes to ensure that metals like lead are recovered and made available for recycling and re-use.

Both steel production routes (blast furnaces and electric arc furnaces) recycle the scrap coming from machining of cutting steel and process it into new steel. In practical terms, the lead enters into the process as a component of the scrap. (it does not matter whether it is charged into a converter or into an electric arc furnace). Because of its low melting and vaporisation temperatures (327 ºC and its boiling point is 1749ºC respectively), lead is one of the first elements to melt. Once vaporised, it is sent to the dedusting system, which is commonly used in the steel industry for the treatments of the OFF gases. The recovery ratio of lead in the dust is about 90%, and the remaining 10 % stays in the liquid steel.

2) **Please indicate where relevant:**

☒ Article is collected and sent without dismantling for recycling
☐ Article is collected and completely refurbished for reuse
☐ Article is collected and dismantled:
  ☐ The following parts are refurbished for use as spare parts: ______
  ☐ The following parts are subsequently recycled: ______
☐ Article cannot be recycled and is therefore:
  ☐ Sent for energy return
  ☐ Landfilled

3) **Please provide information concerning the amount (weight) of RoHS substance present in EEE waste accumulates per annum:** No data available

☐ In articles which are refurbished ______
☐ In articles which are recycled ______
☐ In articles which are sent for energy return ______
☐ In articles which are landfilled ______

6. Analysis of possible alternative substances

(A) Please provide information if possible alternative applications or alternatives for use of RoHS substances in application exist. Please elaborate analysis on a life-cycle basis, including where available information about independent research, per-review studies development activities undertaken

Machining steels:

The European steel industry collaborated in the past in the project *technically and commercially viable alternatives to lead as machinability enhancers in steels used for automotive components manufacture (REF7210-PR/306)*[2] funded by the European Coal and Steel Research (ECSC) with the objective of assessing the potential alternatives to lead for low carbon free cutting steels and carbon/alloy grades. The results of this project were presented in the frame of the ELV Directive review of exemptions back in 2008. It needs to be noted though that the effects of lead in steel apply irrespective of the steel final use. Thus, the conclusions of the project are also applicable to RoHS related applications as the basic requirements for machinability are the same as for the automotive applications. Moreover, these results were included in the Öko-Institut final report on the Adaptation to scientific and technical progress of Annex II to Directive 2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS) published in 2010.

As indicated in the Öko-Institut final report, the machinability tests performed included measurement of tool life, tool wear, surface finish, chip form, tool force and tool temperature. The steel grades selected for these tests were free-cutting steels (11SMn30), steels for hardening and tempering (C45) and case hardening steels (16MnCr5) with the following machinability enhancing additions: lead, bismuth (which is often considered as a potential alternative to lead due to its proximity in the periodic table and its lower health and environmental impacts), increased sulphur (with and without tellurium), tin (with low and high copper), phosphorus and calcium.

[2] http://cordis.europa.eu/project/rcn/66565_en.html

Table 1 Comparison of bismuth and lead metal environmental and health impacts[3]

Impact	Units	Lead	Bismuth	Bismuth / lead ratio
Fresh water eutrophication	kgP-eq/kg	0.0022	0.022	10.00
Cumulative energy demand	MJ eq/kg	18.9	697	36.88
Terrestrial acidification	kg SO2 eq/kg	0.028	0.38	13.57
Global Warming Potential	kg CO2-eq/kg	1.3	58.9	45.31

The relative environmental impact of bismuth (proposed a substitute) and lead, based on life cycle assessment, are given in Table 1.

Moreover bismuth, it is a 'critical raw material' as defined by from the European Commission (2017) and is in limited supply. The current production of bismuth is directly linked to the production of lead, as a byproduct. Therefore, if the usage of lead were to decline in the future, production rates of bismuth would be proportionately impacted. More than 80% of bismuth is mined and produced in China.

The general conclusion of these tests is that leaded steels showed the best performance in tests at lower cutting speeds, with high speed steel tools and in deep hole drilling. Non-leaded alternative grades generally gave poorer chip form and surface finish. It was shown that of all the alternatives, bismuth is best able to substitute lead under certain conditions, the hot workability of bismuth steels is reduced compared to leaded steels. Hot workability is a fundamental requirement for steel production. This parameter is of significance when the steel is being rolled to the required size for a customer from a piece with a larger (as-cast) cross sectional area. The reduced hot-workability of bismuth steels effectively means that it is not possible for a steel roller to produce a bar with the same machining properties and surface integrity if the steel obtains its machining properties from bismuth rather than lead.

In accordance with the study, industry emphasized the importance of the 10% reduction in hot workability compared to low-carbon free-cutting steel. Free-cutting steels are already close to the limit of what can be conventionally rolled, making the rolling of bismuthed steel nearly impossible. This means that the

[3] *Nuss P, Eckelman MJ (2014) Life Cycle Assessment of Metals: A Scientific Synthesis. PLoS ONE 9(7): e101298. doi:10.1371/journal.pone.0101298*

bismuthed steel requires more energy to be rolled in order to increase its ductility. However, this can create ruptures in the steel surface which cannot be rectified and can be difficult to detect, causing problems with material integrity and performance if these ruptures are not detected.

It is therefore expected that the energy cost associated with bismuth would be higher as well as potentially higher error rates (i.e. increased waste).

Although the machining properties of bismuth-treated steels approach those of lead-treated steels for certain machining operations, in the majority of machining operations lead remains the most effective machinability additive through its wide range of machining characteristics.

It was further concluded in the report that calcium can substitute lead in C45 steels for use at higher cutting speeds. However, calcium treated steels require higher cutting forces, have poorer chip form and have their best performance limited to a narrower range of machining speeds in comparison with the leaded product. The more limited benefits of calcium treated grades may not be able to match the benefits of leaded grades in many instances since it is very likely that a large variety of machining operations are required for many engineering components.

Steels containing tin generally did not show good performance in the machinability tests and thus, was not considered as a suitable replacement for lead in steel.

In conclusion, leaded free cutting steels offer advantages in machinability over the non-leaded grades including higher production rates, reduced cutting forces, lower tool wear rates, more finely broken chip morphology and improved surface finish. Since lead additions result in lower cutting forces, the energy required to machine leaded steels should be lower than that required to machine the equivalent steels without lead additions.

Batch galvanized steel

Research is ongoing within the industry to develop new zinc-based alloys for general galvanizing. Principal research goals are: (i) more zinc-efficient coatings (thinner coatings regardless of steel type); and (ii) coatings of more consistent appearance and surface finish. These goals are accompanied with a desire to reduce the presence of hazardous substances, including lead. Intentional use of lead is now limited to a narrow, but important, set of processes and products.

More importantly, requiring lower lead content to meet ROHS default limits will result in reduced use of recycled zinc (remelt). The galvanizing industry is an important user of remelt zinc from roofing applications (where Pb-containing solders are mixed with scrap zinc sheets that are removed after service lives that often exceed 100 years) and remelting of zinc entrained in galvanizers' ashes (which will have a Pb content that reflects the prevailing Pb content of the galvanizing bath).

A life-cycle comparison of the embodied energy of (i) remelt secondary zinc and (ii) primary zinc has been published in ‚Sachbilanz Zink', Prof. J. Krüger, Institut für Metallhüttenkunde und Elektrometallurgie der RWTH Aachen (ISBN 3-89653-939-6, 2001). This publication reports that: „*The energy required for the extraction of zinc from scrap to obtain alloys capable of further use demands a primary energy input of only approximately 2.5 GJ/t. During the extraction of zinc from ores, the primary energy requirement for mining and ore dressing is around 5-9 GJ/t metal content in the concentrate. Concentrate processing to obtain a pure metal however calls for a primary energy input of 46-48 GJ/t zinc*." Based on this information, the use of remelt secondary zinc reduces the embodied energy of the zinc used in batch galvanizing by over 20 times.

As a proportion of a total 7 million tonnes of steel that is batch galvanized in Europe, the volume of components in the scope of ROHS and ELV is extremely small (they are technically important but low volume to the batch galvanizing industry). Also, no other components in the scope of ROHS/ELV interface with the recycling circuits mentioned above. However, there are other factors that will eventually lower the lead levels – for example, customer-driven requirements for lower lead levels in markets outside EEE/ELV and the occasionally higher price of lead than zinc (affecting intentional use). There will also, in the longer term (> ~30-50 years due to the very long product life), be a reduction in the lead-content of recycled zinc arising from scrap roofing/gutters (as new solders are introduced).

Some batch galvanizing plants that are either (i) not using recycled zinc in their input material and/or (ii) are not processing components of complex geometry (for all their product mix) may operate with lead levels in the galvanizing bath that would comply with the default requirements of ROHS requirements in the

EEE products they would process and would not require exemption. It would not be appropriate to describe this as ‘substitution’ and could not presently be extended across the whole industry or for all components.

(B) Please provide information and data to establish reliability of possible substitutes of application and of RoHS materials in application

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7. Proposed actions to develop possible substitutes

(A) Please provide information if actions have been taken to develop further possible alternatives for the application or alternatives for RoHS substances in the application.

The steel mills are continuously researching for new alternatives (elements and processing) in order to find efficient substitutes to avoid the use of lead in steel. The element which has been more extensively investigated is the bismuth. However, as further explained in question 6, lead continues showing the best machinability performance. Again, the alternatives do not show the same hot workability as lead, which is a fundamental requirement for the production of machining steels. In fact, this issue alone is enough to rule out the possibility of using bismuthed steels as a replacement of leaded steels.

(B) Please elaborate what stages are necessary for establishment of possible substitute and respective timeframe needed for completion of such stages.

Machining steels: Substitutes would need first to show the same level of hot workability as lead, which has not occurred so far with the identified alternative materials. The availability and the price of possible substitutes are also important aspects to consider. Not further information can be provided at this stage on a respective timeframe for the substitution.

Batch galvanized steel: Whilst the use of lead within the process have largely (but not completely) been replaced by other techniques, the inadvertent presence of lead in the recycling chain will require the exemption for a further period of 5 years and, likely, much longer.

8. Justification according to Article 5(1)(a):

(A) Links to REACH: (substance + substitute)

1) Do any of the following provisions apply to the application described under (A) and (C)?

☐ Authorisation

☐ SVHC
☐ Candidate list
☐ Proposal inclusion Annex XIV
☐ Annex XIV

☐ Restriction

☐ Annex XVII
☐ Registry of intentions

☐ Registration Provide REACH-relevant information received through the supply chain.

Name of document: _____

Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemptions would not weaken the environmental and health protection afforded by the REACH Regulation. The requested exemptions are therefore justified as other criteria of Art. 5(1)(a) apply

(B) Elimination/substitution:

1. Can the substance named under 4.(A)1 be eliminated?

☐ Yes. Consequences? _____

☒ No. Justification: Please, see the answers to questions 6 and 7.

2. Can the substance named under 4. (A) 1 be substituted?

☐ Yes.

☐ Design changes:
☐ Other materials:
☐ Other substance:

☒No.

Justification: Please, see the answers to questions 6 and 7.

3. Give details on the reliability of substitutes (technical data + information):_____

Machining steels:

As previously explained, to date no substitutes have been identified that can effectively replace lead for the machining of free cutting steels. Some of the tested alternatives such as bismuth or sulphur present the following disadvantages:

- Regarding sulphur, industry has been trying to substitute the effect of the lead by adding bigger quantities of sulphur to free-machining steels. The final result is that the properties are not comparable. In deep drilling operations or high-speed machining, the results of the high sulphur grades are really disappointing compared to those achieved with addition of lead. The machining speed without lead decreases, the tooling wear increases and there is a great amount of parts that cannot be manufactured without lead. In addition to this, the increase of sulphur leads to a big increase in fragility and reduction in hot workability, with an important increase of yield losses due to extra-trimming, cobbles and rejection owing to quality issues such as cracks, scabs, hidden defects etc.
- Regarding bismuth, the main issue is the lack of ductility during the hot rolling process. This is a situation which has not yet been solved by the steel industry. The hot workability of the grades with bismuth is really low and, in the majority of cases, this does not allow a correct rolling process, leading finally to major production stoppages and high rejection rates. Moreover, the results achieved with bismuth in terms of machinability are worse than those obtained with lead. Lead still presents a higher machining speed and a lower tooling wear, not to mention that the surface is more easily controlled with lead.

4. Describe environmental assessment of substance from 4.(A)1 and possible substitutes with regard to
    1) Environmental impacts

Machining steels: Please, see answer to question 6A. As mentioned earlier, the lack of hot workability of possible substitutes is a very significant technical disadvantage. This issue alone is enough to dismiss the possibility of using bismuth as a replacement of lead. It is also important to consider the wider environmental implications of the selection of the material. The lower energy consumption of machining leaded steels means that there is a potential benefit of reduced electricity consumption and CO2 emissions in fabrication.

Batch galvanized steels: Please see the LCA related information provided in section 6.

2) Health impacts
3) Consumers safety impacts

⇨ Do impacts of substitution outweigh benefits thereof?

Please provide third-party verified assessment on this:

Galvanized steels- Please, see the LCA related information provided in section 6 *Analysis of possible alternative substances*

(C) Availability of substitutes:

a) Describe supply sources for substitutes: _____
b) Have you encountered problems with the availability? Describe: _____
c) Do you consider the price of the substitute to be a problem for the availability?
☐ Yes ☐ No
d) What conditions need to be fulfilled to ensure the availability? _____

(D) Socio-economic impact of substitution:

⇨ What kind of economic effects do you consider related to substitution?

☐ Increase in direct production costs

☐ Increase in fixed costs

☐ Increase in overhead

☐ Possible social impacts within the EU

☐ Possible social impacts external to the EU

☐ Other: _____

⇨ Provide sufficient evidence (third-party verified) to support your statement: _____

9. Other relevant information

Please provide additional relevant information to further establish the necessity of your request:

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10. Information that should be regarded as proprietary

Please state clearly whether any of the above information should be regarded to as proprietary information. If so, please provide verifiable justification:

No information given in this application is regarded as proprietary.

Annex I

Assessment of the environmental impact of leaded and non-leaded low carbon free cutting steels including energy used during machining

Assessment of the environmental impact of leaded and non-leaded low carbon free cutting steels including energy used during machining

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Assessment of the environmental impact of leaded and non-leaded low carbon free cutting steels including energy used during machining

Author(s): N Coleman, S Dewey, M Green
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Lead is added to low carbon free cutting steels to enhance machinability and can increase the production rate of a component by up to 40% depending upon part and machining process design. Environmental concerns arising from the toxicity of Pb have led to restrictions in the amount of Pb that can be added (0.35% in the European Directive on End of Life Vehicles and in the Restriction of the use of certain hazardous substances in electrical and electronic equipment Directive). Until now all environmental assessments have ignored any potential reduction in CO_2 emissions resulting from Pb additions due to lower cutting forces in machining. This investigation was aimed at determining the impact of Pb additions on the overall global warming potential of low carbon free cutting steels and comparing this with the other environmental impacts of Pb additions.

Measurements of electrical energy consumption during component production tests on the Speedturn lathe at STC were conducted for a low carbon free cutting steel without Pb and one containing 0.33%Pb. These showed that there is a reduction in electrical energy usage of approximately 27% when machining parts using the leaded steel compared to the non-leaded steel for a component with a yield of 45%.

A life cycle assessment (LCA) of leaded and non-leaded free cutting steels showed that whilst leaded steels have the potential to cause toxicity related environmental impacts there are other environmental benefits from using leaded steels. The reduced energy requirements for machining leaded steels means that there are benefits in terms of lower carbon emissions from electricity production and other impacts relating to power generation. Whilst it is not possible to say that toxicity related impacts are more/or less important than impacts such as global warming it does highlight that there are wider issues to be considered, beyond toxicity, when selecting materials. For the part considered in the current machining trials the global warming potential of the final part was 8.8% lower for a leaded steel compared to a non-leaded steel.

Alternatives to leaded steels are in development and these typically use other elements in small percentages instead of lead. LCAs should be carried out in order to assess the environmental impacts of alternatives to lead in free-cutting steel to examine their environmental performance compared to leaded steel alongside the evaluation of machinability.

Customer: Long Products Europe / Speciality Steels – Bar Products
Programme manager/ Project leader: A Dunsmore

Approved by: A W F Smith

Assessment of the environmental impact of leaded and non-leaded low carbon free cutting steels including energy used during machining

1. Introduction

Leaded low carbon free cutting steels offer advantages in machinability over non-leaded grades including higher production rates, reduced cutting forces, lower tool wear rates, more finely broken chip morphology and improved surface finish. Since lead additions result in lower cutting forces the energy required to machine leaded steels should be lower than that required to machine the equivalent steels without lead additions. Despite the benefits of adding Pb to free cutting steels there is concern over the potential environmental impact of Pb as a result of its toxicity; currently an exemption exists in the European Directive on End of Life Vehicles (EELVD) and the Restriction of the use of certain hazardous substances in electrical and electronic equipment Directive (RoHS) that permits Pb additions up to 0.35% to be made to steel for the purpose of enhancing machinability.

Previous studies in the area of Pb additions to free cutting steels have demonstrated that a shift to unleaded steels will be disadvantageous from a global warming point of view but advantageous from a toxicity perspective [1]. The current study focuses on the environmental aspects of producing and fabricating components from leaded and non-leaded steels using a Life Cycle Assessment (LCA) approach. It builds on a previous LCA study which focused on the manufacture of leaded steels but did not include downstream machining operations [3]. The LCA study is based around the principles outlined in the ISO14040: 2006 and ISO14044: 2006 standards on LCA [4]. By undertaking a life-cycle assessment, environmental benefits have been identified which strengthens the case for manufacturing leaded steel. These results can be used to inform those involved in future product development work and policy-making.

To provide data for this life cycle assessment a programme of work has been undertaken at STC to compare the energy consumption during the machining of two low carbon free cutting steels of similar base composition; one containing a lead addition and the other without. This report describes the results of that investigation and subsequent LCA [5].

2. Materials and test methodology

The product analyses of the two batches of bright drawn bar are presented in Table 1. These were originally rolled to 20.5mm diameter coil at Thrybergh Combination Mill (TCM) and then bright drawn to 19.05mm diameter bar at Wednesbury. Component production tests were carried out with HSS cutting tools under neat cutting oil using the Speedturn 30 lathe (test procedure presented in Appendix 1) and these showed that the non-leaded steel had a minimum cycle time of 24s whereas the leaded steel had a minimum cycle time of 13.5s (summary component production test results are given in Table 2). Therefore it was decided for the current test to machine samples at the minimum cycle times for both steels as this would best replicate the way a leaded steel would be used in a production machine shop. A total of 453 components were machined from both steels, which represents roughly 3 hours of machining for the non-leaded steel. During the machining process spindle current sensor signals were monitored for a small number of components in order to allow qualitative comparisons of the cutting forces to be compared against energy measurements.

Table 1 Product Analyses (wt.%)

Cast no.	Type	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Sn	N	Pb	O
L1024A	LCFCS	0.066	0.01	1.06	0.051	0.28	0.09	0.02	0.09	0.15	0.01	0.01		0.020
L1094H	LCFCS+Pb	0.070	0.01	1.18	0.060	0.29	0.08	0.03	0.10	0.10	0.02	0.01	0.33	0.017

Al level for both steels <0.001 wt.%

Table 2 Component production test results

<table>
<tr><th></th><th>Cycle time (s)</th><th>Speed (rpm)</th><th>No. of parts</th><th>RSF (µm)</th><th>FSF (µm)</th><th>PGA (mm)</th><th>PGB (mm)</th><th>PGC (mm)</th></tr>
<tr><td></td><td>Spec.</td><td></td><td></td><td></td><td></td><td>0.07</td><td>0.13</td><td>0.13</td></tr>
<tr><td rowspan="3">LCFCS L1024A</td><td>22.5</td><td>1348</td><td>3</td><td colspan="5">Failed on circular form tool</td></tr>
<tr><td>24</td><td>1348</td><td>660</td><td colspan="5">Failed on parting tool</td></tr>
<tr><td>24</td><td>1598</td><td>900</td><td>7.0 ±1.9</td><td>1.5 ±0.7</td><td>0.04</td><td>0.03</td><td>0.02</td></tr>
<tr><td rowspan="3">LCFCS+Pb L1094H</td><td>12</td><td>1348</td><td>3</td><td colspan="5">Failed on circular form tool</td></tr>
<tr><td>13.5</td><td>1348</td><td>1596</td><td>7.1 ±2.4</td><td>2.3 ±0.6</td><td><0.01</td><td>0.05</td><td>0.05</td></tr>
<tr><td>13.5</td><td>1598</td><td>3</td><td colspan="5">Failed on circular form tool</td></tr>
</table>

The electrical energy measurements were taken by a "Dranitz-BMI PP4300 Power Platform" mains harmonic analyser, using wide-band clamp-on current probes. The instrument serial number is 430ETA247, and it was calibrated on 26/08/2011 prior to the tests being carried out in October 2011. A current clamp was placed on each of the incoming phases of the Speedturn 30 lathe. A voltage probe was connected to each phase; these connections were made on the exit of the low-current circuit breakers to protect the instrument and its wiring. The wiring was taken to the instrument through an existing ventilation opening in the machine. This allowed the machine to be run with all covers closed, minimising the risk of arc-flash exposure.

The instrument was operated in cumulative energy measurement mode. The reading was noted at the beginning of each test and at regular intervals during the tests. In addition a series of measurements was made with the machine idle, to measure the quiescent energy consumption.

3. Machining test results

Energy measurement results for each of the steels are presented in Tables 3 and 4. On the basis of these results the leaded steel uses approximately 75% of the gross energy or 73% of the net energy (machining only) required to machine the same component from non-leaded steel.

Table 3 Energy measurement results for the non-leaded steel

Time	No. of pieces	Energy	Cumulative energy per piece		Cumulative Time	Time per piece
		kWh	kWh	kJoules	hh:mm:ss	s
09:17	0	0.560			00:00:00	
10:00	84	5.754	0.062	222.609	00:43:00	31
11:00	199	12.790	0.061	221.246	01:43:00	31
11:30	265	16.460	0.060	216.000	02:13:00	30
12:00	321	20.020	0.061	218.243	02:43:00	30
12:30	374	23.602	0.062	221.795	03:13:00	31
13:00	445	27.290	0.060	216.243	03:43:00	30
13:05	453	27.914	0.060	217.383	03:48:00	30
13:05	-	27.914	0.000			
13:55	-	32.015	4.101			
Quiescent consumption:			4.921kW			
Gross energy consumption per piece:			27.354/453 = 0.06kWh = 217.4 kJ			
Net energy consumption per piece:			(27.354 - 4.921*3.8) / 453 = 0.0191kWh = 68.8 kJ			

Table 4 Energy measurement results for the leaded steel

Time	No. of pieces	Energy	Cumulative energy per piece		Cumulative Time	Time per piece
		kWh	kWh	kJoules	hh:mm:ss	s
08:27	0	0.188			00:00:00	
08:30	9	0.537	0.039	139.600	00:03:00	20
09:00	90	4.110	0.044	156.880	00:33:00	22
09:30	168	7.673	0.045	160.393	01:03:00	23
10:00	246	11.164	0.045	160.624	01:33:00	23
10:30	320	14.743	0.045	163.744	02:03:00	23
11:00	400	18.359	0.045	163.539	02:33:00	23
11:19	453	20.640	0.045	162.532	02:52:00	23
Quiescent consumption:			4.921kW			
Gross energy consumption per piece:			20.452 / 453 = 0.045kWh = 162.5kJ			
Net energy consumption per piece:			(20.64 - 4.921*2.8) / 453 = 0.0140kWh = 50.4kJ			

The weight of the final component was measured as 31g and the weight of the starting blank of size 30.8mm x 19.05mm diameter (component length measured as 27.8mm with 3mm added for the width of the part off blade) was calculated to be 69g on the basis of a density of 7.86 g/cm^3. A photograph of the part is shown in Figure 1 and a drawing is included in Figure A1.2 of Appendix 1.

Figure 1 STC component production test component

A comparison of the spindle torque sensor outputs during machining one component of each grade is shown in Figure 2. The S1 spindle sensor output would be expected to correlate with energy usage as the torque applied is in the direction of the cutting force on the rake face of the tool and the distance moved correlates with time. Therefore the difference in the areas above the curves in Figure 2 should correlate with the difference in energy used. The area under the LCFCS curve averaged 14.7 V.s whereas that under the LCFCS+Pb curve averaged 9.9V.s making the mean energy usage estimated from the spindle sensor output for the leaded steel 67% that of the non-leaded steel. The reduction in energy usage is slightly higher than measured from using net energy consumption of the machine where the leaded steel used 73% of that required to machine the non-leaded steel.

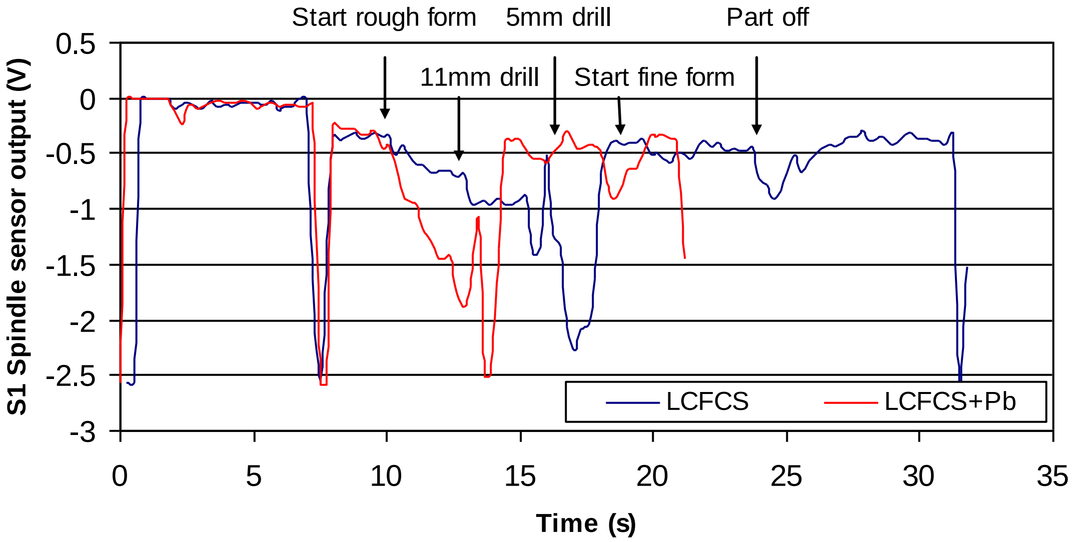

Figure 2 Spindle power sensor readings
(annotations refer to the LCFCS trace)

4. LCA methodology

4.1 Goal and Scope

The primary goal of this study was to assess the overall environmental impact of both leaded and non-leaded steels.

It was envisaged that the outputs from this could be used in the following ways:

- To demonstrate the environmental impacts and benefits of leaded steels to inform policy related discussions
- To raise awareness life cycle thinking in future development work on non-leaded steels.

In the future, if the study is extended and updated then an appropriate audience may be the automotive industry. The study could also be extended to include economic and social issues to provide a full sustainability assessment of leaded steels and the alternatives.

4.2 Functional Unit

The functional unit for this study is defined as 1 component weighing 31g, manufactured from a blank weight of either leaded or non-leaded free cutting steel weighing 69g. The machined component is shown in Figure 1.

This component was chosen for the study because its manufacture exhibits a yield loss of 55%, which was considered a typical average for many types of components. Some components would require less material to be removed while others may exhibit higher yield loss and this is considered in the sensitivity analysis described later in this report.

4.3 Data Collection and Quality

The following data were required to complete the study:

- Material and energy inputs of leaded and non-leaded steel.
- Material and energy outputs, these are known as product and waste (emissions).
- Power consumption and yield loss during the machining of components of the two types of steel
- UK energy grid

The majority of the data used in the study was primary data (ie sourced directly and not taken from literature). The data quality can also be considered to be high as the steel manufacturing data was collected directly from Rotherham Works [3] and the machining data collected from tests carried out at Swinden Technology Centre as described in Sections 2 and 3 of this report. The energy used in machining each component was the gross energy consumption per part in Tables 3 and 4 of this report and the calculation of the component yield was described in Section 3. Data for the UK energy grid was provided by GaBi software.

4.4 Geographical and Time Coverage

The Life Cycle Inventory data for the leaded and non-leaded steels was collected in 1998/1999 with the data about the machining process collected in 2011. Since 1998/1999 manufacturing process efficiency is likely to have improved and hence the use of the older data is likely to give a conservative estimate of the impact of energy consumption during machining on the overall embodied CO_2.

Two sites contributed data to the study;

- Rotherham Aldwarke Works for the steel manufacturing data
- Swinden Technology Centre for the machining data

UK grid electricity data was obtained from the GaBi database and was based on information from 2008. This is a later than the data used for the leaded steels manufacturing study carried out in 1999. However, during the period 1999-2008 there would not have been a significant reduction in CO_2 emissions from electricity production as data from IEA shows only small variations in the mix of energy sources for electricity. While renewable energy increased, this tended to replace nuclear power rather than natural gas or coal, over this time period (Figure 3). Therefore, it was reasonable to assume that using data from 1999 rather than the existing 2008 data would not impact on the conclusions of the study significantly.

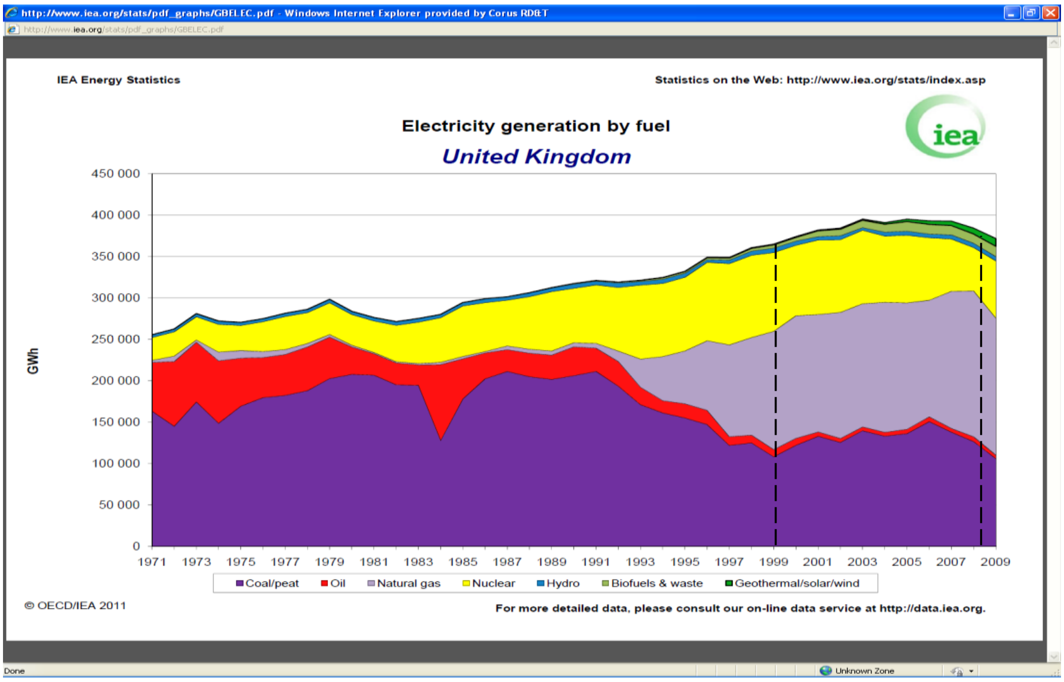

Figure 3 Electricity Generation by fuel from 1971 to 2009 in the UK.

4.5 System Boundaries

Ideally, an LCA should cover the full life-cycle of a product; from the extraction of raw materials such as iron to the manufacturing of steel, the fabrication of the product, the use-phase and finally what happens at the end of life. For the purposes of this study, it was decided that the assessment should be carried out on a cradle-to-gate basis. This was based on the assumption that there would be no difference, in terms of functionality, during the use phase or at end-of-life for a leaded or non-leaded steel.

The system boundary included in the study can be seen in Figure 4. Raw material extraction and production included metallic lead production in addition to the other materials used for steelmaking. Steel scrap inputs and outputs were not modelled in this study as it was thought reasonable to assume that there would be no differences between leaded and non-leaded steels.

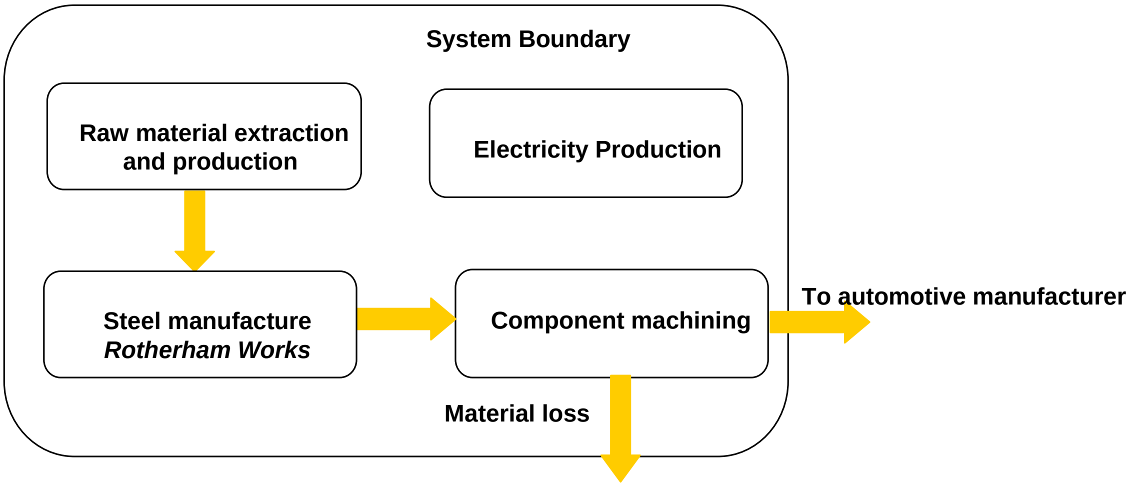

Figure 4 Systems Boundary of the study.

For the machining process only electricity consumption was considered. Consumables such as tooling and operating fluids were excluded as these were though to be less significant in terms of environmental impact for high volume production. Inclusion of operating materials would more likely favour leaded steels due to their improved machinability.

Transport of the steel to the location of machining was also excluded from the study as it was assumed there would be no difference between the two steel grades in terms of transport distances or modes of transport.

4.6 Modelling

LCA, modelling was carried out using GaBi 5 software, which is produced by PE International and is recognised as the industry standard in the metals and automotive sectors for LCA modelling.

In GaBi, LCA models can be built by creating plans that contain a number of processes and flows. A machining plan was created to carry out the life-cycle assessment. Figure 5 shows the ‘Machining’ plan that was created with its associated processes and flows. The model was fully parameterised so it was possible to change steel types and machining variables as shown in Figure 6.

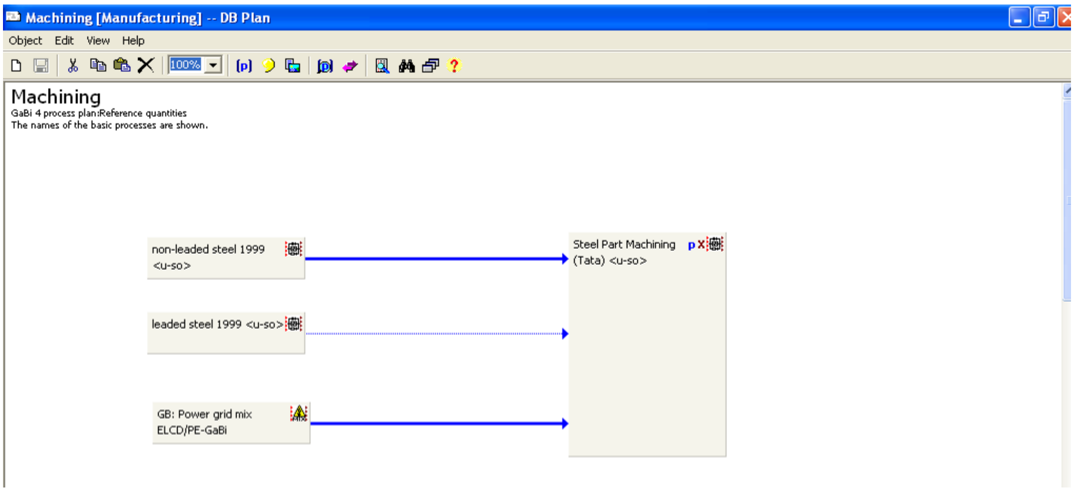

Figure 5 A screenshot of the machining plan

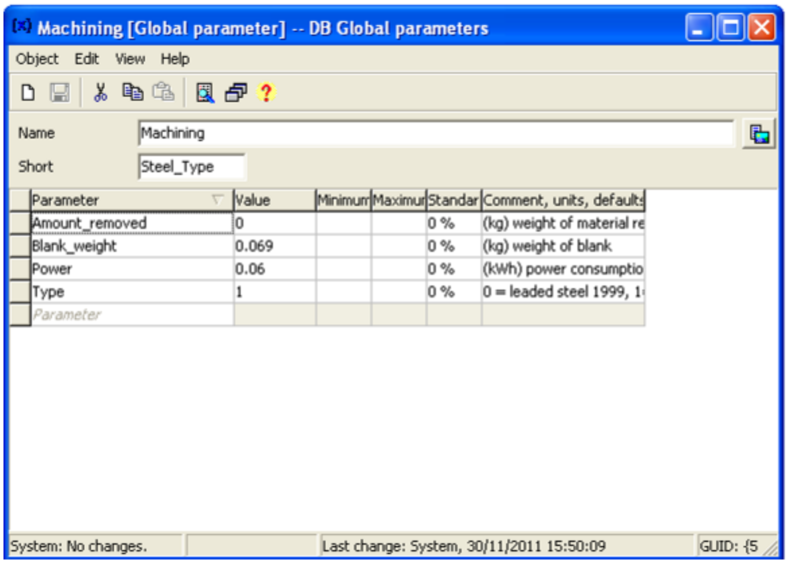

Figure 6 A screenshot showing the model variables

5. Life Cycle Inventory Analysis and Impact Assessment

From the LCA model described in the previous section it was possible to generate Life Cycle Inventories (LCIs) that contain all the inputs and outputs associated with the supply chain up to the point of the machined part leaving the factory gate. On the input side these include material from the earth (e.g. ores) and on the output side emissions to the environment such as CO_2 and airborne lead. An analysis of the origin of emissions from the Rotherham works (Aldwarke) is given in the earlier LCA study.

In isolation, emission and resource consumption data does not quantify environmental impact. To translate the LCI data into environmental impacts a number of life cycle impact assessment methods were applied. The purpose of Life Cycle Impact Assessment (LCIA) is to asses the LCI results of a product system to better understand their environmental significance. In this study the following impact assessment methods were applied

- CML2001 Global Warming Potential (GWP)
- CML2001 Human Toxicity Potential (HTP)
- CML2001 Photochemical Ozone Creation Potential (POCP)
- CML2001 Acidification Potential (AP)
- CML2001 Eutrophication Potential (EP)
- CML2001 Abiotic Depletion Fossil (ADP fossil)
- CML2001 Abiotic Depletion Elemental (ADP elements)
- CML2001 Terrestic Ecotoxicty Potential (TETP)
- CML2001 Ozone Layer Depletion Potential (ODP)

The methodologies behind these impact assessments are described in more detail in Appendix 2 and these were selected based upon their relevance as issues in the context of steel and leaded steels. The impact assessment methods are not absolute indicators of environmental impact and should only be considered as indicators of potential environmental impact. This is because the assessment methods are not yet advanced enough to fully characterise environmental impact and some assessment methods are in a more advanced state than others. Toxicity issues are particularly difficult to characterise using LCA because of issues with threshold levels and the nature of the receiving environment. None the less they are still useful tools and currently there are limited alternatives to assess environmental impact.

The impacts of Global Warming and Human Toxicity are described below as these are the most topical. This is followed by an overall assessment, which considers a wider set of impact assessment methods.

5.1 Global Warming Potential

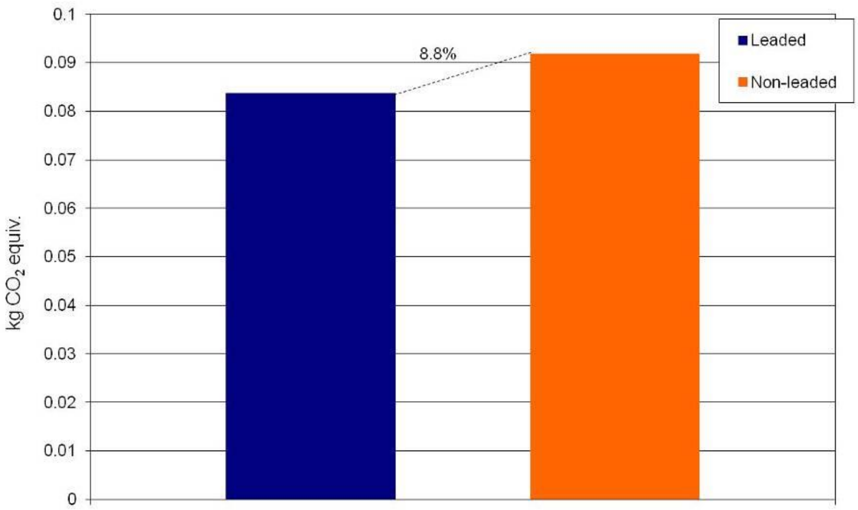

Figure 7 Global Warming Potential per component piece.

Two factors contribute to the global warming potential of both types of steel; production and machining. The emissions from production are approximately the same, 57g of CO_2

equivalent, to manufacture 69g of leaded or non-leaded steel. The difference between the two types of steel occurs during the machining process. Non-leaded steel has a higher global warming potential because more electricity is required to machine the blank into the desired component. The overall difference is 8.8% of the impact of non-leaded steels as shown in figure 7. The impact assessments used for assessing global warming potential are relatively accurate because greenhouse gasses have global impacts rather than specific local impacts.

5.2 Human Toxicity Potential

The human toxicity potential for leaded steels is higher, than for non-leaded steels (Figure 8). This is due to emissions of lead in the steel manufacturing stage relative to emissions in power generation. However, it should be noted that the impact assessment method applied here takes a global approach to emissions so may not represent actual impacts in term of toxicity as this depends on the local receiving environment for the lead, which is a major deficiency of this impact category. Dilution effects and personal protective equipment (PPE) are not taken into account for example and therefore it is only an indication of potential impact.

As mentioned earlier in this report, lead as an alloy in steel is exempt from legislation such as RoHS. In the few cases where lead poisoning is suffered, it is by manufacturing site employees who are in close contact with lead. In the UK, lead poisoning is very rare due to adequate controls by employers and legislation. In the UK, and the rest of Europe, fume extraction is employed to limit exposure to lead fume, blood lead level testing is performed and the correct PPE is supplied.

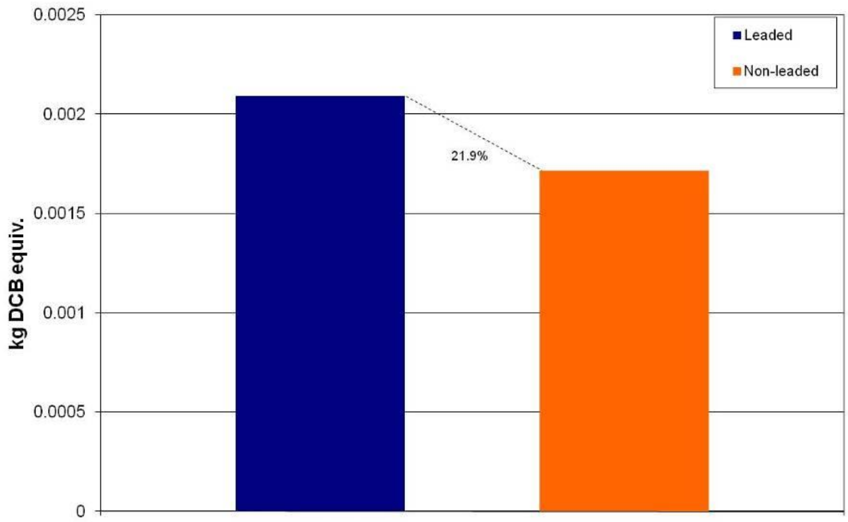

Figure 8 Human Toxicity Potential per component piece.

5.3 Relative environmental impacts

Beyond the impacts of global warming and human toxicity potential it is again a mixed picture in terms of environmental impacts as shown in Figure 9. Leaded steels tend to fair better for impacts that are associated with power generation such as global warming, acidification, tropospheric ozone creation, ozone layer depletion and eutrophication potential. Non-leaded steels tend to be better for the toxicity related impacts. In terms of resource depletion, leaded steels require less fossil fuels (ADP fossil) but consume more resources in terms of minerals (ADP elements) due to the additional requirement for lead, which is much less abundant than Iron.

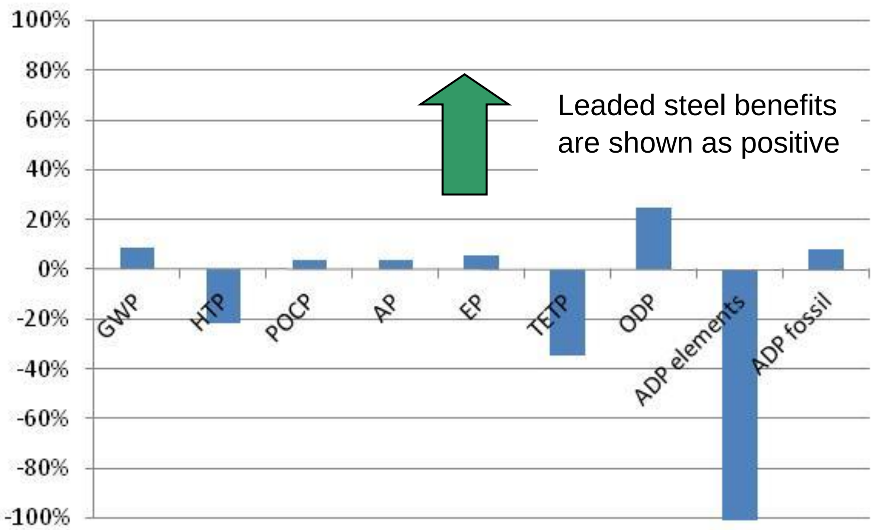

Figure 9 Environmental Impacts of leaded steels vs. non-leaded steels.

It should be noted that the Magnitude of the bars in Figure 9 provides an indication of the relative difference between leaded and non-leaded steels in terms of potential environmental impacts but it does not indicate which impact is more significant. For example, the size of the bar relating to human toxicity is larger than that relating to global warming potential but this does not mean that human toxicity is therefore a more significant impact. To make a judgement between different environmental impact categories requires ranking and weighting of environmental priorities. Weighting environmental impacts, to give a ‘single score’, is not recommended in the ISO standards on LCA, for making comparisons, due to the range of differing views regarding environmental priorities.

5.4 Sensitivity Analysis (Cross-over percentage removal).

A sensitivity analysis was carried out around the amount of material removed during the machining process. This was to identify the cross-over point at which leaded steel became beneficial relative to non-leaded steel based on the amount of material removed for a number of environmental impacts. In the case of global warming potential it was found that it was beneficial to use leaded steels when more than 4.5% of the component was removed during the machining process (Figure 10). In the case of other impacts this percentage varies considerably (Table 5) . Overall this demonstrates that, for the non-toxicity related impact categories and excluding resource depletion; leaded steels are beneficial for machining complex objects where greater than 10% of material is removed.

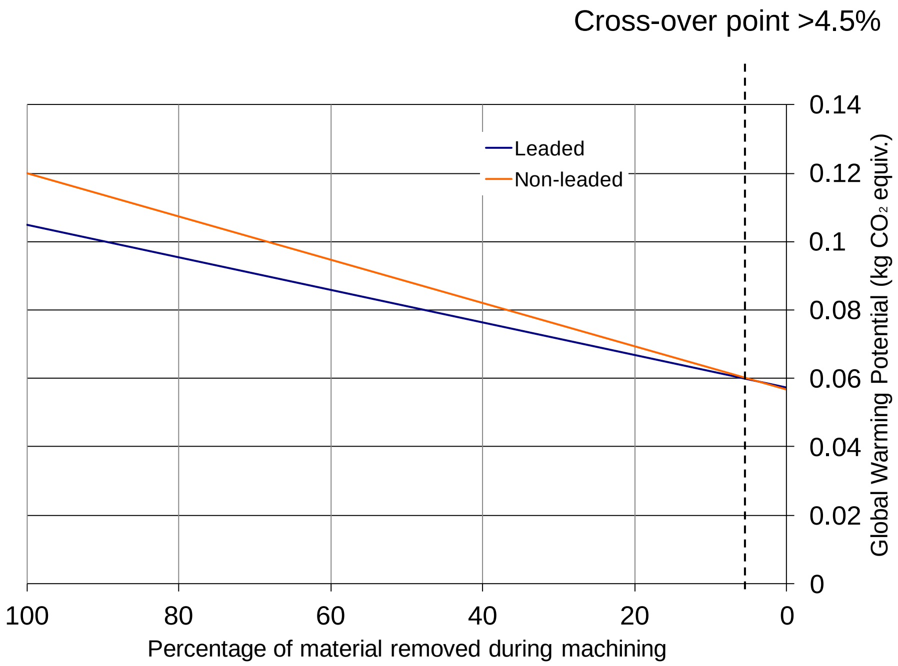

Figure 10 Cross-over percentage removal chart for global warming potential

A summary of the cross-over percentage removal for environmental impact is given in Table 5.

Table 5 Summary of cross-over points for percentage removal of material in machining

Impact Assessment	**Beneficial to use Leaded Steel when the percentage removed is…**
Global Warming Potential	>4.5
Human Toxicity Potential	Never Beneficial
Photochemical Ozone Creation Potential	>10.0
Ozone Layer Depletion Potential	Always Beneficial (>0.0)
Acidification Potential	>10.9
Eutrophication Potential	Always Beneficial (>0.0)
Terrestric Ecotoxity Potential	Never Beneficial
Abiotic (element) depletion potential	Never Beneficial
Abiotic (fossil) depletion potential	>5.9

6. Conclusions

Measurements of electrical energy consumption during component production tests on the Speedturn lathe at STC have shown that there is a reduction in electrical energy usage of approximately 27% when machining parts using leaded low carbon free cutting steel compared to non-leaded low carbon free cutting steel for a component with a yield of 45%.

A life cycle assessment of leaded and non-leaded free cutting steels has been carried out. This has shown that whilst leaded steels have the potential to cause toxicity related environmental impacts there are other environmental benefits from using leaded steels. The reduced energy requirements for machining leaded steels means that there are benefits in terms of lower carbon emissions from electricity production and other impacts relating to power generation. This is particularly the case when greater than 10% of the original blank weight is removed through the machining operation. Whilst it is not possible to say that toxicity related impacts are more/or less important than impacts such as global warming it does highlight that there are wider issues to be considered, beyond toxicity, when selecting materials.

For the part considered in the current machining trials the global warming potential of the final part was 8.8% lower for a leaded steel compared to a non-leaded steel.

Alternatives to leaded steels are in development and these typically use other elements in small percentages instead of lead. Sulphur and tellurium are two examples although there are also toxicity concerns associated with these elements. Bismuth is another alternative to lead but bismuth is expensive to produce and is also a by product of lead production.

A recommendation, of this study, is that LCAs should be carried out in order to assess the environmental impacts of alternatives to lead in free-cutting steel to examine their environmental performance compared to leaded or traditional non-leaded steel alongside the evaluation of machinability.

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5. Coleman N., Jones L., 2012: A Life Cycle Assessment of Leaded and Non-leaded Free-cutting Steels, Ref Source: 156365.

Appendix 1 Component production test procedure

The component production test is performed in accordance with internal test procedure MCP LPP 511.

The objective of the test is to determine the fastest production rate (feed / speed combination) at which a target number of components (equating to the number that could be machined in 6 hours on a single spindle cam automatic lathe) can be manufactured while remaining within dimensional tolerances.

Lathe: BSA Speedturn CNC automatic lathe

Cutting tools:	Circular form, 11mm step drill and 5mm drill all manufactured from M2 HSS Parting tool – JJ Churchill Emprite 3mm wide manufactured in M42 HSS
Cutting oil:	Shell Macron 401 (F32)
Feedstock:	19mm diameter bright drawn bar

Sequence of machining operations (in conjunction with Figure A1.1):

i) Feed to stop
ii) Circular form machines outer diameters and step drill machines 11mm hole
iii) Circular form completes outer diameters and 5mm drill machines 5mm hole
iv) 5mm drill completes internal hole and finish form tool machines 14mm diameter
v) Part off

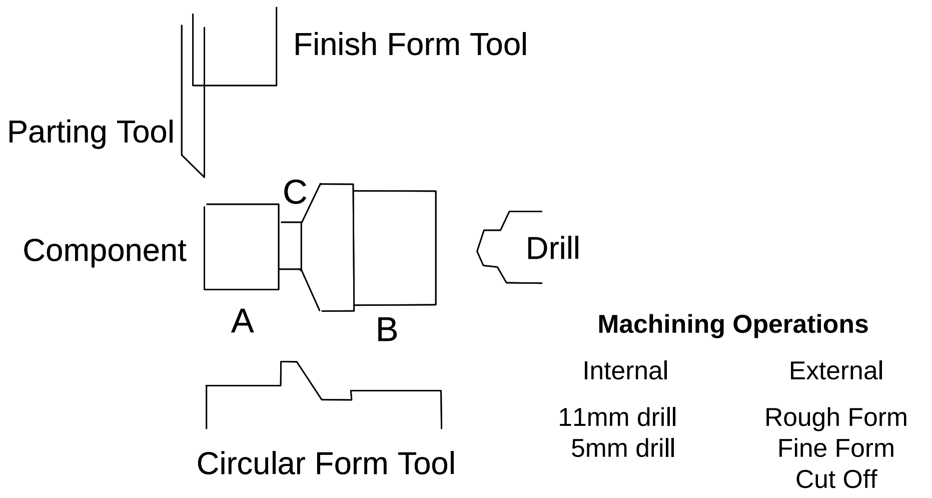

Figure A1.1 Tooling set up and machining operations

Part dimensional requirements (external diameters):
i) Diameter A: 14mm – change in diameter from start to finish of the test <0.07mm
ii) Diameter B: 16.5mm – change in diameter <0.13mm
iii) Diameter C: 10mm – change in diameter <0.13mm

A drawing of the test component including nominal dimensions is presented in Figure A1.2

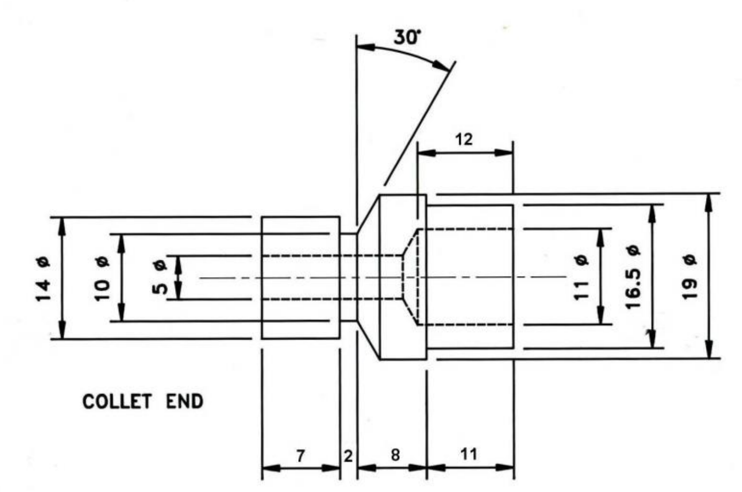

Figure A1.2 Component drawing

Appendix 2 Life Cycle Impact Assessment

i) Fossil and Elemental Abiotic Resource Depletion

Abiotic resource depletion can be defined as the decreasing availability of natural, non-living, non-renewable resources. The resources considered in this impact assessment are fossil and mineral (including primary energy). Biotic resources and associated impacts such as species extinction and loss of biodiversity are specifically excluded. This index addresses only the depletion of various resources rather than the impacts caused by their extraction from the environment (e.g., methane emissions from coal mining).
It has been said that resource depletion should not be considered an environmental impact:

- market price mechanisms are believed to take care of the scarcity issue, price being a measure of the level of depletion of a resource, its scarcity, and value to society;
- the known reserves of fossil fuels are still growing;
- major potential of cleaner energy substitutes such as solar energy have not yet been fully explored.

However, a counter argument may be that:

- prices are influenced by many more factors such as the existence of non-perfect markets (monopolies, subsidies, etc.);
- other energy substitutes such as solar energy will probably be a long term and partial solution;
- the continued use of resources may lead to a shift to poorer or less favourably sited reserves thus resulting in greater emissions.

Whichever stance is taken, the resource depletion issue is at the heart of the sustainability debate and is important enough to attempt to provide a measure of scarcity using indicators. The assessment of the relative importance of the resource depletion index compared to other impact scores, however, remains subjective.

Elemental abiotic depletion covers minerals & metals from earth. Fossil abiotic depletion covers reserves of fossil fuels such as coal, oil and gas.

ii) Global Warming Potential

Global warming potential, GWP, is the most topical environmental impact category and is sometimes referred to as a carbon footprint in the context of products.. Approximately half of the Earth's incoming solar radiation is absorbed by the surface. Around one-fifth of the incoming solar radiation is absorbed by the atmosphere by greenhouse gases (CO_2, NO_2 and methane). Re-emitted infrared radiation, 396 W m^{-2}, leaves the atmosphere but 'back radiation' occurs when radiation is then re-radiated back to Earth, which causes a rise in temperature. The higher the concentration of greenhouse gases in the atmosphere, the greater this 'back radiation' occurs, a process known as the enhanced greenhouse effect. Climate change is caused by the enhanced greenhouse effect. The change in concentration of greenhouse gases, mainly CO_2, is caused by man-made emissions from the burning of fossil fuels to generate energy and power and to fuel vehicles. Following on from the Intergovernmental Panel on Climate Change (IPCC) recommendation, the UK is committed to reducing CO_2 gas emissions by at least 80% in 2050 compared to the baseline year of

1990. This will limit the global temperature rise to 2°C, and will avoid worsening effects to human, wildlife, and land. Some of the consequences resulting from climate change include sea-level rises but also droughts in other parts of the globe and a higher frequency of extreme weather such as hurricanes plus more. GWP is measured in kg CO_2 equivalent, as CO_2 is the largest contributor of the three main greenhouse gases (N_2O and Methane) to the greenhouse effect. Manufacturers, retailers, and consumers are all trying to reduce their carbon emissions, and hence reduce the global warming potential of products and services.

iii) Human Toxicity Potential

Human toxicity is concerned with the impacts on human health of heavy metal elements such as lead present in the environment. Lead toxicity may cause high blood pressure, minor congenital malformations, minor skin anomalies, defects in skeletal growth and development and effects on erythropoiesis. There is uncertainty as to whether lead should be classed as a carcinogen according to the International Agency for Research on Cancer (IARC). The units are in kg dichlorobenzene (DCB) equivalents.

iv) Terrestial EcoToxicity Potential

A terrestrial ecosystem is ‘a system of plants, animals, nutrients, and elements and the interactions between them that is found on land’ and the emissions of elements and compounds into the ecosystem can have serious consequences. Terrestric ecotoxity potential measures the potential to do harm and the unit of characterisation factor is the amount, in kg, of dichlorobenzene per 1kg emission of element or compound.

v) Photochemical Ozone Creation Potential

Photochemical Ozone Creation Potential measures the likelihood of Ozone creation in the lower altitudes of the atmosphere, the troposphere. Under UV light, photochemical oxidation of VOCs (volatile organic compounds) and CO (carbon monoxide) in the presence of NO_x, creates ozone in the Troposhere.

Equation 1 $NO + O \rightarrow NO_2$
Equation 2 $NO_2 + hv \rightarrow NO + O$
Equation 3 $O + O_2 + M \rightarrow O_3 + M$

O_3 is Ozone and a high concentration at lower altitudes can cause environmental problems such as smog which can cause reduced visibility (less than 1km) or damages to plant cells causing a change in appearance.

Additionally there are impacts on human health as there are some risks of respiratory problems or enhanced suffering for those people who already have respiration conditions such as the elderly, asthma sufferers, bronchitis sufferers and smokers.

vi) Ozone Layer Depletion Potential

The ozone layer is present in the stratosphere and acts as a filter absorbing harmful short wave ultraviolet solar radiation whilst allowing longer wavelength radiation to pass through. Since the late 1970s a thinning of various parts of the ozone layer over the Antarctic has been observed during the spring, amounting to 80-98% removal of this layer. This "hole" over the Antarctic is partly attributable to the unique chemistry present over the poles. During the winter a cyclonic vortex forms over the Antarctic, within which temperatures become very cold (less than -80°C). This allows the formation of polar stratospheric clouds (PSCs). Most chlorine and bromine in the atmosphere (from CFCs and other sources) is bound in reservoir compounds which render them inert to ozone. However, in the presence of the PSCs, complex reactions occur which release active chlorine and bromine from the reservoir compounds. The addition of ultraviolet light during the spring sets up catalytic reactions involving the chlorine and bromine, which result in ozone depletion. As the vortex breaks down this ozone depleted air mixes into the rest of the stratosphere. These reactions also occur, although to a lesser extent, in the Arctic.

A decline in the ozone layer allows more harmful short wave radiation to reach the earth's surface. The varying susceptibility of flora and fauna to this increase in radiation has the potential to cause relatively sudden changes to ecosystems. There may also be adverse effects on agricultural productivity. Effects on humans can include increased skin cancer rates (particularly the fatal melanoma type) and eye cataracts, as well as suppression of the immune system. Another potential problem is the uncertain effect the phenomenon might have on the global climate.

vii) Acidification Potential

Acidification, or more commonly known as acid precipitation or acid rain, occurs when the pH level of rain or snow is below pH5.6. The combustion of fossil fuels, whether that be to generate electricity or in a vehicle engine, release SO_x and NO_x gases that will dissolve in clouds and precipitate as rain or snow. This acidic rain or snow can also destroy crops and harm wildlife. Acidic rain or snow can react with the limestone in statues and buildings to cause damage.

viii) Eutrophication Potential

Eutrophication is the leaching of nutrients; most important are Nitrogen and Phosphorus into ponds, lakes, rivers and soil. A change in nutrient concentration has two effects; surface water becoming unacceptable for drinking and a change in composition and variation of species. What is seen is a rapid growth of a dominant biomass species production, which eventually leads to rapid decay as oxygen concentration decreases. Oxygen production is further inhibited as decomposition of the decaying biomass.