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Series on Emission Scenario Documents Number 25

EMISSION SCENARIO DOCUMENT FOR CHEMICALS USED IN THE ELECTRONICS INDUSTRY

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IOMC
INTER-ORGANISATION PROGRAMME FOR THE SOUND MANAGEMENT OF CHEMICALS
A cooperative agreement among
UNEP, ILO, FAO, WHO, UNIDO, UNITAR and OECD

Environment Directorate

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Paris, 2010

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The Environment, Health and Safety Division publishes free-of-charge documents in ten different series: **Testing and Assessment**; **Good Laboratory Practice and Compliance Monitoring**; **Pesticides and Biocides**; **Risk Management**; **Harmonisation of Regulatory Oversight in Biotechnology**; **Safety of Novel Foods and Feeds; Chemical Accidents; Pollutant Release and Transfer Registers; Emission Scenario Documents; and the Safety of Manufactured Nanomaterials.** More information about the Environment, Health and Safety Programme and EHS publications is available on the OECD's World Wide Web site (http://www.oecd.org/ehs/).

This publication was developed in the IOMC context. The contents do not necessarily reflect the views or stated policies of individual IOMC Participating Organizations.

The Inter-Organisation Programme for the Sound Management of Chemicals (IOMC) was established in 1995 following recommendations made by the 1992 UN Conference on Environment and Development to strengthen co-operation and increase international co-ordination in the field of chemical safety. The participating organisations are FAO, ILO, OECD, UNEP, UNIDO, UNITAR and WHO. The World Bank and UNDP are observers. The purpose of the IOMC is to promote co-ordination of the policies and activities pursued by the Participating Organisations, jointly or separately, to achieve the sound management of chemicals in relation to human health and the environment.

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or contact:

OECD Environment Directorate,
Environment, Health and Safety Division

2 rue André-Pascal
75775 Paris Cedex 16
France

Fax: (33-1) 44 30 61 80

E-mail: ehscont@oecd.org

EXPLANATORY NOTES

Purpose and background

This OECD Emission Scenario Document (ESD) is intended to provide information on the sources, use patterns and release pathways of chemicals used in the electronics industry, to assist in the estimation of releases of chemicals into the environment.

This ESD should be seen as a 'living' document, which provides the most updated information available. As such, an ESD can be updated to take account of changes and new information, and extended to cover the industry area in countries other than the lead (the United Kingdom). Users of the document are encouraged to submit comments, corrections, updates and new information to the OECD Environment, Health and Safety Division (env.riskassessment@oecd.org). The comments received will be forwarded to the OECD Task Force on Exposure Assessment, which will review the comments every two years so that the lead country can update the document. The comments will also be made available to users within the OECD web-site (www.oecd.org/env/riskassessment).

How to use this document

The user of this ESD needs to consider how the information contained in the document covers the situation for which they wish to estimate releases of chemicals. The document could be used as a framework to identify the information needed, or the approaches in the document could be used together with the suggested default values to provide estimates. Where specific information is available it should be used in preference to the defaults. At all times, the values inputted and the results should be critically reviewed to assure their validity and appropriateness.

How this document was developed

This ESD was developed under the leadership of the United Kingdom. The proposal to develop this ESD was approved by the OECD Task Force on Environmental Exposure Assessment (TFEEA) in October 2005 and the draft ESD was circulated to the Task Force in 2008. After the discussions in the Task Force, the final draft ESD was approved by the Task Force on Exposure Assessment which was reorganised from the TFEEA in early 2009, at its first meeting in November – December 2009.

This document is published on the responsibility of the Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology of the OECD.

EXECUTIVE SUMMARY

This report constitutes an emission scenario document (ESD) for chemicals used in the electronics industry. It provides information on the sources and release pathways of chemicals during various processing techniques relevant to this varied industry sector, to help estimate releases of chemicals into the environment. Therefore, it will assist in the development of exposure scenarios and risk characterisation and assessment, for example as required by the REACH regulation (Registration, Evaluation, Authorisation and Restriction of chemicals.

This is a diverse and innovative industry, and many of its important features are described in detail. However, it is not possible to cover every product, process or chemical substance. By grouping them, it should be possible to assess releases for areas not covered explicitly. It is also noted that many chemicals used in the electronics industry are used in other sectors, and indeed, their use in the production of electronic components may be a minor specialist application of such chemicals.

The information in this report should be considered in the context of the situation for which estimates of chemical releases are being made. The document can be used as a framework to identify the information needed, or its recommended approaches can be used together with suggested default values to provide estimates. Where specific information is available, this should be used in preference to the default values. At all times, starting information and results should be critically reviewed to ensure they are valid and appropriate. Worked examples are provided.

Whilst this report may help to provide an estimate of potential chemical releases into the environment, it should not be used as an alternative to more detailed procedures (where these are available) used by industry to estimate emissions from specific processes.

The report also provides information on the regulations affecting the use of chemicals in the electronics industry. Regulations are necessarily complex and not all aspects are covered in this ESD. The full regulations should therefore be consulted.

This ESD has been compiled based on a combination of industry input and extensive research, using existing reports and material in the public domain, expert experience, previous risk assessments, and academic and other material from the Internet. A list of cited references is presented at the end of this document. A particularly useful contribution was made by direct consultation with over forty UK companies and trade organisations operating in various areas of the electronics industry. The assistance of these organisations is gratefully acknowledged. Information was collected during 2005 and was largely provided by industry practitioners with a breadth of knowledge and experience. Published sources are cited where appropriate. In cases where values are based on expert judgment, these are intended to represent a realistic worst case scenario – not the absolute worst possible case, but the worst which might reasonably be expected to occur under normal conditions.

It is impractical (for reasons of readability) to cite support for every statement made in this document, but all have been made on the basis of the research itself. Statements made in Section 3 regarding relative levels of release reflect the opinions of the authors on the basis of research

undertaken, together with experience of risk assessment of chemicals for the environment associated with releases from various industrial uses.

ACKNOWLEDGEMENTS

The input of the following companies and organisations is gratefully acknowledged. All of the companies named below were consulted directly during the course of the preparation of this ESD, and in some cases meetings and/or site visits were held. Not all of the named companies have made written contributions or been involved with the latest redraft phase.

- Intellect
- Air Products (Chemicals)
- Alltec Uk Limited
- Arch Chemicals
- Arrow
- Amphenol
- ASMEC Electronics Limited
- ATMI UK (MLS Europe)
- Axiom Manufacturing
- BI Electronics Limited
- Brecon Ridge
- CJ Circuits
- Compugraphics International Ltd
- Computer Salvage
- Cookson Electronics Assembly
- Custom Interconnect Limited
- Data Display UK Limited
- Data Entry Products Limited
- Data Sound Laboratories
- Display Solutions Limited
- Dow Corning
- Edinburgh Instruments
- Edwards Limited

- Eflow Tool Company
- Electrotek
- European Semiconductor Industry Association
- Freescale Semiconductors
- GC Metals Limited
- GSI Group (Laser)
- Hansatech Group
- Harwin PLC
- Henkel Loctite
- HITEK Electronic Materials Limited
- Intel
- Metron Technology Limited
- Moulded Electronic Components International Limited
- NEC Semiconductors (UK) Limited
- National Semiconductor (UK) Limited
- Newbury Electronics Limited
- Nortel Networks
- NPL
- P and M Services Limited
- Plade – UK agents
- USED4semicon Limited
- Plus Opto Limited
- Qualitetch Components Limited
- RID UK Limited
- Rohm and Haas
- S2S Electronics
- Schneider Electric
- Merlin Gerin Transformers
- Semefab (Scotland) Limited
- Shin Etsu

- Sims Group UK Limited
- SRS (Solder recovery)
- Swantek
- Tecan Limited
- ITRI Limited
- Toroid Technology Limited
- Total Frequency Control Limited
- Zytronic Displays Limited

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1. INTRODUCTION

This Emission Scenario Document (ESD) has been prepared to describe the use of chemicals in the electronics industry, and to allow evaluation of the potential for release of these chemicals to the environment. A wide range of processes takes place within the electronics industry, involving a diverse range of chemical products. Specific processes and types of chemicals used within the industry are both covered in this document.

The target application of an ESD is primarily environmental risk assessment of substances new to the market as well as more established ones. The main regulatory use of this document will be under the REACH Regulation (Registration, Evaluation, Authorisation and Restriction of Chemicals). The regulation requires chemical safety reports and risk characterisation which require exposure assessment. Voluntary activities such as the International Council of Chemical Associations (ICCA) and Organisation for Economic Co-operation and Development (OECD) high production volume (HPV) initiatives also require some consideration of potential for exposure. Increasingly, industry sectors are conducting risk assessments on a voluntary basis. Therefore the ESD should also be useful for REACH[1] and HPV submissions.

This is a diverse and innovative industry. For the present purpose, the "electronics industry" is considered to include manufacture of electronics components. It is not possible to cover every product, process or chemical substance, but by putting these starting points into groups, it should be possible to use this ESD as a tool to help in the assessment of release, for the majority of cases. It is also noted that many chemicals used in the electronics industry are used in other sectors, and indeed, their use in the production of electronic components may be a minor specialist application of such chemicals.

This ESD is intended to link to other existing ESDs and references are made to the relevant documents as appropriate.

The ESD has been compiled based on a combination of industry input and extensive research, using existing reports and material in the public domain, expert experience, previous risk assessments, and academic and other material from the Internet. A list of cited references is presented at the end of this document. A particularly useful contribution was made by direct consultation with over 40 UK companies and trade organisations operating in various areas of the electronics industry. The assistance of these organisations is gratefully acknowledged.

It is impractical (for reasons of readability) to cite support for every statement made in this document, but all have been made on the basis of the research itself.

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[1] In the context of the electronics industry and REACH, the European Semiconductor Industry Association (ESIA), together with suppliers and the European Chemicals Bureau, has prepared a template format for written communication to facilitate development of appropriate generic exposure scenarios. The result is an industry-specific template to encourage straightforward and efficient communication of the necessary information (for example regarding risk management measures in place) by downstream users back to suppliers of relevant chemicals, who must undertake risk characterisation as part of the REACH Chemical Safety Assessment. Some of the resulting materials are published on ECB's website as part of the records for RIP 3.2.2 (Arona Network on Exposure Scenarios) through the March 2007 workshop meeting documentation.

1.1 Purpose and scope

The scope of the ESD is to cover the life cycle stages of chemical products (either as substances or as preparations), and how they fit into processes involved in the manufacture of electronic components. Relevant stages of the chemical life cycle are:

- Formulation.
- Industrial use.
- Waste disposal.
- In-service loss.
- Recycling and waste.

More detail about the scope of this document will follow in the next section. However, some chemical types, processes and components are not covered by this ESD. These are activities or chemical types that are considered to be covered adequately by other ESDs, or involve processes that are not specific to the electronics industry. These exclusions include:

- Chemical synthesis: covered by an existing ESD (European Commission (EC), 2003b).
- Transport and distribution of chemicals: covered by an existing Environment Agency ESD (Environment Agency, 2007a).
- Plastics and other components present in finished articles; in particular plastics additives covered by the existing ESD (OECD, 2004a).
- Packaging materials, such as metal or plastic casings and structural components, and assembly processes involving only these parts (for example, bolting, gluing, painting activities).
- General purpose cleaning agents, lubricants for machinery (OECD, 2004c) and similar chemicals that are not specific to the industry.
- Interchangeable batteries.
- Wire and cable manufacture.
- Optical disc (such as CD and DVD) manufacture, which is essentially a simple plastics process and would therefore be covered by the existing ESD for plastics additives as mentioned above.
- Components associated with electricity supply, such as transformers, are excluded on the basis that they are not part of the electronics industry in the context of this document.

An ESD has already been prepared for photoresist use in semiconductor manufacturing (OECD, 2004b). This covers the specific area of photoresist use in the production of micro-electronic components and does not include use of this technique in printed circuit board (PCB) manufacture.

The present document considers the use of photoresists in PCB manufacture, but users are referred to the existing ESD for other relevant details.

The Electronics section of the Environment Agency NetRegs website (Environment Agency, 2005) makes recommendations to some areas of industry relevant to electronics manufacturing, with regard to prevention of pollution. The guidance is aimed at small and medium-sized enterprises (SMEs) not subject to IPPC (Integrated Pollution Prevention and Control) or LAAPC (Local Authority Air Pollution Control).

This document does not seek to describe theory, mechanism or design of electronics components, or detail how electronics devices or components function and perform. Various existing published reference sources provide useful information on this subject.

1.2 How to use this document

The breadth of the industries involved with electronics is such that this ESD is unlikely to be read from start to finish by many users, whereas sub-sections will be useful. The document can be approached from the perspective of a chemical supplier, a processor involved in specific processes, or from those involved in generic product types. It is expected that most users of the document will be seeking information on the entire life cycle for specific chemicals. To obtain data needed for environmental risk assessments, it is important to understand how to extract the relevant information from this ESD.

For example, users may have interest in some or all aspects of:

- A distinct chemical type and function (for example, etchants).
- A particular industry sector or application (for example, semiconductor manufacture).
- A specific process (for example, soldering).
- A certain life cycle stage (for example, disposal).

The user can approach the ESD either from the starting point of a chemical supplier, or as an electronic component manufacturer using chemicals. The different sectors of the electronic industry and the types of chemicals being supplied to them are listed in Section 1.2.1. A number of generic and specific processes can be identified, but within the industry as a whole, there is a diverse range of activities and types of chemicals used. It is therefore impossible to list or define every activity. This guide is intended to provide sufficient background information and examples to enable the user to make informed decisions when considering chemical risk assessments.

Section 2 describes the nature of the electronics industry and provides context by presenting useful summary information regarding how the various processes associated with the electronics industry are used in the manufacture and life cycle of various common components and end products. Risk assessors can expect to find useful information here, particularly if the substance of interest is used in specific end products.

For many users, the primary purpose of consulting an ESD is as a source of release rates and other parameters for use in risk assessment. To derive release rates, it is necessary for a user to identify the processes in which the substance of interest is used. This information is expected to be readily available to a risk assessor. Users should access the relevant sub-section in Section 3 (that is, ‘3.X’ for the appropriate ‘X’), which describes each process specifically. Discussion of chemical types relevant to the process is presented (Section 3.X.2) and users should find useful information about the supply and usage of relevant substances. Release scenarios are also described, with a section devoted to each process (Section 3.X.3) supported by discussion and release scenarios for more generic tasks associated with that process (Section 3.X.4).

Table 3.4 explains clearly how the details of the release scenarios should be interpreted and used, and all users should consult this.

Worked examples are presented in Section 4, in which kg/d release rates are derived for some diverse chemical types, using the information and release scenarios of Section 3.

For site-specific risk assessment, a risk assessor should take into account any information they may already have on key parameters, such as measured concentration in site waste water.

2. INDUSTRY OVERVIEW

The electronics industry is defined herein as comprising organisations involved in the manufacture or assembly of electronic components, which are subsequently used in larger industrial or consumer devices. The wider industries that assemble such components into finished products, such as power supply, defence, aerospace, domestic appliances, toys or the motor industry have not been covered, as these activities are considered to be engineering or assembly processes that are not specific to the electronics industry and are not likely to give rise to any specific releases of chemicals to the environment.

The electronics sector is diverse, particularly due to the increasing role of its products throughout all types of industry and consumer products. The industry can be viewed in terms of product types (for example, semiconductors, printed circuit boards (PCBs), components, displays, connectors), or markets (for example, consumer electronics, automotive, telecommunications, aerospace, defence). Electronic components are built into a wide range of modern products and it has been estimated that they represent over 20 per cent of the cost of a product (Department of Trade and Industry (DTI), 2004a).

In general terms, demand for electronics-based products is increasing and unit prices are falling. The world market has grown in recent years at an average of 8 per cent per annum and now exceeds £669bn (DTI, 2004a). As a result, there is a trend to outsource bulk production to the Far East or other areas with lower production costs, while activities in Europe are becoming limited to small-scale specialist or development activities.

This section sets out the regulatory background, followed by an overview of the scope of the industry, its products, chemicals and processes used.

2.1 Specific regulatory background

The ESD is not intended to cut across any existing or forthcoming legislation, and relevant legislation now summarised. Certain regulations have a direct influence on this sector and are a priority for the industry:

- Waste Electrical and Electronic Equipment (WEEE) Directive (2002/96/EC), as amended.

- Restriction of the use of certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) Directive (2002/95/EC).

- Water Framework Directive (2000/60/EC) and related legislation, in which a number of metals used widely in this sector are subject to controls in terms of the level of releases to the environment.

- Integrated Pollution Prevention and Control (IPPC) Directive (96/61/EC), as implemented in member states, for example in the UK through The Pollution Prevention and Control Act 1999, the Pollution Prevention and Control (England and Wales) Regulations 2000, and subsequent amendments.

It has been remarked (European Semiconductor Industry Association (ESIA)/International SEMATECH Manufacturing Initiative (ISMI), 2008 that, for cost reasons, risk management measures applied at large companies may differ from those used at SME sites. This further supports the approach of calculating emissions for small processing locations in a different way, so that the risks may be evaluated separately.

2.1.1 Waste electrical and electronic equipment directive (2002/96/EC)

The WEEE Directive was published on 13 February 2003 and was required to be transposed into national legislation by 13 August 2004. The original Directive has been amended by Directive 2003/108/EC and Commission Decisions 2004/249/EC and 2005/369/EC. Directive 2003/108/EC amended Article 9 of Directive 2002/96/EC on finance in respect of WEEE. Decision 2004/249/EC concerned a questionnaire for Member States on implementation of the WEEE Directive. The questionnaire is to be used as a basis for drawing up a report on how the Directive has been transposed and is being implemented within the Member State. Decision 2005/369/EC established rules for monitoring compliance with WEEE.

The Directive was transposed into UK legislation by the UK Waste Electrical and Electronic Equipment Regulations 2006 (S.I. 2006/3289). Requirements specific to site licensing and WEEE treatment were implemented in the Waste Electrical and Electronic Equipment (Waste Management Licensing) (England and Wales) (Amendment) Regulations 2007 (S.I. 2007/1085), and the Waste Management Licensing Amendment (Waste Electrical and Electronic Equipment) (Scotland) Regulations 2007 (S.S.I. 2007/172). The Regulations came into force between 2 January and 1 July 2007, and were amended by the Waste Electrical and Electronic Equipment (Amendment) Regulations 2007 (S.I. 2007/3454), which came into force on 1 January 2008.

WEEE is a major source of heavy metal and organic pollutants and there are concerns that without special treatment, many of these materials could lead to serious soil and ground water pollution. There is also the concern that valuable materials are being wasted by being consigned to landfill, when they could be recycled and reused.

The key issues covered by the Directive can be summarised as follows:

- The aim is to minimise the impact of a wide range of electrical and electronic equipment on the environment, both during its lifetime and when it becomes waste.
- The Directive encourages and sets criteria for the collection, treatment, recycling and recovery of waste electrical and electronic equipment (WEEE).
- Member States must ensure that waste is collected at no cost to the householder and that adequate collection facilities are available.
- The WEEE Directive places responsibility upon manufacturers of electrical equipment to recover and recycle a set proportion of product waste at its end-of-life.
- Producers are responsible for financing most of these activities (‘producer responsibility’).
- Private householders are to be able (but not compelled) to return waste to retailers on a ‘one-for-one’ basis without charge.

- Retailers will be allowed to establish alternative collection systems so long as these are no less convenient for householders.
- There are targets for recycling and recovery of materials and components from the waste collected separately.
- There are separate provisions for waste from business users.
- The Directive sets national recovery targets that should have been met by 31 December 2006.

All electronic waste must be transported to authorised treatment facilities after collection and producers are responsible for ensuring that adequate treatment facilities are available. These facilities will normally require a permit (such as a pollution prevention and control permit. Refer to Section 2.1.6).

The impact of the WEEE Directive and the WEEE Regulations on this ESD is that they encourage industry to recover electronic goods and components at the end of their life. Refer to Section 3.13 (Recovery Processes) for further details. The industry is international, with retailers and end users often in a different country or continent to the location of initial manufacture. EU countries consume large volumes of electronics products and the Directive therefore affects European producers and importers very directly.

Guidance on Best Available Treatment Recovery and Recycling Techniques (BATRRTT) and treatment of WEEE was issued by Defra (Department for Environment, Food and Rural Affairs) for those treating WEEE (Defra, 2006). This document explains WEEE and other legislation affecting electrical and electronic waste. Government guidance notes, which are not legally binding, have also been issued by the UK Department for Business Enterprise and Regulatory Reform (BERR, 2007a). These explain the scope of the legislation and answer frequently asked questions. The Environment Agency has also published guidance on WEEE (Environment Agency, 2009).

Industry associations focus generally on the official guidance from the EC or UK authorities, but there is some industry guidance available, such as the Orgalime WEEE and RoHS scope guide, which includes decision trees for determining whether equipment falls within the scope of either directive (Orgalime, 2006a).The WEEE Directive and Regulations apply to electrical and electronic equipment (with some exceptions) rather than to individual components. However, some specific components must be recovered from waste electrical and electronic equipment. (See Annex I for a list of components to be recovered).

2.1.2 Restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS) directive (2002/95/EC)

The RoHS Directive was initially implemented in the UK by The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2006 (S.I. 2006/1463) These Regulations came into force on 1 July 2006 at the same time as the RoHS Directive. Changes to the UK regulations have been subject to consultation and are awaited. The 2006 regulations have now been revoked and replaced by The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations 2008 (S.I.2008/37), which came into force on 1 February 2008. The 2008 regulations implement European Commission decisions on amendments.

The RoHS Directive facilitates the dismantling and recycling of electrical and electronic equipment by restricting the use of certain hazardous substances in its manufacture. Since July 2006, new products should not contain more than the permitted levels of lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs). PBBs and PBDEs are flame retardants used in plastics. The main effect of the RoHS Directive is that many electronic components will be assembled using lead-free solders, although exemptions apply in some cases (BERR, 2007c; Annex C paragraph18). Manufacturers must ensure that their products comply with the Directive.

This Directive covers the same scope as the WEEE Directive, except for medical devices and monitoring and control instruments, which are subject to WEEE but are not within the scope of RoHS. It also applies to light bulbs and light fittings in households. Imported electronic goods will also need to meet the criteria for hazardous substance content.

There have been several amendments to the RoHS Directive. These set maximum concentration values and altered the exemptions for hexavalent chromium, lead and cadmium, and lead crystal glass. Exemptions are reviewed at least every four years. An up-to-date record of Commission decisions amending the RoHS Directive is available from http://ec.europa.eu/environment/waste/weee/legis_en.htm.

The RoHS legislation sets maximum concentration values for the restricted substances. These are:

- 0.1 per cent by weight in homogeneous materials for lead, mercury, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE).
- 0.01 per cent by weight in homogeneous materials for cadmium.

UK Government Guidance notes on the RoHS Regulations have been published, (e.g. BERR, 2007c and 2008) explaining the law and its scope, exemptions, definitions and enforcement. The obligations of the RoHS Directive are also explained in various industry association documents, including Orgalime's RoHS guide (Orgalime, 2006b).

2.1.3 Exemptions from RoHS

Exemptions from RoHS are explained in the Government Guidance notes (BERR, 2008). The following is an extract from the guidance notes:

"The RoHS Regulations do not apply:

- To large-scale stationary industrial tools. (This is a machine or system, consisting of a combination of equipment, systems, products and/or components installed by professionals, each of which is designed, manufactured and intended to be used only in fixed industrial applications).

- To spare parts for the repair of EEE that was placed on the market before 1 July 2006. It should be noted that, following discussions in the technical advisory committee, the European Commission and Member States have agreed that this exemption extends to parts that expand the capacity of and/or upgrade EEE placed on the market before that date provided the EEE concerned is not put on the market as a new product.

- To the reuse of EEE that was placed on the EU market before 1 July 2006.

- To the specific applications of lead, mercury, cadmium, hexavalent chromium and PBDE set out in the Annex to the RoHS Directive, as amended by six Commission Decisions."

2.1.4 Possible future changes to RoHS

Requests from industry for exemptions to RoHS for specific applications are reviewed by the European Commission. These reviews have already resulted in changes to the list of exemptions, and the EC will continue to review requests. Commission decisions relating to exemptions will automatically enter into UK law when published in the EU Official Journal (Restriction of hazardous substances regulations 2008, paragraph 5). Reviews of exemptions are required at least every four years.

Proposals to include the two categories of WEEE that are excluded from RoHS, (medical devices and monitoring and control instruments), will be presented once scientific and technical evidence has demonstrated that such proposals are feasible. This is likely to take place during 2008.

2.1.5 Water Framework Directive

The Water Framework Directive (WFD) requires all inland and coastal waters to reach 'good status' by 2015. It will do this by establishing a river basin district structure within which demanding environmental objectives will be set. 'Good status' in terms of chemical pollution is defined according to compliance with all the environmental quality standards established for chemical substances at the European level by all relevant European legislation. Council Decision 2455/2001/EC, which amends the WFD, established a list of 33 Priority Substances which have been shown to be of major concern for European waters. Of these, 11 substances have been identified as Priority Hazardous Substances (PHS) that are of particular concern. A Daughter Directive setting Environmental Quality Standards (EQSs) for these Priority Substances, two of which are reclassified from Priority Substance to PHS, and eight other pollutants, was proposed in 2006. These EQSs will ensure at least a minimum chemical quality, particularly with regard to very toxic substances.

The impact of this legislation on the electronics industry needs to be considered within the scope of WEEE and specifically RoHS, in that emissions of hazardous substances, particularly metal pollutants, will need particular attention.

It has been noted from industry research while preparing this document that many small electronic component manufacturers do not have on-site waste water treatment facilities and instead rely on controlling quantities of waste water effluent to meet standards set by local regulators charged with meeting the conditions of national and Community legislation.

The control of effluent is conducted through assigning discharge consents (or similar authorisations), which set limits on the quality of waste water that is discharged to municipal treatment. These limits are most frequently in terms of pH, total organic carbon and certain metals. Larger sites subject to IPPC need to describe the chemical contaminants in waste water and work to more controlled (perhaps substance-specific) limits.

2.1.6 Integrated Pollution Prevention and Control (IPPC)

The most directly relevant aspect of the application of the PPC Regulations is in respect of chemicals used in metal plating and other surface treatment processes. To this end, the most important source of guidance is the Best Available Techniques Reference Document (BREF) on Surface Treatment of Metals and Plastics (EC, 2006). The Environment Agency has produced a sector guidance document (S2.07) derived from the BREF: 'Guidance for the Surface Treatment of Metals and Plastics by Electrolytic and Chemical Processes' (Environment Agency, 2004b). Defra has produced a process guidance document (Defra, 2004) for IPPC activities regulated by Local Authorities: 'Secretary of State's Guidance for the Surface Treatment of Metal Processes'. Whilst these documents set out best practice, they can never describe what is actually happening at a particular or generic site with a particular substance, which is covered by the IPPC documentation for the site.

The submissions that a company makes for the purposes of IPPC can help in developing an exposure assessment for that site. Furthermore, since IPPC submissions enter the public domain, they may prove of interest to those concerned to investigate a particular type of site or substance.

2.2 General information on the UK industry

This ESD draws mainly on the experience of UK industry, through consultation with manufacturers and suppliers, and use of information available in the public domain.

The UK electronics market ranks seventh in the world in terms of production, and fifth in terms of consumption, based on 2003 data. The only EU nation with larger production and consumption than the UK is Germany (Reed Electronics Research, 2004, cited in DTI, 2004a). In 2002, the electronics manufacturing sector represented the equivalent of approximately six per cent of UK manufacture (DTI, 2004a).

In recent years, the focus of the electronics industry in the UK and the rest of Europe has tended to move towards small- and medium-scale production units, with high-profile closures of certain bulk manufacturing units due to relocation to the Far East. A market forecast newsletter (Reed Electronics Research, 2007) reports that the share of the electronics production taking place in the Asia-Pacific region has increased from 20 to 40 per cent in the period 1995 to 2005.

However, the UK industry remains important for the design and development of electronic equipment, and a large number of research and development and pilot-scale organisations exist. Reed Electronics Research (2007) reports that although production in Western European centres has fallen significantly, with UK production declining by 55 per cent in the period 2000 to 2005, the market is now expected to stabilise. Small specialist manufacturers (in areas such as the defence industry) also remain in the UK.

2.3 Scales of operation

As stated above, the electronics industry in the UK is experiencing a period of change. The BERR website states that in the UK, over 250,000 people are involved in the design, production and distribution of electronic products, working in 11,000 companies.

A report published by the Department of Trade and Industry (DTI, 2004a) provides a particularly useful description of the UK electronics industry. The following information is relevant to risk assessments:

- The main areas of activity in the supply chain are raw material supply, component and sub-component manufacture, design, production, distribution and logistics, process research (scale-up), and quality control.

- The UK electronics sector is dominated by small and micro-sized companies, which account for 80-90 per cent of total UK enterprises, but only amount to about 10 per cent of total turnover. Most firms are micro-sized, with the exception of electronic component and process control equipment manufacturers, where there is a higher concentration in the small-to-medium range (see Table 2.1).

- The few large UK-based companies employ about 50 per cent of the workforce, and generate about three-quarters of the wealth. Only a handful of firms have over 1,000 employees.

- There are an estimated 9,400 electronics enterprises in the UK, employing an average of 26 people.

- An analysis of the regional distribution of electronics establishments and their employees shows the industry is well represented across all areas of the UK, with no obvious clusters. Since 2004, a small number of major production sites for electronic component manufacturing that were clustered in central Scotland have effectively ceased full-scale production. The position of UK industry is therefore dominated even further by micro-companies covering pilot work, research or specialist component manufacturing.

Table 2.1 Size distribution of companies involved in the electronics industry (UK)

	% of total number of companies	**% of total employment**	**% of total turnover**
Micro (1-9 employees)	80 – 90	5 – 15	2 – 12
Small (10 – 49 employees)	10 – 20	6 – 18	6 – 12
Medium (50 – 249 employees)	6 – 8	17 – 30	10 – 20
Large (250 or more employees)	2 – 4	45 – 55	60 – 80

Source: Small Business Service database 2004, cited in DTI, 2004a

This indicates that there are a relatively small number of large units, and that these are responsible for a high percentage of employment and turnover. Experience suggests that these few large organisations are also responsible for an above average proportion of chemical use. Conversely, the greatest numbers of organisations employ a small number of people. These are responsible for the use of a wide range of chemicals, but at low total volumes.

This variation in scale of use was apparent from the research conducted in preparing this document. It was also noted during research that the smaller organisations had the lowest availability of on-site waste water treatment, with many discharging directly into municipal sewers within locally agreed discharge consent limits.

Variation from site to site can be considerable, with the plating industry presenting particular variability. The BREF for surface treatment of metals and plastics (EC, 2006) reports that "it is likely that no two of the 18,000 installations operated in the 15 EU Member States (EU-15) are similar enough in design and customers to be directly comparable with one another on a like-for-like throughput basis. The variations in the options for plant design are due to the large number of the operating parameters".

2.4 Industry associations

The industry association Intellect represents most areas of the electronics industry in the UK, and also the UK information technology and telecommunications industries. Intellect has over 1,000 member companies. At the European level, the central industry association for electronics component manufacture is the European Electronic Component Manufacturers Association (EECA). EICTA (European Information and Communication Technologies Association) is the representative body for the electronics sector and ICT products.

A list of all relevant industry associations is provided in Annex II.

2.5 End products

Electronic components are used in almost any type of industry sector or consumer product. Some examples of final products are:

- Aerospace equipment.
- 'Brown' goods such as televisions, video recorders, DVD and CD players.
- Food processing and dispensing equipment.
- Lasers.
- Medical equipment.
- Mobile telephones.
- Automotive industry.
- Personal computers, monitors, printers and associated components.
- Toys.
- 'White' goods such as microwave ovens and washing machines.

The assembly of end products will generally involve the use of bought-in components, and this type of assembly process is best described as an engineering activity. The uses of chemicals, such as adhesives, lubricants, paint, and cleaning agents, are considered to be generic functions of the chemical product being used rather than its specific application in the electronics industry. Many of these generic chemical product types are used in relatively low levels in the electronics industry when compared to their use in other sectors. For these reasons, with the exception of solder, the assembly of such goods is not considered in detail within this ESD. However, there is potential for the release of chemicals during the disposal or recycling of such end products, and this is considered further in the ESD. Site visits, to locations where both manufacture and assembly take place, support the view that assembly can be realistically excluded, as it is not a significant source of chemical release.

2.6 Chemical categories in the electronics industry

Over 500 different chemical substances have been identified for use in the manufacture of electronic components. These chemicals can be grouped into product categories that will either describe the class of substance (for example, atmospheric gas) or their function (for example, etchant).

List of chemical types:

- Atmospheric gases.
- Auxiliary materials.
- Ceramics.
- Cleaners.
- Dopants.
- Etchants.
- Films*.
- Flux.
- Inorganic metal salts.
- Liquid crystals.
- Metals.
- Photoresists.
- Plating chemicals.
- Polymers.
- Silicon.
- Solder.
- Solvents.
- Speciality gases.

* Note that films of different chemical types are used in various processes, and this is not in fact considered to be a specific chemical category.

These specific chemical types are described in more detail in Section 3 of this ESD, in subsections relating to the processes in which the chemicals are relevant. Those sections also provide examples of specific substances or preparations that fit into these categories.

When approaching the ESD from the perspective of a chemical supplier, it is essential that the life cycle of the substance is understood. The life cycle starts with synthesis or extraction, when the substance is first produced or isolated, and finishes with degradation or mineralisation, back to a native state or destruction of the substance. In the context of risk assessment in compliance with standard technical guidance, this should be understood in relation to the following stages:

- Production.
- Formulation.
- Processing.
- Service life.
- Recovery.
- Releases associated with disposal.

For example, organic substances will be synthesised using carbon feedstock from biological or fossil fuel sources, formulated into usable products, which will be used and may then face final destruction by incineration or degradation to carbon dioxide, water, and ammonia, or be recovered and recycled in some way. Metals will typically be extracted from the earth in an oxidised form, processed, used and will return to the earth as oxides on destruction.

This document describes briefly types of chemicals in the context of the processes in which they are used, and considers the handling of chemicals from the point of formulation into specialist products, their use, and disposal. References are made to examples of processes and Release Scenarios listed in Section 3. Some chemical substances or preparations will fit into two or more groups, for example copper chloride could be described either as ‘inorganic metal salt’ or as ‘plating chemical’.

The reason for this method of categorising groups of chemical, using both functionality and chemical description, reflects the nature of use. Some chemicals are used because of some fundamental non-specific property (such as solvent cleaners) and others may have only one specific function in the industry (such as photoresists).

2.7 Electronic components

Components and products have been divided into groups that reflect either specific components or functional articles:

List of component types:

- Cathode ray tubes (CRT).

- Connectors and wires.
- Displays (flat-panel displays, LCD, LED and plasma screens).
- Electro-optical components (light emitting diodes (LED), lasers).
- Hybrid circuits (including multi-chip modules and resistor arrays).
- Liquid crystal displays (LCD).
- ‘Passive’ components (capacitors, resistors and so on).
- Power cells (such as solar cells).
- Printed circuit boards.
- Semiconductors.

Note that the word ‘component’ is used here to represent either an individual component or sub-assembly, as distinct from a complete final piece of equipment.

This section describes the types of components and end-products manufactured in the electronics industry.

Although most risk assessments will be prepared using a specific substance as a starting point, it is important to describe product types, or industry sub-sectors, to improve the understanding of these groups.

This section is intended to assist a user with a general interest in a particular end product to identify processes that would usually be relevant in its life cycle. Relevant Release Scenarios in Section 3 can then be applied.

It is noted that in some cases the component being manufactured is subject to quality standards or at least a specification; thus the level of repeatability between batches would be high.

2.7.1 Cathode ray tubes

Cathode ray tubes (CRTs) are used in ‘traditional’ televisions and computer monitors, although flat panel displays are becoming increasingly common. CRTs function by accelerating electrons towards a glass panel coated with luminescent materials (phosphors) that convert the electrons into light. The electrons pass through a ‘shadow mask,’ which absorbs any electrons directed at the wrong colour phosphor. The main components of the CRT are:

- Faceplate (glass panel).
- Shadow mask.
- Leaded glass funnel to protect the electron gun (note that use of lead for this application is exempt from the RoHS Directive).

- Electron guns (three; for red, green and blue).
- Other parts such as connectors, wires, printed circuit boards (PCBs) and so on.

The required patterns are created on the faceplate using photolithography (see Section 3.9 on photolithography and spin coating). The glass is first coated with photoresist (for example, using spin-coating), which is exposed using the shadow mask as a template. The photoresist polymerises in the exposed areas, and the unpolymerised material is removed with water (a process known as developing). A black coating is applied using carbon slurry, which is developed again, removing the exposed photoresist and leaving clear areas in a negative image of the original pattern.

Next, coloured phosphors are added to the clear areas using a series of photolithography steps similar to preparation of the black matrix coating. Spun-off phosphor slurry and material removed in the developing stage are usually recovered and re-used, or returned to the manufacturer (US Environmental Protection Agency (EPA), 1995). A lacquer coating is applied (silica-based wax) to seal the internal surface, followed by a coating of aluminium, to enhance brightness and improve conductivity (US EPA, 2001). The shadow mask and glass panel are reattached after further cleaning.

The leaded glass funnel is washed and coated with graphite before being joined to the faceplate/shadow mask assembly. Finally, the electron guns are mounted in the glass funnel, gases (air) are removed under vacuum and the whole CRT coated with carbon black paint. Organic solvents and aqueous cleaners are typically used during these processes (US EPA, 1995).

A large number of processes are involved in the production of cathode ray tubes and their associated components. Assembly with wires and solder connections is considered to be on the non-micro scale (large components). Soldering (see Section 3.10 on soldering) will typically use ‘spot’ soldering techniques where solder metal is applied directly to the joint to be made.

2.7.2 Connectors and wires

The production of connectors and wires can be described as an engineering process, but specialised connectors, particularly for micro-electronics, can be considered to be specific to the electronics industry. In many cases, the use of materials will be similar to production of large-scale units (for example, copper wire, plastic clips) but in the case of micro-electronic components, exotic metals and ceramics are used to provide correct conductivity or resistance between components.

Connectors and wires can be described generally as chemicals formed into articles; whether metals, polymers or ceramics, their final form is functionally shaped. The processes therefore involve handling the substances and preparations, forming them into the correct shape or size and then ensuring that that physical form is retained.

Some components are supplied in the form in which they will be used, but other materials, especially wire, may be supplied in a form that needs final cutting and shaping by the user.

Connectors providing electrical conductivity or resistance, or that are in contact with sensitive electronic components, may need to be cleaned prior to use.

Waste metals will have a recovery value at the end of life, but ceramics and plastics will not be recovered from waste components.

Assembly is considered to be more appropriate process than ‘formulation’ when describing the manufacture of connectors.

2.7.3 Displays (flat-panel displays and monitors)

Display systems involving the production and assembly of LCD (see Section 2.7.7 on liquid crystal displays, and also Section 3.11.1 on liquid crystals) and LED components can be considered largely as engineering processes (joining of pre-manufactured components). However, in addition to assembly, glass and other substrates need to be chemically treated for correct polarisation and colour patterning. This is considered to be the only direct chemical input (other than solder/flux).

Assembly will involve soldering, use of adhesives, use of connectors and wires, as well as the use of components such as LCDs, LEDs, packaging materials, ceramics and glass, metals, PCBs and micro-electronic components. Therefore, the dismantling and recovery of components after use needs to be considered in detail in view of the range of components and the constituent chemicals present in the finished product.

A plasma screen display is composed of glass cells containing a mixture of neon and xenon. The light source comes from red, blue and green coloured phosphors behind these cells. Manufacture of plasma screens is not believed to take place in the UK; however, disposal and recovery of units used in the UK could take place and potentially lead to release of the neon and xenon gases to the atmosphere.

2.7.4 Electro-optical components

The term ‘electro-optical’ includes light emitting diodes (LEDs) and liquid crystal displays (LCDs) as well as lasers and other sources of light and radiation. LCDs are described in 2.7.7.

Manufacturing techniques to produce inorganic semiconducting LEDs are similar to those used to grow and alter silicon wafers for semiconductor production, described in Section 2.7.11.

An LED is effectively a semiconductor that emits light when an electrical current is applied. The colour of the light depends on the choice of chemicals used in the semiconducting material. A variety of semiconducting materials can be used, including aluminium gallium arsenide, gallium nitrides, zinc selenide, indium gallium nitride, silicon carbide and others. Organic (polymer) LEDs are in development to provide flexible products.

LED semiconductors are made by ‘growing’ or doping layers of semiconducting materials onto wafers of inorganic substrates such as silicon. The processes are conducted under carefully controlled conditions and involve very small quantities of materials. Many of the substances used are very expensive and waste is minimised, with recovery of unused materials. Supply is in kilogram quantities.

Lasers (Light Amplification by Stimulated Emission of Radiation) rely on a visible light source or electrical energy exciting a suitable ‘gain medium’ that emits light at a higher intensity as a specific wavelength. Laser gain medium can take the form of gas, solid state, metal vapour or semiconductors, and the production of lasers involves the handling of such chemical substances.

Examples of chemicals are:

Gas phase: argon, helium , neon, xenon, carbon dioxide, carbon monoxide
Metal vapour: helium/cadmium, helium/selenium, helium/mercury, copper vapour

Solid state: ruby, neodymium, titanium sapphire
Semiconductor: gallium nitride, gallium aluminium arsenide.

Very little bulk manufacture of lasers takes place in Europe (for example, for CD/DVD applications, laser printers and similar products), with production limited to research or specialist equipment. Production takes place under very controlled conditions using very small quantities of chemical substances.

2.7.5 Hybrid circuits (including multi-chip modules and resistor arrays)

The description of hybrid circuits covers circuit boards designed for specialist use where multifunctional components need to be placed together. Such circuits will be based on a laminate, ceramic (or other) motherboard and will often have a thick layer of copper or tin as a base on which to build the unit. The metal will have a dual function, as a heat sink and as a very electrically conductive layer on which to build.

Direct Bond Copper (DBC) involves placing conductive copper foil onto substrates such as ceramics, aluminium oxide or beryllium salts (which have good high-temperature characteristics).

Many of the processes are similar to printed circuit board (PCB) production (see Section 2.7.10), but substrates other than laminates are common and metal layers are generally built up *in situ* using electroless plating or electroplating (see sections 3.4 and 3.5). The units are then assembled to provide multi-functional capabilities with different types of components joined together.

2.7.6 Laminates

Laminates are used as a base for printed circuit boards (PCBs, see Section 2.7.10) on which circuits are etched and micro-components (such as transistors, see Section 2.7.8 on passive components; and semiconductors, see Section 2.7.11) are fixed. The laminates are themselves made from polymeric materials (such as phenolic papers and epoxy resins) and are coated with copper or tin to provide a metallic surface. Speciality laminates may be multi-layered.

There is very little bulk laminate board production in Europe for the electronics industry, although specialist activities, such as multi-layered composites, will take place. Refer also to Section 3.8.

2.7.7 Liquid crystal displays

Liquid crystal displays (LCDs) are used in flat panel display screens for items such as televisions, computer monitors and mobile phones (refer also to Section 2.7.3, on displays).

The basic structure of the LCD display is two glass panels, between which is a layer of liquid crystal. The front glass panel is coated with a polyimide orientation film, and the orientation of the liquid crystals in this film determines whether or not light can pass through the panel. Transparent electrodes (indium-tin oxide) run in parallel vertical and horizontal lines to form a matrix, and each intersection of the matrix is a pixel. A thin film transistor (TFT) positioned at each intersection acts as a switch to activate the individual pixels. When no current is applied, the liquid crystals are positioned in parallel to the orientation film, whereas when a current is applied, the crystals are perpendicular to the orientation film, allowing light from a source (usually cathode fluorescent tubes) to pass through.

The manufacturing process for a typical LCD panel is summarised as follows:

- Glass is cleaned.
- Front panel: colour filters are applied in four separate photolithography and etching processes. A layer of indium-tin oxide is applied using a sputtering technique. The electrical circuit pattern is then created using photolithography and etching processes in four separate stages.
- Rear panel: the electrode layer is applied, then thin film transistors are created by applying a semiconductor using electron beam, sputtering or chemical vapour deposition. The required pattern is created using photolithography and etching processes in eight separate stages.
- Both panels: The polyimide orientation layer is applied and cured. Spacers are inserted and the two panels merged, applying a UV-cured adhesive.
- The liquid crystals are inserted between the panels (phenylcyclohexanes, biphenyls) and the adhesive is cured.
- Polarising laminates are applied to the front and rear panels.
- Other components, including integrated circuit chips and printed circuit boards (PCBs), to drive the display are assembled.

For an in-plane switching (IPS) LCD, an electrode is incorporated in the rear panel only, and uses substances such as molybdenum, tantalum, aluminium/chromium alloy or molybdenum/tungsten.

2.7.8 'Passive' components

The term 'passive' components describes those that do not require power to function and will act by impeding or delaying electrical currents. Such components include capacitors, resistors and varistors that modulate currents.

Resistors come in different sizes, from large wire-wound components for the power supply industry, to microscopic semi-conducting materials mounted on a circuit board. Many resistors commonly used in electronic devices are a few millimetres in size and are typically colour coded to indicate their resistance.

Certain resistors alter their resistance depending on other factors, such as temperature or voltage (varistors, thermistors).

Capacitors have the ability to store electricity and as with resistors, come in different scales of size from large units for the power supply industry, to small units for use in electronic equipment. Capacitors work by storing electrical charge that is released after a current is switched off.

These passive components involve the use of metals (wire or particulates), semi-conducting materials and insulating materials for out casing or fixing (such as polymers and ceramics).

2.7.9 Power cells (such as solar power)

This ESD does not consider batteries or other transferable power sources and storage devices.

Power sources, such as solar cells, rely on the reaction of light (photons) with semi-conducting materials to emit electrons to power a circuit. Manufacture of the semi-conductors involves growing or doping substrates such as silicon with specific metals or non-metallic inorganic materials. The small power cells will typically be assembled together into larger units.

2.7.10 Printed circuit boards (PCB)

A printed circuit board (PCB) or printed wiring board (PWB) is the physical structure on which electronic components are assembled in a finished device. The boards may be single or double-sided, or multi-layered. Single and double-sided boards have circuit patterns on the outer surfaces, while multi-layered boards allow more complex circuits to be formed by having circuit patterns on internal and external layers.

The production of PCBs is a multi-process operation that typically takes place on one site. Each of the steps is described separately.

Laminate boards

Laminate sheets (see Section 3.8 on laminates) are typically sourced from outside Europe and are pre-coated with thin layers of copper or perhaps tin. Very rarely, other metals or alloys are used.

The laminates are drilled and cut to size by a semi-automatic machine working from computer aided design programs. Waste laminates are treated as non-hazardous waste, with some recovery of metals taking place.

Electroless plating

The cut and drilled laminate boards are coated with fresh copper in a process that involves brief cleaning, activation, electroless copper deposition with copper salts, rinsing and washing through a series of tanks. This process appears to be fundamentally the same throughout the industry, although the particular chemicals employed will vary between users. Chemicals used include copper sulfate, copper nitrate, nitric acid, phosphates, corrosion inhibitors, catalysts and other inorganics. The copper boards emerge looking new and shiny with the holes coated with copper and a few extra micrometres of metal coating across the whole surface. Tin is plated on to some boards to enhance performance and solder adhesion.

Copper solutions and ‘first wash’ liquor are recycled and topped up with fresh copper-salt. Waste is minimised due to cost, but spent chemicals and final washings are collected to a settling tank, neutralised and discharged as waste water within local discharge consent. The consent will typically be based on pH, copper, zinc and other metals (not iron) and biochemical oxygen demand (BOD) (total carbon).

Photolithography and etching

The clean, drilled and recoated (plated) boards are coated with photo-resist film and exposed to UV light through the template for the circuit design. The exposed boards are then cleaned with solvents such as acetone, to remove the photoresist from the areas to be etched. They are then immersed in alkaline, acid or oxidising preparations to dissolve (etch) the exposed copper, leaving the pattern of the circuit board. A variety of inorganic chemicals are used, including iron chloride, ammonia preparations, peroxides, sulfuric acid and others. Other than formaldehyde, no organic substances are used.

Processes are similar between producers, but the precise mixture of chemicals will vary. Positive and negative photo-resists are used. Processes are carried out inside etching machines and the solution is both topped up and extracted from machine by automatically controlled dosing pumps, as the specific gravity of the etchants is increased by dissolving the copper. Spent solution can be returned back to the original supplier for recovery.

The etched boards will now have the pattern of the required circuit in very thin copper or tin.

Waste copper salt solids have little value and are sent for chemical waste disposal. Other chemicals will be present in this solid, including residues of other inorganics, spent photo-resist and other wastes. First phase wash water can be circulated back into the etching tank, but subsequent wash water is typically discharged (subject to settling and neutralisation) within consent orders.

Soldering processes

Once etched, solder is coated onto the residual copper (or less commonly, tin) coating. Where thin metal film laminates have been used, the copper or tin would quickly oxidise (reducing conductivity), be abraded or crack, unless coated in solder. Wave soldering can be used, but hot air solder levelling (HASL) is popular. In each case, flux preparations are used.

Screen printing – resin coating

The final stage is to coat protective coloured resins onto the PCB, typically in green but any colour is possible. Writing is often added to the PCB to indicate, for example, the name of the supplier or component identification. This is done through silk screen-printing.

Washing processes

Not all suppliers wash PCBs, but washing can take place at a variety of stages. Water-based detergents are used in the main, but there is some use of alcohol washes. It appears that most waste from washing is discharged as waste water, with filtering and settling to reduce solid metal content. Even the smallest units work to consent orders, relating for example to pH, BOD, and metals.

2.7.11 Semiconductors

This section considers the production of semiconductors for micro-circuits. Semiconductors used in optical devices are described in 2.7.4.

Silicon dioxide (silica) of very high purity is reduced to form silicon that is supplied in massive form as ‘ingots’, made by melting the oxide and crystallising onto a ‘seed’, forming a single crystal of silicon. These are up to 30 cm in diameter and 20 – 30 cm long. Thin slices are prepared and duplicate units can be formed before cutting the wafers into the familiar ‘chip’ size articles. These wafers can be up to 30 cm wide.

Silicon ingots are sliced into wafers and rinsed. Before any further processing, these wafers may be ground mechanically, smoothed and polished, or etched chemically, to ensure a smooth surface, free of oxides and other contaminants. A film of silicon dioxide is produced by thermal oxidation at high temperatures, and the wafers are then cleaned and dried. The required circuit pattern is produced by photolithography, followed by chemical etching.

The most commonly used dopants are antimony, arsenic, phosphorus, and boron compounds. Dopants are introduced into the patterned wafer using either diffusion or ion implantation, and further silicon layers may then be added if necessary, using techniques such as epitaxial growth (resulting in the mineral deposit having the same crystal structure as in the substrate layer) or chemical vapour deposition.

The silicon wafer is then coated with thin layers of metal to produce external connections for the electrical circuit. The most common metals used in this process are aluminium, platinum, titanium, nickel/chromium, silver, copper, tungsten, gold, germanium, and tantalum. Metal layers may be deposited using techniques such as sputtering or high vacuum evaporation (metallisation) whilst photolithography and etching are used to remove unwanted metal. A protective coating of silicon dioxide or silicon nitride is then added, in a step known as ‘passivation’. Finally, the wafer is rinsed with deionised water, and the back of it is ground to remove any unwanted material.

A layer of gold may be added to the back of the wafer to allow connection of leads at a later stage. The semiconductor device is assembled by mounting the chip onto a metal frame, adding connecting leads and wires, and enclosing in plastic or ceramic packaging. Leads may be produced from metal sheets coated in plastic that is punched or etched (using photolithography and etching techniques). The chip is then mounted using a thermoset plastic packaging material such as epoxy resin, and leads are connected to the chip with thin aluminium or gold wires before enclosing the final packaging in a moulding press.

Due to their size, semiconductors are not often recovered as units at the end of life, but melted to recover metals. Silicon and other inorganic materials are not recovered.

2.8 Processes in the electronics industry

Many different processes take place in the production and construction of electronic components and devices. These processes have been rationalised in terms of chemical usage and functionality; for example, the etching processes for semiconductor and printed circuit board manufacture involve similar chemistry functions, but take place on a different scale with different chemical substances.

Examples of processes are:

- Chemical formulation. Covered in individual sections where applicable (estimates repeated from TGD A-tables).
- Chemical handling by the user. *Covered in individual sections.*
- Assembly of components.
- Chemical disposal.
- Chemical vapour deposition.
- Electroless plating.

- Electroplating.
- Etching.
- High vacuum evaporation, sputtering.
- Laminate production.
- Photolithography, spin coating.
- Soldering.
- Cleaning of components and equipment. Covered in individual sections where applicable (estimates repeated from TGD A-tables).
- Service life.
- Recovery from waste.
- Waste.

Section 3 describes these processes in detail.

Figure 2.1 (overleaf) shows the processes in the electronics industry and how this ESD relates to other reference sources in relation to each stage.

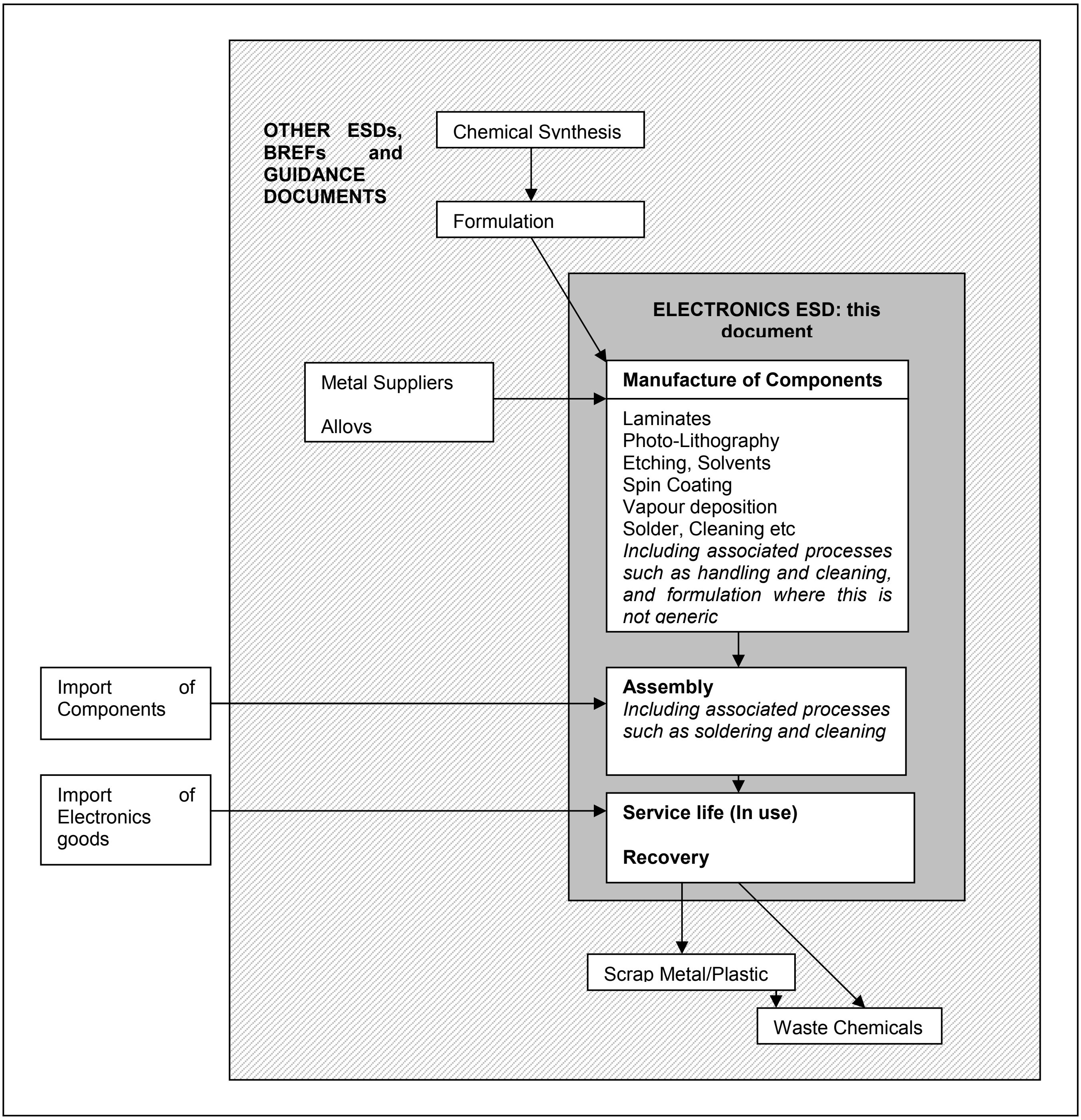

Figure 2.1 **The order of processes that occur in the electronics industry**

3. INDUSTRY PROCESSES AND EMISSIONS ESTIMATION

Sections 3.2 to 3.14 present information relating to industry processes, enabling a user to derive release scenarios. The type of information presented, and how to interpret it, is first described in Section 3.1.

3.1 Estimation overview

This section is set out in terms of processes listed in Section 2.8. To use this section, it is necessary to first consider the chemicals being used and the type of component or product being produced.

Overall, this section describes processes in the electronics industry in terms of unit operations, with reference to the use of specific chemical types, and identifies potential routes of release to the environment. Often, these are associated with the manufacture of specific components, and these are described within the relevant section. It aims to provide useful background information to risk assessors, particularly to support understanding of the role of specific chemical types in each process, and also to provide a useful overview of the nature of the process, and the working environment in which it takes place. **It is important to note that each of the unit operations do not necessarily take place at separate locations; any one location may have several processes taking place, each involving the use of chemicals as described in this section.** Furthermore, for sites at which multiple processes take place, the releases could be summed to give total kg/d for the relevant site. The release scenarios are process scenarios for specific substances and if more than one process takes place on any site, then they should be added together, calculating according to the actual substance in use. This document suggests scenarios and does not seek to instruct the reader on how to conduct a risk assessment.

The use of chemicals in the electronics industry is very often on a small scale when compared with other industry sectors, with a high reliance on manual handling and consequently use of small containers. Chemical suppliers will re-package bulk products for use by small organisations, and some organisations will themselves decant from larger containers to smaller unit sizes for day-to-day use. This is common in small to medium enterprises.

During manufacturing processes for electronic components, the focus will be on the quality of the products being produced with engineering designed to ensure quality of the final products, which may themselves be of high unit value. Less attention may be given to efficiency in the use of chemicals that, in some processes, are a relatively low-cost element. This is true particularly for etching and cleaning processes, but conversely, certain fine chemicals and ultra-pure materials used in semiconductor manufacture will be very expensive, and their cost will ensure that careful handling is used.

This document presents release estimates that may be cautious, but are considered to be realistic. It may be that the rate of release and environmental footprint of typical manufacturing facilities in particular industry sectors, for example parts of the European semiconductor industry, may be significantly better than these figures indicate. Indeed the industry has indicated in general terms that this may be the case (ESIA, 2008). The release pathways of chemicals during various processing techniques relevant to this report also vary across different parts of the components industry sector. The relevance of some abatement techniques is discussed where applicable.

3.1.1 Approach to assessment

A user may approach the need for assessment from the point of view of knowledge of chemical type, component type or process type. The process is itself a function of chemical use and end component type, and all three ‘factors’ in the industry need to be considered. For example, the use of etchants in the production of printed circuit boards or semiconductors will be described as ‘etching’ in both cases, but the conditions and scale of use will vary depending on the component being produced.

As a result of this approach to the ESD, some information within the document is duplicated; this is to allow those with specific interests to find the relevant information quickly, without the need to read the whole document.

By the nature of industrial processes in an innovative sector where new products and processes are being continually developed, this ESD cannot provide an exhaustive list of scenarios. However, it is hoped that the examples described in this section will help in determining generic exposure scenario assessments. Other factors also need considering and should be taken into account if it is found that the ESD conditions described do not fit site-specific activities.

This section leads the user of the ESD to the Release Scenario Tables that quantify exposure to the environment. If the precise conditions of the user are not described, this section should still provide a basis for exposure assessment. Table 3.1 below identifies the sections in this document that summarise each process. Later sections set out release scenarios, with those sections are identified in Table 3.2 (refer to Section 3.1.3).

Table 3.1 Summary of processes

Process Description	Section reference(s)
Assembly of components	3.2
Chemical formulation	3.4.4.1, 3.5.4.1, 3.6.4.1, 3.9.4.1, 3.10.4.1
Chemical handling by the user	3.3.4.1, 3.4.4.2, 3.5.4.2, 3.6.4.2, 3.7.4.1, 3.9.4.2, 3.10.4.2
Chemical vapour deposition	3.3
Cleaning of components and equipment	3.2.4.1, 3.3.4.2, 3.4.4.3, 3.5.4.3, 3.6.4.3, 3.7.4.2, 3.8.3.1, 3.9.4.3
Electroless plating	3.4
Electroplating	3.5
Etching	3.6
High vacuum evaporation / sputtering	3.7
Laminate production	3.8
Photolithography / spin coating	3.9
Soldering	3.10
Service life	3.12
Recovery from waste	3.13
Waste	3.14

3.1.2 Data required for developing a release scenario

A risk assessment utilises various data and a risk assessor will normally have access to some such data. This ESD will support a user when developing that data set.

Substance tonnage associated with relevant usage

Tonnage data may be available from manufacturers, importers or the public domain. The Nordic countries' SPIN database is a useful source of information on a substance-specific basis (identified by CAS number), and identifies some substances used in electronics-related applications.

A number of relevant NACE Industrial codes are listed, including:

- 30 (Manufacture of electrical and optical equipment).
- 31 (Manufacture of electrical machinery and apparatus).
- 32 (Manufacture of radio, television and communication equipment).

From the SPIN database, 39 CAS are relevant to these industries, accounting for 381 products and over 2,250 t used in these industries in the year 2005. More specific data could be accessed by potential risk assessors for use in developing risk assessment scenarios.

Characteristics of the 'main site' or sites

Site-specific or typical characteristics that need to be considered include:

- What on-site waste stream treatment is there?
- Are air waste streams scrubbed prior to release?
- Is process waste water mixed with any other waste (such as storm run-off or sewage)?
- Are waste waters treated on-site?
- Do they pass to an on-site or municipal WWTP, and if so what is the flow rate?
- Is the site located close to the sea?

When considering the scale of the process at the main site, it may be helpful to consider any available information from the site regarding process turnover, for example, for surface treatments, the surface area treated.

Some points to bear in mind

Biodegradation is important when considering the final fate of material rinsed to waste water.

Certain metal salts may adsorb from waste water during waste water treatment, including on-site treatment. This may result in the balance of metal passing to waste water in the first instance changing, as some metal adsorbs to solid waste (process sludges or solids from settled waste water). There are also wider implications for assessment of environmental fate, which are outside the scope of this ESD.

Consider existing risk assessments, and also the biotic ligand model of environmental risk assessment (for example as described in MERAG, ICMM, 2007, and metals-specific guidance recently incorporated into RIP 3.2 draft technical guidance).

3.1.3 Sources of release rates

The release scenario tables bring the findings of this work together with relevant default values from the A- and B-tables of the EU Risk Assessment Technical Guidance Document, or TGD (EC, 2003a), in order to arrive at a set of information for risk assessors that is easy to use.

Unit operations and other life cycle stages

Many processes have been identified, termed frequently in industry as 'unit operations'. There are also many chemicals. In combination these make up what any one company does. A company may use several of these unit operations. Manufacture of a specific component may involve a series of unit operations and several may need to be considered in order to evaluate the whole life cycle of a substance in the electronics industry.

Most installations will include more than one unit operation, and a risk assessor will need to take account of whether there should be a summation of releases.

Table 3.2 highlights the existence of release scenario tables for each type of process (as listed in Section 2.8). The physical form and broad description of the chemical (that is, whether metal, inorganic solid, organic solid, aqueous solution or organic solution) will be sufficient in determining the correct release scenario.

Table 3.2 Relevant Release Scenarios

Operation	**Chemical description**				
	Solids			**Liquids**	
	Metals	**Inorganic**	**Organic**	**Aqueous preparation**	**Non-aqueous preparation**
Assembly of components	3.2.3.1	3.2.3.1	3.2.3.1	-	3.2.3.2
Chemical vapour deposition (doping)	-	3.3.3.1	3.3.3.1	-	3.3.3.1
Electroless plating	-	-	-	3.4.3.2	-
Electroplating	-	-	-	3.5.3.2	-
Etching	-	-	-	3.6.3.2	-
High vacuum evaporation / sputtering	3.7.3.1	3.7.3.2	-	-	3.7.3.2
Laminate processing	3.8.2.1	-	3.8.2.1	-	-
Photolithography / spin coating	-	3.9.3.1	3.9.3.1	3.9.3.1	3.9.3.1
Soldering	3.10.3.1	-	-	3.10.3.2	3.10.3.3
Service life	-	-	3.12.1.1	-	3.12.1.2
Recovery from waste	3.13.1.1	-	3.13.1.2	-	-
Waste	3.14.1.1	3.14.1.2	3.14.1.3	-	-

Table 3.3 provides guidance on which chemical type best fits into the five chemical descriptions in Table 3.2.

Some types of materials, such as etchants, may be supplied in a solid form, but diluted for use. Losses may be different for handling as a solid or using as a solution, therefore different release scenarios are appropriate.

It is possible that there will be examples of chemicals that do not fit into these generalised descriptions, and the user of the ESD should then determine which release scenario is most appropriate.

Introduction to the release scenario tables

These tables include the data needed to prepare a risk assessment, or refer to existing TGD information (A-Tables; EC, 2003a). The appropriate A-Tables are reproduced in Annex IV. In all cases, there is assumed to be continuous use of chemicals in the electronics industry, with a figure of 300 days use indicated.

During discussion with electronic component manufacturers, it was noted that specialist disposal of waste was limited to large-scale manufacturers.

Table 3.3 Applicability of chemical types

Chemical Type	**Chemical description**				
	Solids			**Liquids**	
	Metals	**Inorganic**	**Organic**	**Aqueous preparation**	**Non-aqueous preparation**
Atmospheric gases*	-	-	-	-	-
Auxiliary materials	Y	Y	Y	Y	Y
Ceramics	-	Y	-	-	-
Cleaners (aqueous and solvent)	-	-	-	Y	Y
Dopants	-	-	Y	-	Y
Etchants	-	Y	-	Y	-
Flux	-	-	-	Y	-
Inorganic salts	-	Y	-	Y	-
Liquid crystals	-	-	-	-	Y
Metals	Y	-	-	-	-
Packaging materials / polymers	-	-	Y	-	-
Photoresists	-	-	Y	-	Y
Plating chemicals	-	Y	-	Y	-
Silicon	-	Y	-	-	-
Solder / solder paste	Y	-	-	-	Y
Solvents	-	-	-	-	Y
Speciality gases*	-	-	-	-	-

Note:
* Gases are omitted on the grounds that it is difficult to derive general rules

It is imperative to note that a risk assessor may possess information specific to a site, substance or process which could override the default releases. However, application of valid data for one site to other sites should only be done with great care.

The release scenario tables have been presented to provide guidance information for risk assessment in more detail than that provided by the TGD. An explanation of the Tables, and the supporting information provided for each one, is given in Table 3.4.

Table 3.4 Example release scenario table

Description	Small scale	Large scale	Comments
Notes on format	*Indicates the situation for smaller sites.*	*Indicates the situation for larger sites.*	*Any remarks regarding the descriptor or source of the recommended values for large and small scale operations.*
Total use	*Total use on one site. May be for more than one process use.* *Scale of use is important in considering waste control procedures.*		
Days in use	*Duration of use in days is important to determine daily rate of use and potential daily rate of discharge. Infrequent operations resulting in a low number of days per year may result in high daily use and intermittently[2] high concentrations discharged.*		
Percentage releases	*Users of this document may have access to information that overrides this figure and the following releases to specific emission pathways.* *Only in a few cases has reliable information been found from industry. It appears that process loss is not widely monitored, with a possible exception of a few large IPPC registered sites. The figures given are considered to be suitable estimates for preparation of risk assessments and are based on site visits and on TGD A-Tables, which in several cases were supported by the findings of the research. They are intended to give an indication of the realistic worst case, and specific sites may have better control mechanisms in place.*		
% to air	*The percentage loss to air and water is dependent on the physicochemical properties of the substance being considered. Vapour pressure (vp) and water solubility (sol.) are considered the key factors.*		
% to waste water	*Water in this instance will almost certainly be municipal waste water. Research suggests that there is no uncontrolled discharge directly into surface water of anything other than perhaps cooling water, and that even this is most unusual in the UK.*		

Other information:

Type of waste: Physical form of waste will be described. Solids may be collected for disposal and non-water-soluble solids in waste water may settle out before discharge. Liquids may be discharged to waste water.

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[2] In accordance with the TGD definition of intermittent release.

Waste disposal: This may be discharge to waste water, collection for hazardous waste disposal, collection as low-hazard waste or recovery. The degree of recovery will reflect the value of waste or need for control under RoHS.

In certain cases, there is specialist waste control involving removal from site by authorised disposal specialists. When considering hazardous substances, suppliers must inform customers of appropriate disposal methods.

'Waste solids' in this context is intended to indicate process sludges or settling tanks on-site. This information is provided as a rough guidance, but partitioning between water and sludge on-site must be considered on a chemical-specific basis when preparing a risk assessment. In most cases, sludges would be settled out and collected on site for disposal, but in the worst case these could be washed into the municipal drain system. Even at sites where sludge is settled, some suspended sludge will be washed to drain. The percentage loss to waste solids is dependent on the physicochemical properties of the substance being considered. Water solubility (sol.) is the key factor.

Fraction to sludge in on-site biological WWTP could be calculated as part of the risk assessment using SimpleTreat or some suitable model. Such treatment is not usual for this sector.

Solid wastes generated as part of the processes are not included in the release tables as these are collected and should not reach the environment, usually being handled by specialist disposal companies.

Total loss from process is presented. This is a relatively generic figure indicating losses associated with typical process efficiency (unwanted or discarded material sent off for recovery or re-use), but not necessarily being released to the environment. It may be useful for a risk assessor in understanding the process, but should not be taken to indicate a release to the environment from a processing site.

Important note regarding release rate for gases

Percentage release rates for gases from specific life cycle stages are not presented, on the grounds that few specialist gases are used and it would be difficult to derive general rules. More specific information is needed in order to proceed with development of a release scenario for a specific location. However, it can be assumed that in the worst case, 100 per cent of the gas used would be released to the atmosphere by the end of the life cycle.

Gases used in the industry can include acid, amine or unstable (pyrophoric) materials releasing gases as well as solvent vapours. For occupational hygiene reasons these will typically be extracted via exhaust. This is especially the case in circumstances where harmful gases such as ammonia, alkylamines and sulfur, and halide degradation products are released.

Gases may be vented to the atmosphere with a greater or lesser degree of scrubbing abatement, prior to emission through the exhaust stack. This is certainly the case with larger scale users of materials that release gas. Smaller users (such as development and pilot plant sites) will use low levels of such materials typically resulting in release of only a few kilos per annum to the atmosphere.

The gases typically released will not be of major environmental concern and will degrade or combine with other elements in the atmosphere with no cause for long-term accumulation. Degradation products, such as oxides of halides, sulfur, or nitrogen, will dissolve in water and be washed out of the atmosphere. The contribution of such materials to the environment by the electronics industry is not significant when compared to losses of such materials by the power generation industry or by vehicles.

Release of solvent vapours may be possible from some applications, but the level of use is lower than that in many other industry sectors. The control and fate of volatile organic compounds is well documented and is not explored in more detail in this document.

Extraction and venting of gases from handling, processing and also some maintenance operations is again reported to be subject to abatement treatment before discharge (ESIA/IMSI, 2008; Freescale Semiconductor; 2004; Industry Pers. Comm., 2008).

3.2 Assembly of components

3.2.1 Summary

Table 3.5 Summary of processes relevant to assembly of components

Life cycle stage	Description	Loss mechanisms
Micro-components	Placement of micro-electronic components onto mother boards (such as printed circuit boards).	Excess materials used for joining components, such as adhesives (auxiliary chemicals), solder, wires and so on.
Specialist components	Manufacture of optical equipment (LED, LCD lasers), passive components, solar cells and so on.	Excess materials used for joining components, such as adhesives (auxiliary chemicals), solder, wires and so on. Waste coating and packaging materials, such as polymers, ceramics. Usually solid waste; little use of water-based processes. Cleaning processes using solvents.
Large components	Joining of components into finished articles, such as production of white or brown goods.	Mostly considered as ‘engineering’ activities and not covered by this ESD. Specialist joining of electronic connections and use of packaging materials (inert fillers) is covered. Losses will include excess solder, wires, packing materials and so on, typically in the form of solid waste.

This ESD considers only the assembly of components using processes specific to the electronics industry. This excludes engineering (for example, bolting, gluing, painting) activities required to build finished products such as computers, televisions, and telephones.

Processes specific to the electronics industry will be making electrical connections between components (such as wires, solder) and providing insulation and heat-sinks around components (packaging materials). Soldering processes are covered in detail (see Section 3.10)

The use of wires, packing materials and insulators will be mainly in solid form and waste will be excess material including off-cuts, dust, and drilling debris. Some finished assembled articles will be washed, but there will be little use of aqueous systems.

Direct loss to waste water from assembly processes are considered to be low, with most waste being disposed of as low-hazard solid or sent for metal recovery.

3.2.2 Substances relevant to assembly processes

3.2.2.1 Silicon

Silicon dioxide (silica) is reduced to form silicon that is supplied in massive form as ‘ingots’, made by melting the oxide and crystallising onto a ‘seed’, forming a single crystal of silicon. These are up to 30 cm in diameter and 20 – 30 cm long. Thin slices are prepared, and duplicate patterns can be etched before cutting the wafers into the familiar ‘chip’ size articles. These wafers can be up to 30 cm wide.

Under controlled conditions, using pure oxygen, a thin layer of oxide is formed on the silicon wafers and this oxide layer is used as part of the photolithography and etching process.

Silicon waste is in the form of particulates and off-cuts from physical handling of the wafers. The silicon will oxidise quickly under atmospheric conditions and waste will be in the form of silicon dioxide. Although this may remain in suspension following washing phases with water, silica will be removed through settling or filtering processes during water treatment.

3.2.2.2 Ceramics

The term ‘ceramics’ typically describes inorganic solids that will usually have poor electrical conductivity and high heat tolerance. Their use can be spilt between micro-electronic components (such as substrates for semiconductors, capacitors, and resistors) and use in larger components, with a function as a non-conducting screen or heat shield placed between components.

The use of ceramics, whether in the production of micro-components or for use in larger units is limited to the ‘assembly’ process; the ceramic item is pre-cast and other components are built round it or on it. The ceramic item itself is not chemically active and other than drilling, grinding or cutting, the item (article) is not processed further in its own right. Waste ceramic materials will be stable and inert and will remain as solid waste for disposal in landfill or added with ash and other minerals to cement.

The manufacture of technical grade ceramics outside the scope of this ESD and is not covered here. However, this industry is well described in the IPPC BREF for Ceramics (EC, 2007). In particular, Section 3.3.8 of the BREF presents typical emission rates of specific pollutants from the manufacture of technical ceramics used in the electronics industry. Section 5.2.8 describes the best available techniques for pollution control.

Silicon is covered in a separate section, with particular emphasis on silicon deposition processes.

3.2.2.3 Solder

Solder is used to provide an electrically-conductive join between electronic components during assembly or to provide pathways for electric current between components.

Solder alloy is made by melting and blending tin with other metals, using processes common to the metal industry. There is strict control of exposure to lead fumes to protect health and these controls will also reduce exposure to the higher melting point metals being used. The solder is supplied either as ingots (which are melted during use), as solder paste or as solder wire.

Solder paste is an amalgam of solder particles with flux (rosin, organic acids and halides) plus high flash point solvents. Solder paste will contain at least 90 per cent metal, 5 per cent flux (of which <1 per cent is typically acid or halide) and the remainder solvent. Other speciality chemicals, such as wetting agents may be used, but at <1 per cent by weight of solder.

Solder paste is made by atomising solder alloy into <100 μm particles and blending with flux and high-flash point solvents to modify viscosity.

Solder wire, often with up to 5 per cent flux embedded within it (multi-core), is used mainly for precision joining of individual components.

It is difficult to quantify the level of waste from production, but most waste is recycled due to the value of the alloys and starting metals. For example, floor sweepings and dust removed from air extraction filters are collected for scrap or returned to the suppliers of metals. Water washing systems include a settlement treatment stage that will collect metal solids.

Solder paste manufacturing equipment is washed with the solvent used in the paste and either re-used if ‘fresh’ or disposed of as hazardous waste. The metal is not always recovered as old waste can contain oxides. The level of solder recovery is currently less clear than for precious metals and other materials used in circuit boards. Washing of equipment with water or proprietary aqueous cleaners will involve discharge of waste water for treatment or for collection at chemical waste, depending on the level of contamination.

In the absence of quantified reports, it is appropriate to use the default figure of two per cent waste.

3.2.2.4 Flux

Flux provides better adhesion of solder to metal surfaces by penetrating and lifting off thin layers of metal oxides on the components being soldered and on the solder surface itself.

Flux preparations

Flux is made by blending rosin with proprietary additives at elevated temperatures to reduce viscosity. The flux is dispersed or dissolved in water or alcohol (such as isopropyl alcohol) at ambient or slightly elevated temperatures to make preparations containing two to five per cent rosin. Formulation takes place batch-wise in dedicated vessels. The process is regular throughout the year, although there may be certain changes in the precise formulation details. Equipment is serviced periodically and cleaned with water. If it is not possible to use the water in the next batch formulated, it may be discharged to waste water treatment.

Rosin itself, and some additives (such as inorganic and organic acids and halides), are potentially hazardous. The finished preparations are classified and labelled accordingly in some cases. Rosin and its constituents (such as resin acids) are under investigation by the UK Health and Safety Executive (HSE), with a specific concern about potential sensitisation, and some rosin-free fluxes are on the market using other forms of fatty acid. Rosin-based flux is subject to a worker exposure limit - WEL - (HSE, 2004), and users should therefore monitor the use of flux.

The formulation of flux can be considered as no different in terms of potential exposure to other aqueous mixing and blending processes, and the default release rate of 2 per cent to waste water is appropriate.

Fluid flux preparations are supplied in containers of up to 25 litres.

Solder paste

Flux is mixed with solder metal and high flash point solvents to make solder paste formulations. The paste is dispensed into buckets of up to 25 kg. Smaller containers may also be used, in view of the potential for metal to oxidise or for the solvents to evaporate once the containers have been opened.

Equipment is periodically serviced and cleaned with water. If it is not possible to use the water in the next batch formulated, it may be discharged to waste water treatment. Solvents will be used for cleaning production equipment and solvent waste will be sent for disposal. Typically, metals will be recovered by specialist organisations and organic components will be disposed of as chemical waste or possibly incinerated.

Other forms of flux

Flux can also be incorporated into multi-core solder, and other compositions, for specialist uses such as assembly of components, and used to a lesser degree for the DIY market.

Use of flux

Most use (>90 per cent) is in wave soldering or hot air solder levelling (HASL) processes.

For wave soldering, the components are sprayed or dipped in the flux solutions, and with HASL flux is added to the solder bath, forming a layer on the surface that components must pass through. This layer of flux also protects the hot solder from oxidation.

Solder paste, containing a few per cent flux, is spread onto screens with holes that allow a small amount of solder to be forced onto a PCB or other components using a rubber blade. The components are then heated to melt the solder mixture, joining the components to the circuit board when cooled. The flux present will remain on the components, migrating rapidly to the surface of the solder joints.

With all processes, flux will remain on the components, or perhaps volatilise at the high temperatures of the process, leading to emissions to the local air compartment. In some cases, components are washed with alcohol preparations to remove excess flux before further assembly and the waste liquor (containing flux) will be disposed of as chemical waste or to waste water.

Once components are joined and assembled into products, there is not expected to be exposure to the residues of flux, unless components are removed during servicing or for disassembly at end-of-life. Soldered articles, used solder and waste solder paste will contain rosin acids that may remain in waste from metal recovery processes at end-of-life recovery.

3.2.2.5 Miscellaneous - auxiliary materials

The types of chemical product used in any industry are usually too wide to put into definitive groups. When considering the processes in the electronics sector, a large number of chemical products will be used on any site, some of which are not necessarily essential to the processes. Examples of these will include dyes and pigments for colouring finished circuit boards or other components, printing inks for text, ‘packaging’ materials to act as inert buffers between components, protective resin coatings, adhesives to reinforce solder joints and similar uses.

Many of these chemical products will be widely used in other industry sectors. Adhesives, for example, may be found in the motor industry for assembly, pigments and dyes may be applied in paint and varnish systems and so on. It is not considered necessary to describe these products in detail in this ESD, but the suppliers must be aware of the processes they may be being used in, and consider the potential for exposure to man or the environment when considering the risk assessment.

An important example of auxiliary chemicals is flame retardants. These have no direct enhancing effects on the function of the electronic device, but are included to reduce the risk of combustion caused by overheating or faulty circuitry. There have been many reports of flame retardants being found on the surface of or near electronic equipment during use, and there are also reports of such substances being released during breaking, recovery and recycling of components from electronic equipment.

The handling and use of flame retardants during manufacture of plastic components (such as insulating sheaths, casing and structural parts of equipment) is not covered in detail as use patterns are consistent with other industry sectors. However, the breaking, recovery and recycling of electronic equipment is specific to the industry and is considered in Section 3.13 on Recovery of Waste

3.2.2.6 Polymers and support materials

The term ‘polymers and support materials’ describes non-active components of the electronic equipment that are included in the fabrication, such as those that provide a base, heat or electrical insulation, or strength. The types of materials will vary, but by the nature of their function, will be inert and stable, with the choice of material being in terms of the physical properties and not chemical identity. Such components will generally be materials commonly supplied to a range of industry sectors. However, in this industry, they can be referred to as ‘packaging’ even when they are internal parts of an item. This should not be confused with packaging in its normal sense (excluded from this ESD).

Polymers may also contain certain additives used to impart specific physical properties, such as plasticisers, flame retardants, and stabilisers. Although the production of the polymer components and use of the auxiliary additives is not considered in detail in this report, these chemicals are considered in the breaking, recovery and recycling of electronic goods in Section 3.13 on Recovery of Waste

Examples of materials include plastics, polymeric films, fibre board, resins and metals (described in Section 3.9), and can be considered to be insoluble in water.

Exposure and loss of materials during use will be solid waste (cuttings, dust, off-cuts) and will be collected for disposal as solid non-hazardous waste, perhaps being disposed through municipal waste collection for landfill or incineration. Resins or foams used in liquid form will solidify on use and will also be treated as solid waste after use, although unused liquid materials will need to be disposed of.

Environmental impact will be limited to rinsing of residues or sweepings to waste water systems during cleaning or servicing activities. The percentage loss to the environment will be low.

Photoresists for printed circuit board (PCB) manufacture are often supplied within polymer films. Many of these films are based on bisphenols and they will be dissolved or washed off the PCB after developing. Washing off the photoresist (see Section 3.12) is often done with aqueous acid or basic rinses that will most likely be discharged to waste water treatment.

3.2.3 Release scenarios for assembly processes

Please also refer to Section 3.10 on release scenarios for Soldering.

3.2.3.1 Release Scenario for assembly of components: metals, inorganic and organic solids

Metals

Metals used in assembly include metal frames for holding components, conductive wires, heat sinks and joining mechanisms. Solder is described separately (refer to Section 3.10). Most metal will be in bulk form.

Inorganic solids

For inorganic solids, this category covers the use of ceramics in assembly processes. The nature of these materials means they tend to be inert and stable under extreme conditions, and are therefore not expected to change in chemical or physical form during the process or during disposal of process wastes.

Other information: Type of waste will be solid at both large and small scale installations (small particulates, fragments). Solid waste will go for disposal from small scale operations (no specialist disposal methods) and from larger sites (specialist disposal methods).

The expected amount of waste solid (process sludges or solids from settled waste water, in the form of non-water-soluble solid particulates) is estimated to be of the order of 5 per cent at small scale sites and 2 per cent at large scale sites.

Organic solids

Organic solids used in assembly are limited to polymeric materials for use as insulation, packaging or as a ‘base’ (laminates). These are likely to be of low solubility in water and will be disposed of as non-hazardous solid waste.

Other information: Type of waste will be solid at both large and small scale installations (small particulates, dust, fragments). Solid waste will go for disposal from small scale operations (no specialist disposal methods) and from larger sites (specialist disposal methods) with little or no recovery of waste.

The expected amount of waste solid (process sludges or solids from settled waste water, in the form of non-water-soluble solid particulates) is in the order of 5 per cent at small scale sites and 2 per cent at large scale sites. These amounts are estimates.

Table 3.6 Release table for assembly of components: metals, inorganic and organic solids

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/y	> 1000 kg/y	
Days in use	300	300	Continuous use
% to air	0%	0%	Only solid wastes are anticipated (small particulates, fragments)
% to waste water	0%	0%	

Other information: Total loss (wastage) from the process is estimated to be typically 5 per cent at small sites and 2 per cent at large sites. Type of waste will be solid at both large and small scale installations (small particulates, fragments). Solid waste will go for disposal from small scale operations (no specialist disposal methods) and for recovery at larger sites (specialist disposal methods). The degree of recovery will reflect the value of the waste.

The expected amount of waste solid (process sludges or solids from settled waste water, in the form of non-water-soluble solid particulates) is estimated to be of the order of 5 per cent at small scale sites and 2 per cent at large scale sites.

3.2.3.2 Release Scenario for assembly of components: non-aqueous liquids

Non-aqueous liquids will include adhesives, surface coatings and liquid polymers (resins), and solvents (used as carriers). TGD Industry Category (IC) 14 for paints and surface coating is considered to be the most appropriate to follow as a basis for emissions.

Table 3.7 Release table for assembly of components: non-aqueous liquids

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/pa	> 1000 kg/pa	
Days in use	300	300	Continuous use
% to air, vp < 5000 Pa	1%	1%	Ref TGD Table 3.15
% to air, vp > 5000 Pa	5%	5%	Ref TGD Table 3.15
% to waste water, sol. < 100 mg/l	1%	1%	Ref TGD Table 3.15
% to waste water, sol. > 100 mg/l	5%	5%	Ref TGD Table 3.15

Other information: Total loss (wastage) from the process is estimated to be typically 2 - 10 per cent. Types of waste will be liquid and solid at both large and small scale installations (liquids may ‘dry’ or set). Solid waste will go for disposal from small scale operations (no specialist disposal methods) and from larger sites (specialist disposal methods) with little or no recovery of waste. If conducting a site-specific assessment, consider whether solvent waste is collected for specialist disposal.

3.2.4 Associated processes

3.2.4.1 Cleaning of components and equipment

3.2.4.1.1 Summary

Water rinsing, where it is an integral stage of other industrial processes, is considered as part of those processes. This section considers only cleaning using specific chemicals, such as detergents or solvents.

Table 3.8 Summary of processes relevant to cleaning

Life cycle stage	Description	Loss mechanisms
Aqueous cleaning	Immersion or spraying of components in dilute aqueous preparations of detergents. Cleaning of equipment with water-based detergents. Water-based cleaning is not suitable for many electronic components due to sensitivity to water.	*100% loss of detergents to waste water is assumed. There may be some carry-over onto finished components, but this is not considered significant.* Waste water will include the materials being washed off components, such as oils, greases, flux residues, metal salts and so on. *Note applicability of Detergents Regulation EC 648/2004 ensuring minimum standards of biodegradability for surface active components – this does not mitigate loss, but ensures that residues in effluent will not accumulate in the environment.*
Solvent cleaning	Immersion or spraying of components in dilute solvents or solvent preparations. Most use is where non-water-soluble materials are to be removed (such as photoresist, films and so on), where there is sensitivity to water (for example, the final stages of PCB manufacture) or where quick drying is required.	Loss to atmosphere of volatile solvents (such as acetone, isopropyl alcohol, esters and so on.) or as solvent waste for disposal. Some loss expected to waste water

The amount of cleaning appears to vary within the electronics industry, with some suppliers of components conducting very little cleaning and others cleaning all components at every stage. Cleaning adds costs to the process and the amount of cleaning may reflect the final value of the end products. Examples where no cleaning takes place may include components for toys or household appliances and examples of cleaning will be for aerospace or defence industries.

Water is used for early stages of cleaning, either with or without surface-active agents (detergents). Large quantities of water are consumed in preparing silicon wafers and other substrates such as glass and ceramics. Rinsing after electroless plating, electroplating and etching is essential to remove corrosive or otherwise detrimental chemical residues.

Equipment is often cleaned with water-based detergents as part of servicing and maintenance procedures.

Solvent cleaners tend to be used in the later stages of production, with the use of volatile substances such as acetone or alcohols, either as neat substances or as a component of aqueous solutions (or less commonly, with wetting agents). The use of specific types of solvents will be determined by the material to be removed, the rate of drying, and suitability in terms of ensuring that the component being cleaned is not damaged.

Cleaners (aqueous)

Aqueous and non-aqueous cleaning products are used in various stages of electronic component manufacture. Non-aqueous solvent cleaners are described below.

Examples of aqueous cleaners include dilute preparations of surface active agents (such as alkyl ethoxylates) and these will themselves be subject to the Detergents Regulation (648/2004) that imposes a minimum standard of biodegradation. Those failing the prescribed rate of biodegradation can be placed on the market for specialist uses subject to a risk assessment; specialist use in the electronics industry could be an example where a derogation is granted.

Many of the cleaning preparations marketed for the electronics sector will mirror formulations used in other industry sectors, such as domestic applications, metalworking, and the motor industry.

Formulation of such cleaners will be through mixing at ambient or slightly elevated temperatures using processes common to the detergent and cleaning industry sector. Supply takes place in small containers of less than 25 kg, with many suppliers offering containers of one litre or less.

The level of component and surface cleaning in the industry varies, with the highest level of cleaning found in the production of high-value products for the aerospace and defence industries.

The use of ‘clean-room’ processes for semiconductor and other precision components should not be confused with the use of cleaning products. Clean room processes describe the barrier methods used to prevent chemical contamination of micro-electronic components and not the cleaning processes employed during manufacture. Many cleaning products can themselves be considered as potential contaminants in the precision processes that require clean-room technology, and surface-active materials could interfere with subsequent processing of the electronic components. Exceptions to this are purified water and high-quality volatile solvents such as acetone.

The use of aqueous cleaners, by their nature, involves significant volumes of water as many products are supplied as concentrates to be diluted in water at the time of use. Although there may be isolated cases where waste water is collected for disposal as chemical waste, it is assumed that there is a 100 per cent loss of the aqueous cleaning products to waste water discharge. Although the detergents themselves may meet biodegradation criteria, waste effluent will contain emulsified or suspended material that has been removed during the cleaning process.

A small proportion of the surface active agents may remain on the cleaned surfaces, but this will be negligible and is not considered further – any such residues are likely to either degrade completely during the life-time or disposal of the electronic component, or be removed in subsequent washing stages.

Solvents (including organic solvent-based cleaners)

Solvents as a class of substances are used as carriers and cleaners in a wide range of applications in the electronics industry, with functions that are comparable with uses in other industries. Solvents such as xylene are used as a diluent and viscosity reducer, for example in solder flux, in the same way that they will be used in paints, sealants or other applications.

Proprietary formulations will include mixtures with other solvents such as ethanol, iso-propyl alcohol, or methanol. Such preparations will typically contain polar, water-soluble and volatile components. Blending with other solvents will be under ambient conditions with precautions in place in consideration of possible flammability and atmospheric concentration limits. Equipment would not typically require washing with water after use and there is considered to be a low risk of loss to waste water from formulation activities. Similar solvent preparation may be used in other sectors of industry as cleaning agents or thinners (paints and other surface coatings).

Solvent cleaning of printed circuit boards (PCBs) or other components involves spraying or dipping the components in the solvent to remove residues of flux, grease or other contaminants or for removing photoresist layers. The choice of solvent will depend on the required polarity or volatility.

The use of solvents is regulated by Directive 99/13/EC on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations.

Waste solvents are either disposed of as hazardous waste or will be lost in use to the atmosphere. There is not considered to be residual solvent remaining on components after assembly.

3.2.4.1.2 Release scenarios for cleaning processes: aqueous and non-aqueous preparations

Aqueous preparations

Water-based cleaning with detergents, or water rinsing, takes place at the early stages of component manufacture. Due to the nature of water washing, large volumes of water may be involved and it is assumed that a high proportion will be discharged as waste water.

Many cleaning agents may themselves be subject to the Detergents Regulation and the biodegradation thresholds are a key factor in any risk assessment being carried out.

The type of waste will be liquid at both large and small scale installations (water-soluble aqueous waste with emulsified or suspended non-water-soluble materials that have been cleaned from components). This would pass to waste water from small scale operations and from larger sites with no specialist disposal methods, and will be discharged to either municipal or on-site waste water treatment plants.

Non-aqueous preparations

Solvent washing may take place at various stages of processing to remove non-water-soluble contaminants or residues, including later stages of assembly when use of water is not appropriate. Solvents are used to remove residues, of photoresists and flux for example, and although most solvent waste will be collected for disposal, some may evaporate from the surface of cleaned components or equipment or be rinsed to waste water.

The route and quantity of emission is proportional to the water solubility and vapour pressure of the solvent cleaners.

Table 3.9 Release table for cleaning of components: aqueous and non-aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/pa	> 1000 kg/pa	Aqueous preparations: Quantity of active detergent component and not water. Non-aqueous preparations: Quantity of solvent.
Days in use	250	300	Most processes are continuous and not based on campaigns.
Releases information			For non-aqueous preparations: Proportion lost to air, water and soil is variable and dependent upon chemical properties. Refer to TGD Table A4.1, cleaning products UC48 (solvents).
% to air	0%	0%	For aqueous preparations only.
% to waste water	100%	100%	For aqueous preparations only (TGD Table A4.1, cleaning products UC10).

The following data are taken from TGD Table A4.1, cleaning products UC48 (solvents).

Table 3.10 Extract from TGD A-tables

Vapour pressure (Pa)	Water solubility (mg/l)	% emission to air	% emission to waste water	% emission to soil
< 100 Pa	< 10 mg/l	1.5%	10%	20%
100 – 1000	“	15%	10%	20%
1000 – 10 0000	“	40%	10%	20%
> 10 000	“	60%	10%	20%
< 100 Pa	10 – 100 mg/l	7.5%	20%	10%
100 – 1000	“	12.5%	20%	10%
1000 – 10 0000	“	25%	20%	10%
> 10 000	“	40%	20%	10%
< 100 Pa	100 – 1000 mg/l	2.5%	40%	5%
100 – 1000		10%	40%	5%
1000 – 10 0000		15%	40%	5%
> 10 000		22.5%	40%	5%
< 100 Pa	> 1000 mg/l	3%	60%	0.5%
100 – 1000		7.5%	60%	0.5%
1000 – 10 0000		12.5%	60%	0.5%
> 10 000		17.5%	60%	0.5%

3.3 Chemical vapour deposition (doping)

3.3.1 Summary

Table 3.11 Summary of processes relevant to doping

Life cycle stage	Description	Loss mechanisms
Semiconductor production	Hot gases and vapours of specific ions condense onto substrate surfaces.	Carrier gas loss to atmosphere. Residues of dopant (specifically degradation products such as amines, halides, volatile organic substances) into atmosphere or traps / filters. Residues of solid waste deposited in equipment or filters.
End of life	Metal or other deposited materials will remain on the component and be present as waste at end of life.	Loss as solid waste for possible recovery of rare-metals or other materials of value. Non-recovered deposits to landfill or other solid waste disposal.

Chemical vapour deposition (CVD) or metal organic chemical vapour deposition (MOCVD) is a generic name for a group of processes that involve depositing a solid material from a gaseous phase. In some respects it is similar to physical vapour deposition (PVD). PVD differs in that the precursors are solid, with the material being vaporised from a solid target and then deposited onto the substrate.

Precursor gases (often diluted in carrier gases) are delivered into the reaction chamber at ambient temperatures. When these gases pass over or come into contact with a heated substrate, they react or decompose forming a solid phase, which is then deposited. The temperature of the substrate is critical and can influence what reactions will take place.

CVD coatings are usually only a few micrometres thick and are generally deposited at fairly slow rates, usually of the order of a few hundred micrometres per hour.

Generally, precursor compounds only provide a single element to the deposited material, with others being volatilised during the CVD process. However, it is possible that precursors may sometimes provide more than one element. Such materials simplify the delivery system, as they reduce the number of reactants required to produce a given compound.

CVD precursor materials (commonly known as ‘dopants’ fall into a number of categories such as:

- Metal halides.
- Hydrides.
- Metal Alkyls.
- Metal Alkoxides.
- Metal Diallylamides.
- Metal Diketonates.
- Metal Carbonyls.

It should be noted that this process is used in a number of industries to surface treat and coat different types of substrate to a high degree of precision.

Doping is also a colloquial term for any process of introducing a layer of substance onto a substrate. For organometallic dopants, the chemical vapour deposition method is most common. For pure metal dopants, the high vacuum ‘sputtering’ method is used.

3.3.2 Substances relevant to chemical vapour deposition

3.3.2.1 Dopants

Doping, or deposition of particular atoms on silicon wafers, uses very specialist organo-metal, boron, silicon or phosphorus substances that will often degrade functionally as the intended ‘dopant’ atom is deposited. Many types of these materials will degrade to form water-soluble or volatile by-products such as amines, halides and water-soluble or insoluble salts.

Silicon products (such as silicon nitride and silane derivatives) are used to re-deposit silica on the treated wafers to form a new layer in semiconductor manufacture.

The level of chemical use for doping is often very small, with only tens of kilos of certain types of specialist substance being supplied in Europe. The high cost and instability of many dopants supplied will typically result in none of these parent materials being present after processing. Many such materials will degrade under atmospheric conditions, including residues in open containers.

Washing of semiconductors is a key part of the processing and will involve very large volumes of water in relation to the quantity of material used. The washings will include the degradation products of dopants, including amines and metal salts. It appears that most waste from washing is discharged as waste water and although the proportion of the metal or other functionally-active components will be small (high costs will ensure good efficiency) up to 100 per cent of ‘carrier’ components, such as amines, may be lost to waste water. Volatile degradation products may be lost to the atmosphere.

Doping is also a colloquial term for any process of introducing a layer of substance onto a substrate. For organometallic dopants, the chemical vapour deposition method is used most commonly.

It is essential that the supplier or user of these reactive chemicals understands fully the rate of chemical degradation and the identity and properties of degradation products that are formed when considering a risk assessment for such substances.

3.3.2.2 Silicon

Silicon dioxide (silica) is reduced to form silicon that is supplied in massive form as ‘ingots’, made by melting the oxide and crystallising onto a ‘seed’, forming a single crystal of silicon. These are up to 30 cm in diameter and 20 – 30 cm long. Thin slices are prepared and duplicate patterns can be etched before cutting the wafers into the familiar ‘chip’ size articles. These wafers can be up to 30 cm wide.

Under controlled conditions, using pure oxygen, a thin layer of oxide is formed on the silicon wafers and this oxide layer is used as part of the photolithography and etching process.

Silicon waste is in the form of particulates and off-cuts from physical handling of the wafers. The silicon will oxidise quickly under atmospheric conditions and waste will be in the form of silicon dioxide. Although this may remain in suspension following washing phases with water, silica will be removed through settling or filtering processes during water treatment.

3.3.2.3 Atmospheric gases

Atmospheric gases are defined as naturally-occurring gaseous substances isolated from the atmosphere. Examples in the electronics industry include nitrogen as an inert carrier, a cooling medium (liquid form), or to provide an oxygen-free atmosphere for manufacture. Similarly, argon is used as an inert carrier for plasma process and sputtering in semiconductor manufacture. Carbon dioxide, in its solid form, has applications for abrasive cleaning of silicon wafers at very low temperatures.

Gases are supplied as pressurised liquids in the same manner as supplied to other industry sectors. It can be considered that use will result in the gases returning to the atmosphere with 100 per cent loss to air. There will be exceptions, such as the use of oxygen as an oxidising agent that will lead to the formation of oxidised forms of the material being processed.

Neon and xenon gases are also used in plasma screen technology, which is discussed briefly in Section 2.7.3 on Displays.

3.3.3 Release scenarios for chemical vapour deposition processes

3.3.3.1 Release scenario for chemical vapour deposition: inorganic solids, organic solids and non-aqueous liquids

Specialist process involving chemicals of high value that are possibly very pure or are made using rare elements. Typical use is in very small quantities, and the process itself may be very inefficient with only a proportion of the substance reaching the target surface.

Inorganic solids will probably be silicon, boron or other semi-conducting substance-based material.

Many substances used for this process degrade functionally during use, with only specific elements deposited onto the target surface. Degradation products not being applied to the target surface constitute the main source of the waste.

No TGD Tables are considered to reflect this process. The physicochemical and biodegradation properties of the degradation products must also be considered. These may include volatile substances or substances that could adsorb readily to sludge.

Organic substances used in the process are expected to have a similar release pattern to inorganic solids. Organometallic substances will deposit metal onto the target surface and metal will also be lost as solid waste.

For non-aqueous liquids, this is a specialist process involving high value chemicals (very pure or with rare elements) and the release will be similar to that for organic and inorganic solids. The principle of processing is similar irrespective of physical form – the substance is allowed to degrade so that one or more degradation products are deposited onto the target surface.

Table 3.12 Release table for chemical vapour deposition: inorganic solids, organic solids and non-aqueous liquids

Description	Small scale	Large scale	Comments
Total use	< 100 kg/pa	> 100 kg/pa	Very low volume of use.
Days in use	300	300	Continuous use.
% to air, starting materials	0%	0%	Dust will be trapped in filter systems[1].
% to air, gaseous degradation products	100%	100%	Vapour losses of volatile degradation products.
% to waste water, sol. > 1 mg/l	2%	2%	Water-soluble degradation products.

Note

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control.

Other information: This is an inefficient process, despite high costs. The total loss (wastage) from the process is estimated to be typically <50 per cent at small sites and <20 per cent at large sites. At both large and small scale installations, types of waste would be solid and liquid at both large and small scale installations (solid waste and washings from process). Wastes would be collected mainly as chemical waste. Some washings would pass to waste water. Materials may be unstable and breakdown products need to be considered. Specialist disposal methods would generally not be used, but larger scale formulators may have waste disposal and treatment procedures in place.

The expected amount of waste solid (process sludges or solids from settled waste water: solid degradation products and substances of solubility <1 mg/l) is in the order of 2 per cent at both large and small scale sites.

3.3.4 Associated processes

3.3.4.1 Chemical handling by the user

The use of chemicals in the electronics industry is very often on a small scale when compared with other industry sectors, with a high reliance on manual handling and, consequently, use of small containers. Chemicals suppliers will re-package bulk products for use by small organisations, and some organisations will themselves decant from larger containers to smaller unit sizes for day-to-day use. This is common in small to medium enterprises.

During manufacturing processes for electronic components, the focus will be on the quality of the products being produced, with engineering designed to ensure quality of final products that may themselves be of high unit value. Less attention may be given to efficiency in the use of chemicals that, in some processes, may be a relatively low-cost element. This is true particularly for etching and cleaning processes. Conversely, certain fine chemicals and ultra-pure materials used in semiconductor manufacture will be very expensive, therefore their cost will ensure careful handling.

Table 3.13 Summary of processes relevant to chemical handling

Life cycle stage	Description	Loss mechanisms
Storage and handling	Storage of substances and preparations prior to use. Transfer of substances and preparation into different containers. Dilution and mixing of substances and preparations at the point of use.	Surface contamination and emission to drain or ventilation resulting from leakage and spillage (not major accidents) or deliberate release. Disposal of container washings to drain or wastewater treatment plant. Disposal of used containers. Disposal of old material or products not meeting quality specifications.
Use	Application of substance or preparation to substrate or surface to be worked on. Cleaning or servicing of equipment after use.	Surface contamination and emission to drain or ventilation resulting from spillage or deliberate release. Liquid and solid wastes and emissions to drain or wastewater treatment plant arising from washing or servicing chemical plant areas and equipment.

The Electronics section of the Environment Agency NetRegs website (Environment Agency, 2005) makes recommendations to some areas of industry relevant to electronics manufacturing, with regard to prevention of pollution. The guidance is aimed at small and medium-sized enterprises (SMEs) not subject to IPPC/LAAPC. Mandatory requirements for handling and storage of chemicals include the following, for sites manufacturing CDs/DVDs:

- Contain any spilled chemicals to prevent them entering surface water drains, ditches, watercourses or soakaways. Do not hose spillages down drains.

- Check pipe work for leaks regularly. If leaks are identified, ensure that maintenance work is undertaken immediately and the extent and impact of any contamination assessed and cleaned up.

For sites manufacturing printed circuit boards, there are no mandatory requirements, but the following guidelines are included:

- Store all chemical barrels in a secure location which cannot leak. The base of these areas should be chemical resistant and must have secondary containment such as a bund or a drip tray of adequate size.

- Make sure that all unloading areas are away from storm drains and are hard surfaced to prevent water or ground contamination if there is a spill. If this is not possible, make sure that the drains are protected during delivery (for example using suitably-sized and correctly fitted drain covers).

- Storage areas and drip trays should drain to the plant's wastewater treatment plant, as long as the plant can process these wastes. On no account should these be permitted to drain to the storm system.

- Contain any spilled chemicals to prevent them entering surface water drains, ditches, watercourses or soakaways. Do not hose spillages down drains.

These guidelines have been prepared by industry for industry and take into consideration that the primary activities in most cases are the design, manufacture and assembly of electronic components and the sites are not regarded as chemical production or formulating plants.

3.3.4.1.1 Release scenarios for handling processes

Release Scenario for handling by the user: inorganic and organic solids Inorganic solids

Handling of inorganic solids by the user includes direct addition to production process, on-site dilution prior to use, disposal of packaging and servicing equipment that may contain dried residues of solids.

The TGD Industry Category (IC) 2: General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenario, with Table A2.1 being used as a basis for these estimates. Poorly-water-soluble solid waste is expected to be removed during initial settling from waste water, leading to a low level of entry to sludge and subsequent application to agricultural soil. Water-soluble waste will either remain in solution and be discharged (for example, nitrates or sulfates), or in some cases (for example, certain metal ions such as copper or tin) will adsorb onto sludge. The proportions reaching water or soil must be estimated in accordance with the known properties of the solid.

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). The type of waste will be solid and liquid at both large and small scale installations (solid waste and washings from process). These wastes (including solid residues from formulation removed when cleaning equipment) would go to waste water or landfill from small scale operations (no specialist disposal methods) and to waste water, recovery, chemical waste or landfill from larger sites (specialist disposal methods). Larger scale formulators may have waste disposal and treatment procedures in place.

The amount of waste solid is estimated (on the basis of metals/materials adsorbing to process sludges or solids from settled waste water) to be in the order of 2 per cent at small and large scale sites.

Organic solids

Handling of organic solids by the user includes direct addition to production process or on-site dilution prior to use, disposal of packaging and servicing equipment. This category is also used to cover handling of polymeric materials such as films.

The TGD Industry Category (IC) 2: General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenario, with Table A2.1 being used as a basis for these estimates. Poorly-water-soluble solid waste is expected to be removed during initial settling from waste water, leading to a low level of entry to sludge and subsequent application to agricultural soil. However, water-soluble wastes will either biodegrade or remain in solution and be discharged. Biodegradability should be considered when preparing a risk assessment for organic solids.

Other information: as for inorganic solids. If solvent cleaners are used, waste may be collected. Releases to waste solids include substances of water solubility <1 mg/l.

Table 3.14 Release table for handling by the user: inorganic and organic solids

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air, vp < 100 Pa and all inorganic solids	0%	0%	Dust will be trapped in filter systems[1].
% to air, vp > 100 Pa	1%	1%	For organic solids only: Estimate based on TGD Table A2.1.
% to waste water	2%	2%	Estimate based on TGD Table A2.1.

Note

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control.

3.3.4.2 Cleaning of components and equipment

3.3.4.2.1 Summary

Water rinsing, where it is an integral stage of other industrial processes, is considered as part of those processes. This section considers only cleaning using cleaning chemicals, such as detergents or solvents.

Table 3.15 Summary of processes relevant to cleaning

Life cycle stage	Description	Loss mechanisms
Aqueous cleaning	Immersion or spraying of components in dilute aqueous preparations of detergents. Cleaning of equipment with water-based detergents. Water based cleaning is not suitable for many electronic components due to sensitivity to water.	Considered to be 100 per cent loss of detergents to waste water. There may be some carry-over onto finished components, but this is not considered significant. Waste water will include the materials being washed off components, such as oils, greases, flux residues, metal salts and so on. Note applicability of Detergents Regulation EC 648/2004 ensuring minimum standards of biodegradability for surface active components – this does not mitigate loss, but ensures that residues in effluent will not accumulate.
Solvent cleaning	Immersion or spraying of components in dilute solvents or solvent preparations. Most use is where non-water-soluble materials are to be removed (such as photoresist, films and so on), where there is sensitivity to water (for example, the final stages of PCB manufacture) or where quick drying is required.	Loss to atmosphere of volatile solvents (such as acetone, isopropyl alcohol, esters and so on) or as solvent waste for disposal. Some loss expected to waste water.

The amount of cleaning appears to vary within the electronics industry, with some component suppliers conducting very little cleaning and others cleaning all components at every stage. Cleaning adds costs to the process and the amount of cleaning may reflect the final value of the end products. Examples where no cleaning takes place may include components for toys or household appliances and examples of cleaning will be for aerospace or defence industries.

Water is used for early stages of cleaning, either with or without surface-active agents (detergents). Large quantities of water are consumed in preparing silicon wafers and other substrates such as glass and ceramics. Rinsing after electroless plating, electroplating and etching is essential to remove corrosive or otherwise detrimental chemical residues.

Equipment is often cleaned with water-based detergents as part of servicing and maintenance procedures.

Solvent cleaners tend to be used in the later stages of production, with the use of volatile substances such as acetone or alcohols, either as neat substances or as a component of aqueous solutions (or less commonly, with wetting agents). The use of specific types of solvents will be determined by the material to be removed, the rate of drying and suitability in terms of ensuring that the component being cleaned is not damaged.

Cleaners (aqueous)

Aqueous and non-aqueous cleaning products are used in various stages of electronic component manufacture.

Examples of aqueous cleaners include dilute preparations of surface active agents (such as alkyl ethoxylates) and these will themselves be subject to the Detergents Regulation that imposes a minimum standard of biodegradation. Those failing the prescribed rate of biodegradation can be placed on the market for specialist uses subject to a risk assessment – specialist use in the electronics industry could be examples where derogations are granted.

Many of the cleaning preparations marketed for the electronics sector will mirror formulations used in other industry sectors such as domestic applications, metalworking, and the motor industry.

Formulation of such cleaners will be through mixing at ambient or slightly elevated temperatures using processes common to the detergent and cleaning industry sector. Supply takes place in small containers of less than 25 kg, with many suppliers offering containers of one litre or less.

The level of component and surface cleaning in the industry is variable, with the highest level of cleaning found in the production of high-value products for the aerospace and defence industries.

The use of ‘clean-room’ processes for semiconductor and other precision components should not be confused by the use of cleaning products. Clean-room processes describe the barrier methods used to prevent chemical contamination of micro-electronic components and not the cleaning processes employed during manufacture. Many cleaning products can themselves be considered as potential contaminants in the precision processes that require clean-room technology and surface-active materials could interfere with subsequent processing of the electronic components. Exceptions to this are purified water and high-quality grade volatile solvents such as acetone.

The use of aqueous cleaners, by their nature, involves significant volumes of water as more products are supplied as concentrates to be diluted in water at the time of use. Although there may be isolated cases where waste water is collected for disposal as chemical waste, it is assumed that there is 100 per cent loss of the aqueous cleaning products to waste water discharge. Although the detergents themselves may meet biodegradation criteria, waste effluent will contain emulsified or suspended material that has been removed during the cleaning process.

A small proportion of the surface active agents may remain on the cleaned surfaces, but this will be negligible and is not considered further. Any such residues are likely to either degrade fully during the life-time or disposal of the electronic component, or be removed in subsequent washing stages.

Solvents (including organic solvent-based cleaners)

Solvents as a class of substances are used as carriers and cleaners in a wide range of applications in the electronics industry with functions that are comparable with uses in other industries. Solvents such as xylene are used as a diluent and viscosity reducer, for example in solder flux, in the same way that they will be used in paints, sealants or other applications.

Proprietary formulations will include mixtures with other solvents such as ethanol, iso-propyl alcohol, or methanol. Such preparations will usually contain water-soluble and volatile components. Blending with other solvents will be under ambient conditions with precautions in place in consideration of possible flammability and atmospheric concentration limits. Equipment would not typically require washing with water after use and there is considered to be a low risk of loss to waste water from formulation activities. Similar solvent preparation may be used in other sectors of industry as cleaning agents or thinners (paints and other surface coatings).

Solvent cleaning of printed circuit boards (PCBs) or other components involves spraying or dipping the components in the solvent to remove residues of flux, grease or other contaminants or for removing photoresist layers. The choice of solvent will depend on the required polarity or volatility.

The use of solvents is regulated by Directive 99/13/EC on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations.

Waste solvents are either disposed as hazardous waste or will be lost in use to the atmosphere. There is not considered to be residual solvents remaining on components after assembly.

3.3.4.2.2 Release scenarios for cleaning processes: aqueous and non-aqueous preparations

Aqueous preparations

Water-based cleaning with detergents, or water rinsing, takes place at the early stages of component manufacture. Due to the nature of water washing, large volumes of water may be involved and it is assumed that a high proportion will be discharged as waste water.

Many cleaning agents may themselves be subject to the Detergents Regulation and the biodegradation thresholds are a key factor in any risk assessment being carried out.

Type of waste will be liquid at both large and small scale installations (water-soluble aqueous waste with emulsified or suspended non-water-soluble materials that have been cleaned from components). This would pass to waste water from small scale operations and from larger sites with no specialist disposal methods, and will be discharged to either municipal or on-site waste water treatment plants.

Non-aqueous preparations

Solvent washing may take place at various stages of processing to remove non-water-soluble contaminants or residues, including later stages of assembly when use of water is not appropriate. Solvents are used to remove residues, for example of photoresists and flux, and although most solvent waste will be collected for disposal, some may evaporate from the surface of cleaned components or equipment or be rinsed to waste water.

Table 3.16 Release table for cleaning of components: aqueous and non-aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/pa	> 1000 kg/pa	Aqueous preparations: Quantity of active detergent component and not water. Non-aqueous preparations: Quantity of solvent.
Days in use	250	300	Most processes are continuous and not based on campaigns.
Releases information			For non-aqueous preparations: Proportion lost to air, water and soil is variable and dependent upon chemical properties. Refer to TGD Table A4.1, cleaning products UC48 (solvents).
% to air	0%	0%	For aqueous preparations only.
% to waste water	100%	100%	For aqueous preparations only (TGD Table A4.1, cleaning products UC10).

Table 3.17 Extract from TGD A-tables

The following data are taken from TGD Table A4.1, cleaning products UC48 (solvents).

Vapour pressure Pa	Water solubility mg/l	% emission to air	% emission to waste water	% emission to soil
< 100 Pa	< 10 mg/l	1.5%	10%	20%
100 - 1000	“	15%	10%	20%
1000 – 10 0000	“	40%	10%	20%
> 10 000	“	60%	10%	20%
< 100 Pa	10 – 100 mg/l	7.5%	20%	10%
100 - 1000	“	12.5%	20%	10%
1000 – 10 0000	“	25%	20%	10%
> 10 000	“	40%	20%	10%
< 100 Pa	100 – 1000 mg/l	2.5%	40%	5%
100 - 1000		10%	40%	5%
1000 – 10 0000		15%	40%	5%

Vapour pressure Pa	Water solubility mg/l	% emission to air	% emission to waste water	% emission to soil
> 10 000		22.5%	40%	5%
< 100 Pa	> 1000 mg/l	3%	60%	0.5%
100 - 1000		7.5%	60%	0.5%
1000 – 10 0000		12.5%	60%	0.5%
> 10 000		17.5%	60%	0.5%

The route and quantity of emission is proportional to the water solubility and vapour pressure of the solvent cleaners.

3.4 Electroless plating

In the electronics industry, electroless plating methods may be selected because of the superior corrosion resistance and because the solderability of the component is enhanced (Kirk-Othmer, 2001).

3.4.1 Summary

Table 3.18 Summary of processes relevant to electroless plating

Life cycle stage	Description	Loss mechanisms
Immersion tanks	Immersion of components in aqueous preparations of inorganic salts with catalysts and other materials such as acids or alkalis. Tanks may be heated.	Carry over of spent electroless bath materials to rinsing tanks. Vapours of degradation products, such as halides.
Rinsing	Immersion of components in one or more water baths to remove plating chemicals or other materials used in the plating process. Some rinse water is used to top-up the plating baths.	Waste rinse water from first rinse stages will often be recycled into the plating tanks. Subsequent rinse stages may just discharge to waste water systems within discharge consent limits of pH or specific metals (such as copper)
Servicing	Tanks are drained and liquor disposed of periodically to remove contaminants. Solid residues removed.	Water discharged to waste water systems within discharge consent limits of pH or specific metals. Sludge from plating tanks and rinsing waste water treatment disposed as solid waste. Some recovery of certain metal wastes, depending on value of metal.
End of life	Metal or other deposited materials will remain on the component and be present as waste at end of life.	Loss as solid waste for possible recovery of rare metals or other materials of value. Non-recovered deposits to landfill or other solid waste disposal.

Examples of substances used include acids (hydrochloric acid, nitric acid), metal salts (chlorides or sulfates of tin, palladium, copper, zinc), formaldehyde, EDTA and sodium citrate.

Electroless plating involves the large-scale use of water in both providing the medium for the process itself and for the subsequent rinsing and washing of components. There is a degree of recycling of rinse water through use to top-up the plating tanks, but there is ultimately loss through carry-over on components. Spent fluids can only be topped up a limited number of times before the media needs replacing.

Water-soluble waste is discharged in waste water for basic on-site treatment (settling and pH adjustment) before discharge to municipal treatment works, controlled by local discharge consent agreements. Metal ions will adsorb to organic waste during treatment and partition to sludge; this may in turn be spread on agricultural land.

3.4.2 Substances relevant to electroless plating processes

3.4.2.1 Plating chemicals

Plating describes the coating of surfaces with metals, either through an electrolysis or electroless plating processes. Electroless plating is favoured for most component production, but electrolysis is used more frequently for laminate production.

Electroless plating is also known as ‘autocatalytic’ plating, especially in more academic discussions. Since the term ‘electroless’ plating is more common in the wider industry, this is the term used here.

There are usually three stages in the electroless plating process: de-smearing, activation and electroless copper plating. Copper deposition starts on metal nuclei such as palladium and continues autocatalytically, thus providing an initial conductive layer. The deposition rate is 5 – 8 µm/h. The solution has a copper content of 2 – 5 g/l, with sodium hydroxide (15 – 20 g/l), chelating agents such as EDTA (ethylenediaminetetraacetic acid) or similar (10 – 15 g/l) or tartrates (5 – 10 g/l) and reducing agents, such as formaldehyde (3 – 5 g/l). The process solution lifetime is limited by the build-up of reaction products and is proportional to the rate of throughput of components.

Effluent containing EDTA requires separate treatment, as EDTA will prevent the precipitation of metals in the treatment process. There is an industry trend to replace EDTA as a chelating agent, although high specification work may require its use and the trend is currently being reversed. Electroless plating is still a key process in the manufacture of PCBs. However, there is a growing tendency to replace electroless copper by direct plating. Electroless copper baths have a limited lifetime before they require complete replacement and are a major source of waste metals. De-smearing has in the past used chromium salts, but these can now be substituted with potassium or sodium permanganate.

The inclusion of lead/cadmium salts in electroless plating formulations (used in the past as processing aids, but which can result in co-deposition of these metals in the resulting coating) is now prohibited by the WEEE legislation.

Electroless plating and etching often take place within the same stages of component production on the same sites and waste metal salts, acids and alkalis will be disposed of through the same mechanisms.

As an example, electroless plating for PCB manufacture may consume more than 2,000 litres of salts (up to 200 kg at 10 per cent solution) and use 2,000 m^3 water in the production of 100,000 PCB units.

The discussion of Electroless deposition in the Kirk-Othmer Encyclopaedia (2001) provides a useful reference source for further and more detailed information on the usage of specific plating systems.

3.4.2.2 Inorganic salts

This category covers the generic group of inorganic salts that are used in a wide range of applications and not just etching (see Section 3.5) or plating (Section 3.13). Inorganic salts will be supplied as solids or aqueous solutions and handled in aqueous 'wet-chemistry' systems with water washing of components after processing. The chemistry processes will not necessarily be unique to the electronics industry and may have more in common with metalworking or engineering applications.

Supply of inorganic metal salts for the electronics industry will be in relatively low quantities when compared with other industries, but use rates are still higher than for many other types of chemical. In some cases, the metal salts may be hazardous (such as cadmium) and may be subject to additional regulatory controls.

For electroless and electroplating, the metals are deposited on the component being produced and will form part of the final electronic article (although some may be removed in subsequent etching processes). There will be no release during service life, but the metals may be recovered at the end of life. Metals such as cadmium and lead will need particular attention at the end of life stage.

Waste from industrial processes is generated in the form of aqueous solutions (such as spent liquor, washings, and run-off) and solid waste (non-water-soluble sludge from tanks). Some of the solid waste will have a recovery value, but copper and tin salts will normally not be economical to reprocess, as recovery techniques from these salts are expensive. Most solid salts, especially from smaller organisations, will be disposed as chemical waste to landfill or cement block production. Aqueous waste is discharged to waste water, with discharge consents based on pH and specific metal content. There may be on-site treatment to achieve the consented levels.

Inorganic salts can be generated as a by-product of the etching process, and some can be used as etchants (see also Section 3.6).

3.4.3 Release scenarios for electroless plating processes

3.4.3.1 Release scenario for electroless plating, inorganic solids

Metal salts and other inorganic solids used in electroless plating are dissolved in water for use. Therefore, initial handling and formulation presented in section 3.4.4 include scenarios for inorganic solids as well as aqueous preparations.

3.4.3.2 Release scenario for electroless plating, aqueous preparations

Electroless plating involves the use of dilute aqueous preparations of inorganic materials that change in chemical composition during use, with metal deposited on the target surface. There is a high level of carry-over of solution into rinsing and cleaning tanks and although initial rinse solutions may be recycled back into the plating tank, there is a high level of waste.

Large volumes of water are involved and it is assumed that a high proportion will be discharged as waste water.

Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Waste from the process is liquid (water-soluble aqueous waste) which passes to waste water at both large and small scale sites. The level of discharge to waste water relates to local discharge consent for specific dangerous components, such as metal salts. Other aqueous waste may only be subject to cursory control, such as pH. Larger scale formulators may have waste disposal and treatment procedures in place but no specialist disposal methods are to be expected at small-scale sites.

Table 3.19 Release table for electroless plating, aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/y	> 1000 kg/y	Volume relates to quantity of formulated solid added to aqueous systems.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air	0%	0%	Releases to water only are anticipated.
% to waste water	50%	50%	Estimate based on TGD Table A3.7, assuming Main Category of 3 (default indicating non-dispersive use).
	0.002 - 0.1 % w/w of metals	0.002 - 0.1 % w/w of metals	From BREF (EC, 2006; see below).

No release to waste solids is estimated at large or small sites (on the basis of water-soluble material not adsorbing to process sludges or solids from settled waste water). Certain metal salts may adsorb.

Best available techniques used in the industry for mitigating releases are outlined in a BREF for surface treatment of metals and plastics (EC, 2006). These include techniques for minimisation of water and material discharged from the processes (Sections 4.5, 4.6, 4.7 of the BREF) and treating waste water (see Section 4.16 of the BREF). Limitations of such processing are also described in these sections. The BREF reports that “the amount of metals discharged as a percentage of the input metals varies between 0.002 and 0.1 per cent. The limited data indicates that this will be dependent on the in-process and waste water treatment techniques, as well as the combination of process techniques and metals used. The retention and/or removal efficiency is independent of the proportion of the metal used where there is more than one process, showing that it may not be possible to optimise the system to reduce all components discharged equally”.

3.4.4 Associated processes

3.4.4.1 Chemical formulation

Table 3.20 Summary of processes relevant to chemical formulation

Life cycle stage	Description	Loss mechanisms
Formulation	Mixing of substances to produce a preparation. There is often more than one formulation stage.	Surface contamination and emission to drain or ventilation resulting from leakage and spillage (not major accidents) or deliberate release. Liquid and solid wastes, emissions to drain or wastewater treatment plant arising from washing or servicing chemical plant areas and equipment. Disposal of container washings to drain or wastewater treatment plant. Disposal of used containers. Disposal of off-specification product.

The processes used to mix substances to make chemical products for supply to the electronics industry do not involve processing techniques that are unique or specific to this industry. Similar processes for manufacturing or preparing chemical products for supply are used in a wide range of industry sectors. Indeed, it is noted that many chemical products used by the electronics industry are purchased from suppliers who also supply other sectors.

The only significant difference in the supply to the electronics industry, when compared with some other industry sectors, appears to be scale of use – supply of chemicals in containers greater than 25 litres or kilograms is unusual. There is perhaps also a greater degree of manual handling involved in the small-scale use of chemicals when compared with larger chemical users and small pack sizes are normal.

With the exception of certain highly-specialised deposition chemicals (dopants) in the semiconductor manufacturing process (such as organometals), there are not many chemical substances used exclusively in the electronics industry. However, some of the handling and exposure scenarios may be unique to the industry and must be considered in detail.

3.4.4.1.1 Release scenarios for Formulation processes

Release scenario for chemical formulation: inorganic solid

Preparation of inorganic materials for supply includes blending and drying processes. The TGD Industry Category (IC) 2 General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenarios, with Table A2.1 being used as a basis for these estimates. Poorly-water-soluble solid waste is expected to be removed during initial settling from waste water, leading to a low level of entry to sludge and subsequent application to agricultural soil. Water-soluble waste will either remain in solution and be discharged (such as nitrates or sulfates), or in some cases (for example certain metal ions such as copper or tin) will adsorb onto sludge. The proportions reaching water or soil must be estimated in accordance with the known properties of the solid.

Table 3.21 Release scenario for chemical formulation; inorganic solid

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	30	50	Production campaigns may be used for formulating.
% to air	0%	0%	Dust will be trapped in filter systems[1].
% to waste water	2%	2%[2]	Estimate based on TGD Table A2.1.

Notes

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control.

2. At greater than 1,000t/y formulated product a more typical loss rate would be 0.3 per cent (estimate based on TGD Table A2.1).

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Solid and liquid wastes are to be expected (solid residues from formulation removed when cleaning equipment, and washings from the process). These wastes pass to landfill or waste water respectively from small-scale sites. From large-scale sites the wastes may pass to waste water, recovery, chemical waste or landfill. Larger scale formulators may have waste disposal and treatment procedures in place.

The amount of waste solid is estimated (on the basis of metals/materials adsorbing to process sludges or solids from settled waste water) to be in the order of 2 per cent at small and large scale sites.

Release scenario for chemical formulation: aqueous preparations

Preparation of aqueous mixtures for supply includes blending, dilution and packaging processes.

The TGD Industry Category (IC) 2: General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenarios, with Table A2.1 being used as a basis for these estimates. Being water-soluble or miscible, liquid and solid waste from formulating aqueous preparations is expected to result in waste that does not separate out during initial stages of treatment, or result in significant loss to sludge.

Biodegradability should be considered when preparing a risk assessment for organic solids formulated as aqueous preparations.

Table 3.22 Release table for chemical formulation; aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	30	50	Production campaigns may be used for formulating.
% to air, vp < 100 Pa	0%	0%	Dust will be trapped in filter systems[1].
% to air, vp > 100 Pa	1%	1%	Estimate based on TGD Table A2.1.
% to waste water	2%	2%[2]	Estimate based on TGD Table A2.1.

Note

1. A number of commercial filters are available and that the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control

2. At greater than 1000 t/y formulated product a more typical loss rate would be 0.3% (Estimate based on TGD Table A2.1).

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Solid and liquid wastes are to be expected (water-soluble solid wastes, and aqueous preparations and washings). These wastes pass to waste water from small-scale sites. From large-scale sites the wastes may pass to waste water, recovery, or as chemical waste for specialist treatment. Level of discharge to waste water relates to local discharge consent for specific dangerous components, such as metal salts. Other aqueous waste may only be subject to cursory control, such as pH. Larger scale formulators may have waste disposal and treatment procedures in place.

No release of waste solid is estimated (on the basis of water-soluble material not adsorbing to process sludges or solids from settled waste water). Certain metal salts may adsorb.

3.4.4.2 Chemical handling by the user

The use of chemicals in the electronics industry is very often on a small scale when compared with other industry sectors, with a high reliance on manual handling and the subsequent use of small containers. Chemical suppliers re-package bulk products for use by small organisations, and some organisations will themselves decant from larger containers to smaller unit sizes for day-to-day use. This is common in small to medium enterprises.

Table 3.23 Summary of processes relevant to chemical handling

Life cycle stage	Description	Loss mechanisms
Storage and handling	Storage of substances and preparations prior to use. Transfer of substances and preparation into different containers. Dilution and mixing of substances and preparations at the point of use.	Surface contamination and emission to drain or ventilation resulting from leakage and spillage (not major accidents) or deliberate release. Disposal of container washings to drain or waste water treatment plant. Disposal of used containers. Disposal of old material or products not meeting quality specifications.
Use	Application of substance or preparation to substrate or surface to be worked on. Cleaning or servicing of equipment after use.	Surface contamination and emission to drain or ventilation resulting from spillage or deliberate release. Liquid and solid wastes and emissions to drain or waste water treatment plant arising from washing or servicing chemical plant areas and equipment.

During manufacturing processes for electronic components, the focus will be on the quality of the products being produced with engineering designed to ensure quality of final products, that may themselves be of high unit value. Less attention may be given to efficiency in the use of chemicals that, in some processes, may be a relatively low-cost element. This is true particularly for etching and cleaning processes. Conversely, certain fine chemicals and ultra-pure materials used in semiconductor manufacture will be very expensive, thus their cost will ensure careful handling.

The Electronics section of the Environment Agency NetRegs website (Environment Agency, 2005) makes recommendations to some areas of industry relevant to electronics manufacturing, with regard to prevention of pollution. The guidance is aimed at small and medium-sized enterprises (SMEs) not subject to IPPC/LAAPC. Mandatory requirements for handling and storage of chemicals include the following, for sites manufacturing CDs/DVDs:

- Contain any spilled chemicals to prevent them entering surface water drains, ditches, watercourses or soakaways. Do not hose spillages down drains.
- Check pipe work for leaks regularly. If leaks are identified, ensure that maintenance work is undertaken immediately and the extent and impact of any contamination assessed and cleaned up.

For sites manufacturing printed circuit boards, there are no mandatory requirements, but the following guidelines are included:

- Store all chemical barrels in a secure location which cannot leak. The base of these areas should be chemical resistant and must have secondary containment such as a bund or a drip tray of adequate size.
- Make sure that all unloading areas are away from storm drains and are hard surfaced to prevent water or ground contamination if there is a spill. If this is not possible, make sure that the drains are protected during delivery (for example by using suitably-sized and correctly fitted drain covers).
- Storage areas and drip trays should drain to the plant's waste water treatment plant, as long as the plant can process these wastes. On no account should these be permitted to drain to the storm system.
- Contain any spilled chemicals to prevent them entering surface water drains, ditches, watercourses or soakaways. Do not hose spillages down drains.

These guidelines have been prepared by industry for industry and take into consideration that the primary activities in most cases are the design, manufacture and assembly of electronic components and the sites are not regarded as chemical production or formulating plants.

3.4.4.2.1 Release scenarios for handling processes

Release scenario for handling by the user: inorganic solids

Handling of inorganic solids by the user includes direct addition to production process , or on-site dilution prior to use, disposal of packaging and servicing equipment that may contain dried residues of solids.

The TGD Industry Category (IC) 2: General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenarios, with Table A2.1 being used as a basis for these estimates. Poorly-water-soluble solid waste is expected to be removed during initial settling from waste water, leading to a low level of entry to sludge and subsequent application to agricultural soil. Water-soluble waste will either remain in solution and be discharged (such as nitrates or sulfates), or in some cases (for example certain metal ions such as copper or tin) will adsorb onto sludge. The proportions reaching water or soil must be estimated in accordance with the known properties of the solid.

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). The type of waste will be solid and liquid at both large and small scale installations (solid waste and washings from process). These wastes (including solid residues from formulation removed when cleaning equipment) would go to waste water or landfill from small scale operations (no specialist disposal methods) and to waste water, recovery, chemical waste or landfill from larger sites (specialist disposal methods). Larger scale formulators may have waste disposal and treatment procedures in place.

The amount of waste solid is estimated (on the basis of metals/materials adsorbing to process sludges or solids from settled waste water) to be in the order of 2 per cent at small and large scale sites.

Table 3.24 Release table for handling by the user: inorganic solids

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air	0%	0%	Dust will be trapped in filter systems[1].
% to waste water	2%	2%	Estimate based on TGD Table A2.1.

Note

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control.

Release scenario for handling by the user: aqueous preparations

Handling of aqueous preparations by the user includes direct addition to production process or on-site decanting to smaller container prior to use, disposal of packaging and servicing equipment.

The TGD Industry Category (IC) 2: General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenarios, with Table A2.1 being used as a basis for these estimates. Being water-soluble or miscible, liquid and solid waste from formulating aqueous preparations is considered to result in waste that does not separate out during initial stages of treatment, or result in significant loss to sludge.

Biodegradability should be considered when preparing a risk assessment for organic solids formulated as aqueous preparations.

Table 3.25 Release table for handling by the user: aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air, vp < 100 Pa	0%	0%	Estimate based on TGD Table A2.1.
% to air, vp > 100 Pa	1%	1%	Estimate based on TGD Table A2.1.
% to waste water	2%	2%	Estimate based on TGD Table A2.1.

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Solid and liquid wastes are to be expected (water-soluble solid wastes, and aqueous preparations and washings). These wastes pass to waste water from small-scale sites. From large-scale sites the wastes may pass to waste water, recovery, or as chemical waste for specialist treatment. Level of discharge to waste water relates to local discharge consent for specific dangerous components, such as metal salts. Other aqueous waste may only be subject to cursory control, such as pH. Larger scale formulators may have waste disposal and treatment procedures in place.

No release of waste solid is estimated (on the basis of water-soluble material not adsorbing to process sludges or solids from settled waste water). Certain metal salts may adsorb.

3.4.4.3 Cleaning of components and equipment

3.4.4.3.1 Summary

Water rinsing, where it is an integral stage of other industrial processes, is considered as part of those processes. This section considers only cleaning using cleaning chemicals, such as detergents or solvents.

The amount of cleaning appears to vary within the electronics industry, with some component suppliers conducting very little cleaning and others cleaning all components at every stage. Cleaning adds costs to the process and the amount of cleaning may reflect the final value of the end products;

examples where no cleaning takes place may include components for toys or household appliances and examples of cleaning will be for aerospace or defence industries.

Table 3.26 Summary of processes relevant to cleaning

Life cycle stage	Description	Loss mechanisms
Aqueous cleaning	Immersion or spraying of components in dilute aqueous preparations of detergents. Cleaning of equipment with water-based detergents. Water based cleaning is not suitable for many electronic components due to sensitivity to water.	Considered to be 100 per cent loss of detergents to waste water. There may be some carry-over onto finished components, but this is not considered significant. Waste water will include the materials being washed off components, such as oils, greases, flux residues, metal salts and so on. Note applicability of Detergents Regulation EC 648/2004 ensuring minimum standards of biodegradability for surface active components – this does not mitigate loss, but ensures that residues in effluent will not accumulate.

Water is used for early stages of cleaning, either with or without surface-active agents (detergents). Large quantities of water are consumed in preparing silicon wafers and other substrates such as glass and ceramics. Rinsing after electroless plating, electroplating and etching is essential to remove corrosive or otherwise detrimental chemical residues.

Equipment is often cleaned with water-based detergents as part of servicing and maintenance procedures.

Cleaners (aqueous)

Aqueous and non-aqueous cleaning products are used in various stages of electronic component manufacture.

Examples of aqueous cleaners include dilute preparations of surface active agents (such as alkyl ethoxylates) and these will themselves be subject to the Detergents Regulation that imposes a minimum standard of biodegradation. Those failing the prescribed rate of biodegradation can be placed on the market for specialist uses subject to a risk assessment – specialist use in the electronics industry could be examples where a derogation is granted.

Many of the cleaning preparations marketed for the electronics sector will mirror formulations used in other industry sectors such as domestic applications, metalworking, and the motor industry.

Formulation of such cleaners will be through mixing at ambient or slightly elevated temperatures using processes common to the detergent and cleaning industry sector. Supply takes place in small containers of less than 25 kg, with many suppliers offering containers of one litre or less.

The level of component and surface cleaning in the industry is variable, with the highest level of cleaning found in the production of high-value products for the aerospace and defence industries.

The use of ‘clean-room’ processes for semiconductor and other precision components should not be confused by the use of cleaning products. Clean-room processes describe the barrier methods used to prevent chemical contamination of micro-electronic components and not the cleaning processes employed during manufacture. Many cleaning products can themselves be considered as potential contaminants in the precision processes that require clean-room technology and surface-active materials could interfere with subsequent processing of the electronic components. Exceptions to this are purified water and high-quality grade volatile solvents such as acetone.

The use of aqueous cleaners, by their nature, usually involves significant volumes of water as more products are supplied as concentrates to be diluted in water at the time of use. Although there may be isolated cases where waste water is collected for disposal as chemical waste, it is assumed that there is 100 per cent loss of the aqueous cleaning products to waste water discharge. Although the detergents themselves may meet biodegradation criteria, waste effluent will contain emulsified or suspended material that has been removed during the cleaning process.

A small proportion of the surface active agents may remain on the cleaned surfaces, but this will be negligible and is not considered further – any such residues are likely to either degrade fully during the life-time or disposal of the electronic component, or be removed in subsequent washing stages.

3.4.4.3.2 Release scenarios for cleaning processes: aqueous preparations

Water-based cleaning with detergents, or water rinsing, takes place at the early stages of component manufacture. Due to the nature of water washing, large volumes of water may be involved and it is assumed that a high proportion will be discharged as waste water.

Many cleaning agents may themselves be subject to the Detergents Regulation (648/2004) and the biodegradation thresholds are a key factor in any risk assessment being carried out.

Type of waste will be liquid at both large and small scale installations (water-soluble aqueous waste with emulsified or suspended non-water-soluble materials that have been cleaned from components). This would pass to waste water from small scale operations and from larger sites with no specialist disposal methods, and will be discharged to either municipal or on-site waste water treatment plants.

No release of waste solid (process sludges or solids from settled waste water) is estimated.

Table 3.27 Release table for cleaning of components: aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/pa	> 1000 kg/pa	Quantity of active detergent component and not water.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air	0%	0%	Release to water only is anticipated.
% to waste water	100%	100%	TGD Table A4.1, cleaning products UC10.

Table 3.28 Extract from TGD A-tables

The following data are taken from TGD Table A4.1, cleaning products UC48 (solvents).

Vapour pressure Pa	Water solubility mg/l	% emission to air	% emission to waste water	% emission to soil
< 100 Pa	< 10 mg/l	1.5%	10%	20%
100 - 1000	“	15%	10%	20%
1000 – 10 0000	“	40%	10%	20%
> 10 000	“	60%	10%	20%
< 100 Pa	10 – 100 mg/l	7.5%	20%	10%
100 - 1000	“	12.5%	20%	10%
1000 – 10 0000	“	25%	20%	10%
> 10 000	“	40%	20%	10%
< 100 Pa	100 – 1000 mg/l	2.5%	40%	5%
100 - 1000		10%	40%	5%
1000 – 10 0000		15%	40%	5%
> 10 000		22.5%	40%	5%
< 100 Pa	> 1000 mg/l	3%	60%	0.5%
100 - 1000		7.5%	60%	0.5%
1000 – 10 0000		12.5%	60%	0.5%
> 10 000		17.5%	60%	0.5%

3.5 Electroplating

3.5.1 Summary

Plating describes the coating of surfaces with metals, either through an electrolysis or electroless plating processes. Electroless plating is favoured for most component production, but electrolysis is used more frequently for laminate production.

The processes are aqueous, and good rinsing is required to prevent carry over into later stages of production. Cleaners (wetting agents) and anti-foaming agents may also be included in some of the process.

The high level of water use will inevitably lead to a relative high proportion of aqueous waste. In many cases, this will be discharged from site for treatment.

Table 3.29 Summary of processes relevant to electroplating

Life cycle stage	Description	Loss mechanisms
Immersion tanks	Immersion of components in aqueous preparations of inorganic salts with catalysts and other materials such as acids or alkalis. Tanks may be heated.	Carry over of spent electroplating bath materials, to rinsing tanks. Vapours of degradation products, such as halides, ammonia, amines.
Rinsing	Immersion of components in one or more water baths to remove plating chemicals or other materials used in the plating process. Some rinse water is used to top-up the plating baths.	Waste rinse water from first rinse stages will often be recycled into the plating tanks. Subsequent rinse stages may just discharge to waste water systems within discharge consent limits of pH or specific metals (such as copper).
Servicing	Tanks are drained and liquor disposed of periodically to remove contaminants. Solid residues removed.	Water discharged to waste water systems within discharge consent limits of pH or specific metals. Sludge from plating tanks and rinsing wastewater treatment disposed as solid waste. Some recovery of certain metal wastes, depending on value of metal.
End of life	Metal or other deposited materials will remain on the component and be present as waste at end of life.	Loss as solid waste for possible recovery of rare-metals or other materials of value. Non-recovered deposits to landfill or other solid waste disposal.

3.5.2 Substances relevant to electroplating processes

3.5.2.1 Plating chemicals

Most electroplating systems use inorganic metal salts, within acidic or basic (alkaline) systems. Cyanides and other toxic materials may be used, and the degree of control in handling and disposal will need to reflect the occupational hazards of specific chemicals and the metal involved. Chromium salts, for example, need closer control than less hazardous tin or copper salts.

Electroplating is performed using a tank of electrolyte chemicals (such as sulfuric acid and metal salts according to the process) with metal bars acting as anodes. The item to be plated is placed a short distance from the metal anodes and acts as the cathode. Metal deposition occurs when an electrical potential is established between the anodes and the cathode and the metal will migrate to the cathode.

The mass of metal deposited should equal the mass eroded into the electrolyte from the anode, but there is some low level dissolution into salts. As the process is aqueous, the waste electrolyte from changing baths will contain some dissolved metal salts other than the starting electrolytes, and in poorly maintained systems precipitation of salts may occur. Tanks are typically topped up to allow for loss of acidity and to counter evaporation of water; however, there needs to be periodic servicing with disposal of the acid bath and salts.

Some organic substances are used as 'brighteners' that regulate the deposition of metals and ensure a smooth, even finish. A range of water-soluble substances are marketed for this use and include esters and sulfonates.

The discussion of Electroplating in the Kirk-Othmer Encyclopaedia (2001) provides a useful reference source for further and more detailed information on the usage of specific plating systems.

3.5.2.2 Inorganic salts

This category covers the generic group of inorganic salts that are used in a wide range of applications and not just etching (see Section 3.5) or plating (Section 3.13). Inorganic salts will be supplied as solids or aqueous solutions and handled in aqueous 'wet-chemistry' systems with water washing of components after processing. The chemistry processes will not necessarily be unique to the electronics industry and may have more in common with metalworking or engineering applications.

Supply of inorganic metal salts for the electronics industry will be in relatively low quantities when compared with other industries, but use rates are still higher than for many other types of chemical. In some cases, the metal salts may be hazardous (such as cadmium) and may be subject to additional regulatory controls.

For electroless and electroplating, the metals are deposited on the component being produced and will form part of the final electronic article (although some may be removed in subsequent etching processes). There will be no release during service life, but the metals may be recovered at the end of life. Metals such as cadmium and lead will need particular attention at the end of life stage.

Waste from industrial processes is generated in the form of aqueous solutions (such as spent liquor, washings, and run-off) and solid waste (non-water-soluble sludge from tanks). Some of the solid waste will have a recovery value, but copper and tin salts will not normally be economical to reprocess, as recovery techniques from these salts are expensive. Most solid salts, especially from smaller organisations, will be disposed as chemical waste to landfill or cement block production. Aqueous waste is discharged to waste water, with discharge consents based on pH and specific metal content.

Inorganic salts can be generated as a by-product of the etching process, and some can be used as etchants (see also Section 3.6).

3.5.3 Release scenarios for electroplating processes

3.5.3.1 Release scenario for electroplating: inorganic solids

Metal salts and other inorganic solids used in electroplating are dissolved in water for use. Therefore, handling and formulation presented in Section 3.5.4 include scenarios for inorganic solids as well as aqueous preparations.

3.5.3.2 Release scenario for electroplating: aqueous preparations

Inorganic compounds

Electroplating involves the use of dilute aqueous preparations of inorganic materials that change in chemical composition during use, with metal deposited on the target surface. There is a high level of carry-over of solution into rinsing and cleaning tanks and although initial rinse solutions may be recycled back into the plating tank, there is a high level of waste.

Large volumes of water are involved and it is assumed that a high proportion will be discharged as waste water.

Table 3.30 Release table for electroplating: aqueous preparations (inorganic)

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/y	> 1000 kg/y	Volume relates to quantity of formulated solid added to aqueous systems.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air	0%	0%	Release to water only is anticipated.
% to waste water	50%	50%	Estimate based on TGD Table A3.7, assuming Main Category of 3 (default indicating non-dispersive use).
	0.002 - 0.1 % w/w of metals	0.002 - 0.1 % w/w of metals	From BREF (EC, 2006; see below).

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Liquid wastes are to be expected from this process (water-soluble aqueous waste), which will pass to waste water from both small- and large-scale sites. The level of discharge to waste water relates to local discharge consent for specific dangerous components, such as metal salts. Other aqueous waste may only be subject to cursory control, such as pH. Larger scale formulators may have waste disposal and treatment procedures in place but no specialist disposal is to be expected at small sites.

No release of waste solid is estimated (on the basis of water-soluble material not adsorbing to process sludges or solids from settled waste water). Certain metal salts may adsorb.

Best available techniques used in the industry for mitigating releases are outlined in a BREF for surface treatment of metals and plastics (EC, 2006). These include techniques for minimisation of water and material discharged from the processes (Sections 4.5, 4.6, 4.7 of the BREF) and treating waste water (see Section 4.16 of the BREF). Limitations of such processing are also described in these sections. The BREF reports that “the amount of metals discharged as a percentage of the input metals varies between 0.002 and 0.1 per cent. The limited data indicates that this will be dependent on the in-process and waste water treatment techniques, as well as the combination of process techniques and metals used. The retention and/or removal efficiency is independent of the proportion of the metal used where there is more than one process, showing that it may not be possible to optimise the system to reduce all components discharged equally”.

Organic brighteners

These are typically acid-resistant, surface-active agents that could be considered very similar to detergents and will be disposed of in the bath water.

Type of waste will be liquid at both large and small scale installations (water-soluble aqueous waste). This would pass to waste water from small scale operations and from larger sites with no specialist disposal methods, and will be discharged to either municipal or on-site waste water treatment plants.

No release of waste solid (process sludges or solids from settled waste water) is estimated.

Table 3.31 Release table for electroplating: aqueous preparations (organic brightening agents)

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/pa	> 1000 kg/pa	Quantity of active component and not water.
Days in use	250	300	Most use processes are continuous and not based on campaigns.
Total loss from process	100%	100%	TGD Table A4.1, cleaning products UC10.
% to air	0%	0%	Release to water only is anticipated.
% to waste water	100%	100%	

3.5.4 Associated processes

3.5.4.1 Chemical formulation

Table 3.32 Summary of processes relevant to chemical formulation

Life cycle stage	Description	Loss mechanisms
Formulation	Mixing of substances to produce a preparation. There is often more than one formulation stage.	Surface contamination and emission to drain or ventilation resulting from leakage and spillage (not major accidents) or deliberate release. Liquid and solid wastes, emissions to drain or wastewater treatment plant arising from washing or servicing chemical plant areas and equipment. Disposal of container washings to drain or wastewater treatment plant. Disposal of used containers. Disposal of off-specification product.

The processes used to mix substances to make chemical products for supply to the electronics industry do not involve processing techniques that are unique or specific to this industry. Similar processes for manufacturing or preparing chemical products for supply are used in a wide range of industry sectors. Indeed, it is noted that many chemical products used by the electronics industry are purchased from suppliers who also supply other sectors.

The only significant difference in the supply to the electronics industry, when compared with some other industry sectors, appears to be scale of use – supply of chemicals in containers greater than 25 litres or kilograms is unusual. There is perhaps also a greater degree of manual handling involved in the small-scale use of chemicals when compared with larger chemical users, and small pack sizes are normal.

With the exception of certain highly-specialised deposition chemicals (dopants) in the semiconductor manufacturing process (such as organo-metals), there are not many chemical substances used exclusively in the electronics industry. However, some of the handling and exposure scenarios may be unique to the industry and must be considered in detail.

3.5.4.1.1 Release scenarios for Formulation processes

Release scenario for chemical formulation; inorganic solid

Preparation of inorganic materials for supply includes blending and drying processes. The TGD Industry Category (IC) 2 General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenarios, with Table A2.1 being used as a basis for these estimates. Poorly-water-soluble solid waste is expected to be removed during initial settling from waste water, leading to a low level of entry to sludge and subsequent application to agricultural soil. Water-soluble waste will either remain in solution and be discharged (such as nitrates or sulfates), or in some cases (for example certain metal ions such as copper or tin) will adsorb onto sludge. The proportions reaching water or soil must be estimated in accordance with the known properties of the solid.

Table 3.33 Release Scenario for chemical formulation; inorganic solid

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	30	50	Production campaigns may be used for formulating.
% to air	0%	0%	Dust will be trapped in filter systems[1].
% to waste water	2%	2%[2]	Estimate based on TGD Table A2.1.

Note

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control.

2. At greater than 1,000t/y formulated product a more typical loss rate would be 0.3 per cent (estimate based on TGD Table A2.1).

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Solid and liquid wastes are to be expected (solid residues from formulation removed when cleaning equipment, and washings from the process). These wastes pass to landfill or waste water respectively from small-scale sites. From large-scale sites the wastes may pass to waste water, recovery, chemical waste or landfill. Larger scale formulators may have waste disposal and treatment procedures in place.

The amount of waste solid is estimated (on the basis of metals/materials adsorbing to process sludges or solids from settled waste water) to be in the order of 2 per cent at small and large scale sites.

Release scenario for chemical formulation; aqueous preparations

Preparation of aqueous mixtures for supply includes blending, dilution and packaging processes.

The TGD Industry Category (IC) 2: General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenarios, with Table A2.1 being used as a basis for these estimates. Being water-soluble or miscible, liquid and solid waste from formulating aqueous preparations is expected to result in waste that does not separate out during initial stages of treatment, or result in significant loss to sludge.

Biodegradability should be considered when preparing a risk assessment for organic solids formulated as aqueous preparations.

Table 3.34 Release table for chemical formulation; aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	30	50	Production campaigns may be used for formulating.
% to air, vp < 100 Pa	0%	0%	Dust will be trapped in filter systems[1].
% to air, vp > 100 Pa	1%	1%	Estimate based on TGD Table A2.1.
% to waste water	2%	2%[2]	Estimate based on TGD Table A2.1.

Note

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control.

2. At greater than 1,000 t/y formulated product a more typical loss rate would be 0.3 per cent (estimate based on TGD Table A2.1).

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Solid and liquid wastes are to be expected (water-soluble solid wastes, and aqueous preparations and washings). These wastes pass to waste water from small-scale sites. From large-scale sites the wastes may pass to waste water, recovery, or as chemical waste for specialist treatment. Level of discharge to waste water relates to local discharge consent for specific dangerous components, such as metal salts. Other aqueous waste may only be subject to cursory control, such as pH. Larger scale formulators may have waste disposal and treatment procedures in place.

No waste solids are estimated at large or small sites (on the basis of water-soluble material not adsorbing to process sludges or solids from settled waste water). Certain metal salts may adsorb.

3.5.4.2 Chemical handling by the user

The use of chemicals in the electronics industry is very often on a small scale when compared with other industry sectors, with a high reliance on manual handling and the subsequent use of small containers. Chemical suppliers re-package bulk products for use by small organisations, and some organisations will themselves decant from larger containers to smaller unit sizes for day-to-day use. This is common in small to medium enterprises.

During manufacturing processes for electronic components, the focus will be on the quality of the products being produced, with engineering designed to ensure quality of final products that may themselves be of high unit value. Less attention may be given to efficiency in the use of chemicals that, in some processes, may be a relatively low-cost element. This is true particularly for etching and cleaning processes, but conversely, certain fine chemicals and ultra-pure materials used in semiconductor manufacture will be very expensive, thus their price will ensure careful handling.

Table 3.35 Summary of processes relevant to chemical handling

Life cycle stage	Description	Loss mechanisms
Storage and handling	Storage of substances and preparations prior to use. Transfer of substances and preparation into different containers. Dilution and mixing of substances and preparations at the point of use.	Surface contamination and emission to drain or ventilation resulting from leakage and spillage (not major accidents) or deliberate release. Disposal of container washings to drain or wastewater treatment plant. Disposal of used containers. Disposal of old material or products not meeting quality specifications.
Use	Application of substance or preparation to substrate or surface to be worked on. Cleaning or servicing of equipment after use.	Surface contamination and emission to drain or ventilation resulting from spillage or deliberate release. Liquid and solid wastes and emissions to drain or wastewater treatment plant arising from washing or servicing chemical plant areas and equipment.

The Electronics section of the Environment Agency NetRegs website (Environment Agency, 2005) makes recommendations to some areas of industry relevant to electronics manufacturing, with regard to prevention of pollution. The guidance is aimed at small and medium-sized enterprises (SMEs) not subject to IPPC/LAAPC. Mandatory requirements for handling and storage of chemicals include the following, for sites manufacturing CDs/DVDs:

- Contain any spilled chemicals to prevent them entering surface water drains, ditches, watercourses or soakaways. Do not hose spillages down drains.
- Check pipe work for leaks regularly. If leaks are identified, ensure that maintenance work is undertaken immediately and the extent and impact of any contamination assessed and cleaned up.

For sites manufacturing printed circuit boards, there are no mandatory requirements, but the following guidelines are included:

- Store all chemical barrels in a secure location which cannot leak. The base of these areas should be chemical resistant and must have secondary containment such as a bund or a drip tray of adequate size.
- Make sure that all unloading areas are away from storm drains and are hard surfaced to prevent water or ground contamination if there is a spill. If this is not possible, make sure that the drains are protected during delivery (for example by using suitably-sized and correctly fitted drain covers).

- Storage areas and drip trays should drain to the plant's wastewater treatment plant, as long as the plant can process these wastes. On no account should these be permitted to drain to the storm system.

- Contain any spilled chemicals to prevent them entering surface water drains, ditches, watercourses or soakaways. Do not hose spillages down drains.

These guidelines have been prepared by industry for industry and take into consideration that the primary activities in most cases are the design, manufacture and assembly of electronic components and the sites are not regarded as chemical production or formulating plants.

3.5.4.2.1 Release scenarios for handling processes

Release scenario for handling by the user: inorganic solids

Handling of inorganic solids by the user includes direct addition to production process or on-site dilution prior to use, disposal of packaging and servicing equipment that may contain dried residues of solids.

The TGD Industry Category (IC) 2: General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenarios, with Table A2.1 being used as a basis for these estimates. Poorly-water-soluble solid waste is expected to be removed during initial settling from waste water, leading to a low level of entry to sludge and subsequent application to agricultural soil. Water-soluble waste will either remain in solution and be discharged (such as nitrates or sulfates), or in some cases (for example certain metal ions such as copper or tin) will adsorb onto sludge. The proportions reaching water or soil must be estimated in accordance with the known properties of the solid.

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). The type of waste will be solid and liquid at both large and small scale installations (solid waste and washings from process). These wastes (including solid residues from formulation removed when cleaning equipment) would go to waste water or landfill from small scale operations (no specialist disposal methods) and to waste water, recovery, chemical waste or landfill from larger sites (specialist disposal methods). Larger scale formulators may have waste disposal and treatment procedures in place.

The amount of waste solid is estimated (on the basis of metals/materials adsorbing to process sludges or solids from settled waste water) to be in the order of 2 per cent at small and large scale sites.

Table 3.36 Release table for handling by the user: inorganic solids

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air	0%	0%	Dust will be trapped in filter systems[1].
% to waste water	2%	2%	Estimate based on TGD Table A2.1.

Note

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control.

Release scenario for handling by the user: aqueous preparations

Handling of aqueous preparations by the user includes direct addition to production process or on-site decanting to smaller container prior to use, disposal of packaging and servicing equipment.

The TGD Industry Category (IC) 2: General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenarios, with Table A2.1 being used as a basis for these estimates. Being water-soluble or miscible, liquid and solid waste from formulating aqueous preparations is considered to result in waste that does not separate out during initial stages of treatment, or result in significant loss to sludge.

Biodegradability should be considered when preparing a risk assessment for organic solids formulated as aqueous preparations.

Table 3.37 Release table for handling by the user: aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air, vp < 100 Pa	0%	0%	Estimate based on TGD Table A2.1.
% to air, vp > 100 Pa	1%	1%	Estimate based on TGD Table A2.1.
% to waste water	2%	2%	Estimate based on TGD Table A2.1.

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Solid and liquid wastes are to be expected (water-soluble solid wastes, and aqueous preparations and washings). These wastes pass to waste water from small-scale sites. From large-scale sites the wastes may pass to waste water, recovery, or as chemical waste for specialist treatment. Level of discharge to waste water relates to local discharge consent for specific dangerous components, such as metal salts. Other aqueous waste may only be subject to cursory control, such as pH. Larger scale formulators may have waste disposal and treatment procedures in place.

No waste solids are estimated at large or small sites (on the basis of water-soluble material not adsorbing to process sludges or solids from settled waste water). Certain metal salts may adsorb.

3.5.4.3 Cleaning of components and equipment

3.5.4.3.1 Summary

Water rinsing, where it is an integral stage of other industrial processes, is considered as part of those processes. This section considers only cleaning using cleaning chemicals, such as detergents or solvents.

Table 3.38 Summary of processes relevant to cleaning

Life cycle stage	Description	Loss mechanisms
Aqueous cleaning	Immersion or spraying of components in dilute aqueous preparations of detergents. Cleaning of equipment with water-based detergents. Water based cleaning is not suitable for many electronic	Considered to be 100 per cent loss of detergents to waste water. There may be some carry-over onto finished components, but this is not considered significant. Waste water will include the materials being washed off components, such as oils, greases, flux residues, metal salts and so on. Note applicability of Detergents Regulation EC 648/2004

Life cycle stage	Description	Loss mechanisms
	components due to sensitivity to water.	ensuring minimum standards of biodegradability for surface active components – this does not mitigate loss, but ensures that residues in effluent will not accumulate.

The amount of cleaning appears to vary within the electronics industry, with some component suppliers conducting very little cleaning and others cleaning all components at every stage. Cleaning adds costs to the process and the amount of cleaning may reflect the final value of the end products; examples where no cleaning takes place may include components for toys or household appliances and examples of cleaning will be for aerospace or defence industries.

Water is used for early stages of cleaning, either with or without surface-active agents (detergents). Large quantities of water are consumed in preparing silicon wafers and other substrates such as glass and ceramics. Rinsing after electroless plating, electroplating and etching is essential to remove corrosive or otherwise detrimental chemical residues.

Equipment is often cleaned with water-based detergents as part of servicing and maintenance procedures.

Cleaners (aqueous)

Aqueous and non-aqueous cleaning products are used in various stages of electronic component manufacture.

Examples of aqueous cleaners include dilute preparations of surface active agents (such as alkyl ethoxylates) and these will themselves be subject to the Detergents Regulation (648/2004) that imposes a minimum standard of biodegradation; those failing the prescribed rate of biodegradation can be placed on the market for specialist uses subject to a risk assessment – specialist use in the electronics industry could be examples where derogations are granted.

Many of the cleaning preparations marketed for the electronics sector will mirror formulations used in other industry sectors such as domestic applications, metalworking, and the motor industry.

Formulation of such cleaners will be through mixing at ambient or slightly elevated temperatures using processes common to the detergent and cleaning industry sector. Supply takes place in small containers of less than 25 kg, with many suppliers offering containers of one litre or less.

The level of component and surface cleaning in the industry varies, with the highest level of cleaning found in the production of high-value products for the aerospace and defence industries.

The use of ‘clean-room’ processes for semiconductor and other precision components should not be confused by the use of cleaning products. Clean-room processes describe the barrier methods used to prevent chemical contamination of micro-electronic components and not the cleaning processes employed during manufacture. Many cleaning products can themselves be considered as potential contaminants in the precision processes that require clean-room technology and surface-active materials could interfere with subsequent processing of the electronic components. Exceptions to this are purified water and high-quality grade volatile solvents such as acetone.

The use of aqueous cleaners, by their nature, usually involves significant volumes of water as more products are supplied as concentrates to be diluted in water at the time of use. Although there may be isolated cases where waste water is collected for disposal as chemical waste, it is assumed that there is 100 per cent loss of the aqueous cleaning products to waste water discharge. Although the detergents themselves may meet biodegradation criteria, waste effluent will contain emulsified or suspended material that has been removed during the cleaning process.

A small proportion of the surface active agents may remain on the cleaned surfaces, but this will be negligible and is not considered further – any such residues are likely to either degrade during the life-time or disposal of the electronic component, or be removed in subsequent washing stages.

3.5.4.3.2 Release scenarios for cleaning processes: aqueous preparations

Water-based cleaning with detergents, or water rinsing, takes place at the early stages of component manufacture. Due to the nature of water washing, large volumes of water may be involved and it is assumed that a high proportion will be discharged as waste water.

Many cleaning agents may themselves be subject to the Detergents Regulation (648/2004) and the biodegradation thresholds are a key factor in any risk assessment being carried out.

Type of waste will be liquid at both large and small scale installations (water-soluble aqueous waste with emulsified or suspended non-water-soluble materials that have been cleaned from components). This would pass to waste water from small scale operations and from larger sites with no specialist disposal methods, and will be discharged to either municipal or on-site waste water treatment plants.

No waste solids (process sludges or solids from settled waste water) are estimated at large or small sites.

Table 3.39 Release table for cleaning of components: aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/pa	> 1000 kg/pa	Quantity of active detergent component and not water.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air	0%	0%	Release to water only is anticipated.
% to waste water	100%	100%	TGD Table A4.1, cleaning products UC10.

Table 3.40 Extract from TGD A-tables

The following data are taken from TGD Table A4.1, cleaning products UC48 (solvents).

Vapour pressure Pa	Water solubility mg/l	% emission to air	% emission to waste water	% emission to soil
< 100 Pa	< 10 mg/l	1.5%	10%	20%
100 - 1000	“	15%	10%	20%
1000 – 10 0000	“	40%	10%	20%
> 10 000	“	60%	10%	20%
< 100 Pa	10 – 100 mg/l	7.5%	20%	10%
100 - 1000	“	12.5%	20%	10%
1000 – 10 0000	“	25%	20%	10%
> 10 000	“	40%	20%	10%
< 100 Pa	100 – 1000 mg/l	2.5%	40%	5%
100 - 1000		10%	40%	5%
1000 – 10 0000		15%	40%	5%
> 10 000		22.5%	40%	5%
< 100 Pa	> 1000 mg/l	3%	60%	0.5%
100 - 1000		7.5%	60%	0.5%
1000 – 10 0000		12.5%	60%	0.5%
> 10 000		17.5%	60%	0.5%

3.6 Etching

3.6.1 Summary

Various chemical etching processes are used in the electronics industry, including wet, dry, and reactive ion etching and ion milling. These are used to remove contaminants or damaged surfaces, and to cut patterns into the surface of a material. Wet and dry etching are the techniques most relevant to the UK and EU industry, but other specialist techniques are known to exist. The main wastes are likely to be residual etchant and removed surface material, regardless of the etching technique used.

Wet etching uses aqueous solutions or organic solvents, including acids (sulfuric, phosphoric, hydrogen peroxide, nitric, hydrofluoric, and hydrochloric), ethylene glycol, hydroxide solutions, and solutions of ammonium, ferric (iron III), or potassium compounds.

Dry etching uses reactive gases including chlorine, hydrogen bromide, carbon tetrafluoride, sulfur hexafluoride, trifluoromethane, fluorine, fluorocarbons, carbon tetrachloride, boron trichloride, hydrogen, oxygen, helium, and argon.

Various etching techniques may be used in the manufacture of semiconductors, printed circuit boards and integrated circuits.

Table 3.41 Summary of processes relevant to etching

Life cycle stage	Description	Loss mechanisms
Wet etching immersion tanks	Immersion of components in aqueous preparations of inorganic salts and other materials such as acids or alkalis. Tanks may be heated.	Carry over of spent electroless bath materials, to rinsing tanks. Vapours of degradation products, such as halides, ammonia, amines and so on.
Dry etching (gas)	Hot vapours of reactive substances are passed over the components to be etched. This process is typically limited to semiconductor manufacture.	Loss of vapours to atmosphere. Residues of solid waste deposited in equipment or filters.
Rinsing	Immersion of components in one or more water baths to remove plating chemicals or other materials used in the plating process. Some rinse water is used to top-up the plating baths.	Waste rinse water from first rinse stages will often be recycled into the plating tanks. Subsequent rinse stages may just discharge to waste water systems within discharge consent limits of pH or specific metals (such as copper).
Servicing	Tanks are drained and liquor disposed of periodically to remove contaminants. Solid residues removed.	Water discharged to waste water systems within discharge consent limits of pH or specific metals. Sludge from plating tanks and rinsing waste water treatment disposed as solid waste. Some recovery of certain metal wastes, depending on value of metal.

The etching process will burn through areas where the photosensitive layer was not hardened and therefore removed in the photolithography process (refer to Section 3.9). This can be through 'wet' chemical processes or with gas plasma jets. As a result, areas of the silicon oxide layer left exposed after the photolithography are removed, leaving an etched pattern on the wafer.

3.6.2 Substances relevant to etching processes

3.6.2.1 Etchants

The process of etching involves the chemical removal of metal or metal oxides from the surface of substrates onto which circuits are mounted. The two main scenarios involve printed circuit boards (PCBs) and semiconductors ('chips') or integrated circuits. The Kirk-Othmer Encyclopaedia (2001) section on integrated circuits provides more information on the manufacture of these components.

Etching agents vary in composition according to the material to be removed and will be defined as either wet (acid or alkaline) or dry (gas phase) etchants. Dry etching is limited to semiconductor manufacturing processes and will include the use of substances such as ultra-pure ammonia, hydrogen chloride, or hydrogen fluoride in gaseous form. These gases tend to be water-soluble and will be removed as waste in aqueous solution.

Wet etching for PCB manufacture involves the use of alkaline or acidic aqueous preparations. Most etching preparations are supplied in liquid form in containers of up to 25 litres, although occasionally larger containers such as ISO tanks (over 200 litres) may be used where there are semi-automated methods for charging the etching tanks. Some materials are supplied in the solid form for formulation into etching solution *in situ*. A variety of chemicals are used, including iron chloride, formaldehyde, ammonia preparations, peroxides, or sulfuric acid. Other than formaldehyde (supplied in aqueous preparations), no organic substances are used. To improve economy, etching tanks can be quite large, holding more than 100 litres. These large tanks can handle sheets of laminate up to 40 cm x 40 cm, each containing multiple circuit boards that are later cut out to shape.

Processes are similar for most producers, but the precise mixture of chemicals and the conditions of use will vary. During use, the concentration of the solutions in the etching tanks is maintained by addition of fresh material. Simple checks such as specific gravity or conductivity of the solution are used to monitor this. Loss from the tanks is predominantly through carry-over into rinsing tanks, but the etching tanks are also drained and serviced periodically – this varies between users, but may be weekly or less frequently.

The etching takes place at elevated temperatures. Poorly-water-soluble salts form during the process, which are extracted by cooling the liquor and collecting any precipitate formed. Some solid wastes and spent solution can be recycled to recover valuable metals such as copper or tin, although much will be disposed as chemical waste or rinsed to waste water systems. Copper salt solids have little value and will often be sent for chemical waste disposal. In this solid, other chemicals will be present, including residues of inorganic salts, and spent photo-resist.

After etching, the boards are rinsed in fresh water, and the first phase wash water can be circulated back into the etching tank. Subsequent wash water from second rinse is discharged in waste water (subject to settling and neutralisation) within local agreed limits (consent orders). The BREF (EC, 2006) for surface treatment lays particular stress on minimising releases by thorough rinsing and then on-site treatment of the rinse water. Any locations covered by IPPC will conform to this standard.

Many types of etchants are by their nature and functionality ionic, and will dissociate under the conditions of use. It can be assumed that 100 per cent of water-soluble ions involved in the process (those from the etchants and metal ions dissolved from the substrate) will be discharged in waste water. Furthermore, it is assumed that a high proportion of non-water-soluble salts (especially copper and tin) will precipitate out of the etching preparations after use and will either be recovered for recycling or disposed as chemical waste. Some loss of non-water-soluble salts to waste water is to be expected, in the form of particulates.

Etching processes for manufacture of semiconductors follow the same principle, but on a much smaller scale per unit. However, semiconductor manufacture can take place on a very large scale, so although the amount of chemical use per unit component is small, the number of units can be very large, and hence the total level of discharge can be high.

3.6.2.2 Inorganic salts

This category covers the generic group of inorganic salts that are used in a wide range of applications and not just etching (see Section 3.5) or plating (Section 3.13). Inorganic salts will be supplied as solids or aqueous solutions and handled in aqueous ‘wet-chemistry’ systems with water washing of components after processing. The chemistry processes will not necessarily be unique to the electronics industry and may have more in common with metalworking or engineering applications.

Supply of inorganic metal salts for the electronics industry will be in relatively low quantities when compared with other industries, but use rates are still higher than for many other types of chemical. In some cases, the metal salts may be hazardous (such as cadmium) and may be subject to additional regulatory controls.

Waste from industrial processes is generated in the form of aqueous solutions (such as spent liquor, washings, and run-off) and solid waste (non-water-soluble sludge from tanks). Some of the solid waste will have a recovery value, but copper and tin salts will not normally be economical to reprocess, as recovery techniques from these salts are expensive. Most solid salts, especially from smaller organisations, will be disposed as chemical waste to landfill or cement block production. Aqueous waste is discharged to waste water, with discharge consents based on pH and specific metal content.

Inorganic salts can be generated as a by-product of the etching process, and some can be used as etchants.

3.6.3 Release scenarios for etching processes

3.6.3.1 Release scenario for etching, inorganic solids

Metal salts and other inorganic solids used in etching are dissolved in water for use. Therefore, initial handling considerations should take into account release scenarios for chemical handling by the user and for etching (aqueous preparations).

3.6.3.2 Release scenario for etching, aqueous preparations

Etching involves the use of dilute aqueous preparations of inorganic materials that change in chemical composition during use. There is a high level of carry-over of solution into rinsing and cleaning tanks and although initial rinse solutions may be recycled back into the plating tank, there is a high level of waste.

Large volumes of water are involved and it is assumed that a high proportion will be discharged as waste water.

Table 3.42 Release table for etching, aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/y	> 1000 kg/y	Volume relates to quantity of formulated solid added to aqueous systems.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air	0%	0%	Release to water only is anticipated.
% to waste water	50%	50%	Estimate based on TGD Table A3.7, assuming Main Category of 3 (default indicating non-dispersive use).

Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Waste from the process is liquid (water-soluble aqueous waste) which passes to waste water at both large and small scale sites. The level of discharge to waste water relates to local discharge consent for specific dangerous components, such as metal salts. Other aqueous waste may only be subject to cursory control, such as pH. Larger scale formulators may have waste disposal procedures and on-site effluent treatment facilities in place but no specialist disposal methods are to be expected at small-scale sites.

No waste solids are estimated at large or small sites (on the basis of water-soluble material not adsorbing to process sludges or solids from settled waste water). Certain metal salts may adsorb.

3.6.4 Associated processes

3.6.4.1 Chemical formulation

Table 3.43 Summary of processes relevant to chemical formulation

Life cycle stage	Description	Loss mechanisms
Formulation	Mixing of substances to produce a preparation. There is often more than one formulation stage.	Surface contamination and emission to drain or ventilation resulting from leakage and spillage (not major accidents) or deliberate release. Liquid and solid wastes, emissions to drain or wastewater treatment plant arising from washing or servicing chemical plant areas and equipment. Disposal of container washings to drain or wastewater treatment plant. Disposal of used containers. Disposal of off-specification product.

The processes used to mix substances to make chemical products for supply to the electronics industry do not involve processing techniques that are unique or specific to this industry. Similar processes for manufacturing or preparing chemical products for supply are used in a wide range of industry sectors. Indeed, it is noted that many chemical products used by the electronics industry are purchased from suppliers who also supply other sectors.

The only significant difference in the supply to the electronics industry, when compared with some other industry sectors, appears to be scale of use – supply of chemicals in containers greater than 25 litres or kilograms is unusual. There is perhaps also a greater degree of manual handling involved in the small-scale use of chemicals when compared with larger chemical users, and small pack sizes are normal.

With the exception of certain highly specialised deposition chemicals (dopants) in the semiconductor manufacturing process (such as organo-metals), there are not many chemical substances used exclusively in the electronics industry. However, some of the handling and exposure scenarios may be unique to the industry and must be considered in detail.

3.6.4.1.1 Release scenarios for Formulation processes

Release scenario for chemical formulation; inorganic solid

Preparation of inorganic materials for supply includes blending and drying processes. The TGD Industry Category (IC) 2 General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenarios, with Table A2.1 being used as a basis for these estimates. Poorly-water-soluble solid waste is expected to be removed during initial settling from waste water, leading to a low level of entry to sludge and subsequent application to agricultural soil. Water-soluble waste will either remain in solution and be discharged (such as nitrates or sulfates), or in some cases (for example certain metal ions such as copper or tin) will adsorb onto sludge. The proportions reaching water or soil must be estimated in accordance with the known properties of the solid.

Table 3.44 Release Scenario for chemical formulation; inorganic solid

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	30	50	Production campaigns may be used for formulating.
% to air	0%	0%	Dust will be trapped in filter systems[1].
% to waste water	2%	2%[2]	Estimate based on TGD Table A2.1.

Note

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control

2. At greater than 1,000t/y formulated product a more typical loss rate would be 0.3 per cent (estimate based on TGD Table A2.1).

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Solid and liquid wastes are to be expected (solid residues from formulation removed when cleaning equipment, and washings from the process). These wastes pass to landfill or waste water respectively from small-scale sites. From large-scale sites the wastes may pass to waste water, recovery, chemical waste or landfill. Larger scale formulators may have waste disposal and treatment procedures in place.

The amount of waste solid is estimated (on the basis of metals/materials adsorbing to process sludges or solids from settled waste water) to be in the order of 2 per cent at small and large scale sites.

Release scenario for chemical formulation; aqueous preparations

Preparation of aqueous mixtures for supply includes blending, dilution and packaging processes.

The TGD Industry Category (IC) 2: General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenarios, with Table A2.1 being used as a basis for these estimates. Being water-soluble or miscible, liquid and solid waste from formulating aqueous preparations is expected to result in waste that does not separate out during initial stages of treatment, or result in significant loss to sludge.

Biodegradability should be considered when preparing a risk assessment for organic solids formulated as aqueous preparations.

Table 3.45 Release table for chemical formulation; aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	30	50	Production campaigns may be used for formulating.
% to air, vp < 100 Pa	0%	0%	Dust will be trapped in filter systems[1].
% to air, vp > 100 Pa	1%	1%	Estimate based on TGD Table A2.1.
% to waste water	2%	2%[2]	Estimate based on TGD Table A2.1.

Note

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control.

2. At greater than 1,000 t/y formulated product a more typical loss rate would be 0.3 per cent (estimate based on TGD Table A2.1).

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Solid and liquid wastes are to be expected (water-soluble solid wastes, and aqueous preparations and washings). These wastes pass to waste water from small-scale sites. From large-scale sites the wastes may pass to waste water, recovery, or as chemical waste for specialist treatment. Level of discharge to waste water relates to local discharge consent for specific dangerous components, such as metal salts. Other aqueous waste may only be subject to cursory control, such as pH. Larger scale formulators may have waste disposal and treatment procedures in place.

No release to waste solids is estimated at large or small sites (on the basis of water-soluble material not adsorbing to process sludges or solids from settled waste water). Certain metal salts may adsorb.

3.6.4.2 Chemical handling by the user

The use of chemicals in the electronics industry is very often on a small scale when compared with other industry sectors, with a high reliance on manual handling and the subsequent use of small containers. There is evidence to suggest that specialist suppliers will re-package bulk products for use by small organisations, and some organisations will themselves decant from larger containers to smaller unit sizes for day-to-day use. This is common in small to medium enterprises.

Table 3.46 Summary of processes relevant to chemical handling

Life cycle stage	Description	Loss mechanisms
Storage and handling	Storage of substances and preparations prior to use. Transfer of substances and preparations into different containers. Dilution and mixing of substances and preparations at the point of use.	Surface contamination and emission to drain or ventilation resulting from leakage and spillage (not major accidents) or deliberate release. Disposal of container washings to drain or wastewater treatment plant. Disposal of used containers. Disposal of old material or products not meeting quality specifications.
Use	Application of substance or preparation to substrate or surface to be worked on. Cleaning or servicing of equipment after use.	Surface contamination and emission to drain or ventilation resulting from spillage or deliberate release. Liquid and solid wastes and emissions to drain or wastewater treatment plant arising from washing or servicing chemical plant areas and equipment.

During manufacturing processes for electronic components, the focus will be on the quality of the products being produced, with engineering designed to ensure quality of final products that may themselves be of high unit value. Less attention may be given to efficiency in the use of chemicals that, in some processes, may be a relatively low-cost element. This is particularly true for etching and cleaning processes. Conversely, certain fine chemicals and ultra-pure materials used in semiconductor manufacture will be very expensive, thus their cost will ensure careful handling.

The Electronics section of the Environment Agency NetRegs website (Environment Agency, 2005) makes recommendations to some areas of industry relevant to electronics manufacturing, with regard to prevention of pollution. The guidance is aimed at small and medium-sized enterprises (SMEs) not subject to IPPC/LAAPC. Mandatory requirements for handling and storage of chemicals include the following, for sites manufacturing CDs/DVDs:

- Contain any spilled chemicals to prevent them entering surface water drains, ditches, watercourses or soakaways. Do not hose spillages down drains.

- Check pipe work for leaks regularly. If leaks are identified, ensure that maintenance work is undertaken immediately and the extent and impact of any contamination assessed and cleaned up.

For sites manufacturing printed circuit boards, there are no mandatory requirements, but the following guidelines are included:

- Store all chemical barrels in a secure location which cannot leak. The base of these areas should be chemical resistant and must have secondary containment such as a bund or a drip tray of adequate size.

- Make sure that all unloading areas are away from storm drains and are hard surfaced to prevent water or ground contamination if there is a spill. If this is not possible, make sure that the drains are protected during delivery (for example by using suitably sized and correctly fitted drain covers).

- Storage areas and drip trays should drain to the plant's wastewater treatment plant, as long as the plant can process these wastes. On no account should these be permitted to drain to the storm system.

- Contain any spilled chemicals to prevent them entering surface water drains, ditches, watercourses or soakaways. Do not hose spillages down drains.

These guidelines have been prepared by industry for industry and take into consideration that the primary activities in most cases are the design, manufacture and assembly of electronic components and the sites are not regarded as chemical production or formulating plants.

3.6.4.2.1 Release scenarios for handling processes

Release scenario for handling by the user: inorganic solids

Handling of inorganic solids by the user includes direct addition to production process, on-site dilution prior to use, disposal of packaging and servicing equipment that may contain dried residues of solids.

The TGD Industry Category (IC) 2: General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenarios, with Table A2.1 being used as a basis for these estimates. Poorly-water-soluble solid waste is expected to be removed during initial settling from waste water, leading to a low level of entry to sludge and subsequent application to agricultural soil. Water-soluble waste will either remain in solution and be discharged (such as nitrates or sulfates), or in some cases (for example certain metal ions such as copper or tin) will adsorb onto sludge. The proportions reaching water or soil must be estimated in accordance with the known properties of the solid.

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). The type of waste will be solid and liquid at both large and small scale installations (solid waste and washings from process). These wastes (including solid residues from formulation removed when cleaning equipment) would go to waste water or landfill from small scale operations (no specialist disposal methods) and to waste water, recovery, chemical waste or landfill from larger sites (specialist disposal methods). Larger scale formulators may have waste disposal and treatment procedures in place.

The amount of waste solid is estimated (on the basis of metals/materials adsorbing to process sludges or solids from settled waste water) to be in the order of 2 per cent at small and large scale sites.

Table 3.47 Release table for handling by the user: inorganic solids

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air	0%	0%	Dust will be trapped in filter systems[1].
% to waste water	2%	2%	Estimate based on TGD Table A2.1.

Note

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control.

Release scenario for handling by the user: aqueous preparations

Handling of aqueous preparations by the user includes direct addition to production process or on-site decanting to smaller container prior to use, disposal of packaging and servicing equipment.

The TGD Industry Category (IC) 2: General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenarios, with Table A2.1 being used as a basis for these estimates. Being water-soluble or miscible, liquid and solid waste from formulating aqueous preparations is considered to result in waste that does not separate out during initial stages of treatment, or result in significant loss to sludge.

Biodegradability should be considered when preparing a risk assessment for organic solids formulated as aqueous preparations.

Table 3.48 Release table for handling by the user: aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air, vp < 100 Pa	0%	0%	Estimate based on TGD Table A2.1.
% to air, vp > 100 Pa	1%	1%	Estimate based on TGD Table A2.1.
% to waste water	2%	2%	Estimate based on TGD Table A2.1.

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Solid and liquid wastes are to be expected (water-soluble solid wastes, and aqueous preparations and washings). These wastes pass to waste water from small-scale sites. From large-scale sites the wastes may pass to waste water, recovery, or as chemical waste for specialist treatment. Level of discharge to waste water relates to local discharge consent for specific dangerous components, such as metal salts. Other aqueous waste may only be subject to cursory control, such as pH. Larger scale formulators may have waste disposal and treatment procedures in place.

No release of waste solid is estimated (on the basis of water-soluble material not adsorbing to process sludges or solids from settled waste water). Certain metal salts may adsorb.

3.6.4.3 Cleaning of components and equipment

3.6.4.3.1 Summary

Water rinsing, where it is an integral stage of other industrial processes, is considered as part of those processes. This section considers only cleaning using cleaning chemicals, for example detergents or solvents.

The amount of cleaning appears to vary within the electronics industry, with some component suppliers conducting very little cleaning and others cleaning all components at every stage. Cleaning adds costs to the process and the amount of cleaning may reflect the final value of the end products. Examples where no cleaning takes place may include components for toys or household appliances and examples of cleaning will be for aerospace or defence industries.

Table 3.49 Summary of processes relevant to cleaning

Life cycle stage	Description	Loss mechanisms
Aqueous cleaning	Immersion or spraying of components in dilute aqueous preparations of detergents. Cleaning of equipment with water-based detergents. Water based cleaning is not suitable for many electronic components due to sensitivity to water.	Considered to be 100 per cent loss of detergents to waste water. There may be some carry-over onto finished components, but this is not considered significant. Waste water will include the materials being washed off components, such as oils, greases, flux residues, metal salts and so on. Note applicability of Detergents Regulation EC 648/2004 ensuring minimum standards of biodegradability for surface active components – this does not mitigate loss, but ensures that residues in effluent will not accumulate.

Water is used for early stages of cleaning, either with or without surface-active agents (detergents). Large quantities of water are consumed in preparing silicon wafers and other substrates such as glass and ceramics. Rinsing after electroless plating, electroplating and etching is essential to remove potentially corrosive or otherwise detrimental chemical residues.

Equipment is often cleaned with water-based detergents as part of servicing and maintenance procedures.

Cleaners (aqueous)

Aqueous and non-aqueous cleaning products are used in various stages of electronic component manufacture.

Examples of aqueous cleaners include dilute preparations of surface active agents (such as alkyl ethoxylates) and these will themselves be subject to the Detergents Regulation (648/2004) that imposes a minimum standard of biodegradation. Those failing the prescribed rate of biodegradation can be placed on the market for specialist uses subject to a risk assessment – specialist use in the electronics industry could be examples where derogations are granted.

Many of the cleaning preparations marketed for the electronics sector will mirror formulations used in other industry sectors such as domestic applications, metalworking, and the motor industry.

Formulation of such cleaners will be through mixing at ambient or slightly elevated temperatures using processes common to the detergent and cleaning industry sector. Supply takes place in small containers of less than 25 kg, with many suppliers offering containers of one litre or less.

The level of component and surface cleaning in the industry varies, with the highest level of cleaning found in the production of high-value products for the aerospace and defence industries.

The use of 'clean-room' processes for semiconductor and other precision components should not be confused by the use of cleaning products; clean room processes describe the barrier methods used to prevent chemical contamination of micro-electronic components and not the cleaning processes employed during manufacture. Many cleaning products can themselves be considered as potential contaminants in the precision processes that require clean-room technology, and surface-active materials could interfere with subsequent processing of the electronic components. Exceptions to this are purified water and high-quality grade volatile solvents such as acetone.

The use of aqueous cleaners, by their nature, usually involves significant volumes of water as more products are supplied as concentrates to be diluted in water at the time of use. Although there may be isolated cases where waste water is collected for disposal as chemical waste, it is assumed that there is 100 per cent loss of the aqueous cleaning products to waste water discharge. Although the detergents themselves may meet biodegradation criteria, waste effluent will contain emulsified or suspended material that has been removed during the cleaning process.

A small proportion of the surface active agents may remain on the cleaned surfaces, but this will be negligible and is not considered further – any such residues are likely to either ultimately degrade during the life-time or disposal of the electronic component, or be removed in subsequent washing stages.

3.6.4.3.2 Release scenarios for cleaning processes: aqueous preparations

Water-based cleaning with detergents, or water rinsing, takes place at the early stages of component manufacture. Due to the nature of water washing, large volumes of water may be involved and it is assumed that a high proportion will be discharged as waste water.

Many cleaning agents may themselves be subject to the Detergents Regulation (648/2004) and the biodegradation thresholds are a key factor in any risk assessment being carried out.

Type of waste will be liquid at both large and small scale installations (water-soluble aqueous waste with emulsified or suspended non-water-soluble materials that have been cleaned from components). This would pass to waste water from small scale operations and from larger sites with no specialist disposal methods, and will be discharged to either municipal or on-site waste water treatment plants.

No release of waste solid (process sludges or solids from settled waste water) is estimated.

Table 3.50 Release table for cleaning of components: aqueous preparations

Description	**Small scale**	**Large scale**	**Comments**
Total use	< 1000 kg/pa	> 1000 kg/pa	Quantity of active detergent component and not water.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air	0%	0%	Release to water only is anticipated.
% to waste water	100%	100%	TGD Table A4.1, cleaning products UC10.

Table 3.51 Extract from TGD A-tables

The following data are taken from TGD Table A4.1, cleaning products UC48 (solvents).

Vapour pressure Pa	Water solubility mg/l	% emission to air	% emission to waste water	% emission to soil
< 100 Pa	< 10 mg/l	1.5%	10%	20%
100 - 1000	“	15%	10%	20%
1000 – 10 0000	“	40%	10%	20%
> 10 000	“	60%	10%	20%
< 100 Pa	10 – 100 mg/l	7.5%	20%	10%
100 - 1000	“	12.5%	20%	10%
1000 – 10 0000	“	25%	20%	10%
> 10 000	“	40%	20%	10%
< 100 Pa	100 – 1000 mg/l	2.5%	40%	5%
100 - 1000		10%	40%	5%
1000 – 10 0000		15%	40%	5%
> 10 000		22.5%	40%	5%
< 100 Pa	> 1000 mg/l	3%	60%	0.5%
100 - 1000		7.5%	60%	0.5%
1000 – 10 0000		12.5%	60%	0.5%
> 10 000		17.5%	60%	0.5%

3.7 High vacuum evaporation / sputtering

3.7.1 Summary

In vapour deposition techniques by evaporation, conversion into vapour is achieved by applying heat to the source material. This is done in a high-vacuum environment, so that the vaporised atoms or molecules will be transported to the substrate with minimal collision interference from other gas atoms or molecules.

Doping is also a colloquial term for any process of introducing a layer of substance onto a substrate. For organometallic dopants, chemical vapour deposition is most commonly used. For pure metal dopants, the high vacuum or ‘sputtering’ method is used.

Sputtering, also known as partial vacuum evaporation, is a technique used to deposit thin layers of metal onto a substrate. A vacuum chamber contains a solid ingot of metal and the substrate. High-energy ions (for example, positively ionised argon gas) are used to dislodge metal atoms, which are then deposited onto the substrate surface, producing a layer of uniform thickness. Sputtering is used in the manufacture of semiconductors and liquid crystal displays where atomic-scale layers of metal coating are required. The quantity of metal used is very small (gram quantities) and there is some recovery and re-use of the inert gas carriers.

Table 3.52 Summary of processes relevant to high vacuum evaporation/sputtering

Life cycle stage	Description	Loss mechanisms
Chemical handling	Typically low volume, high value substances and metals handled through automated dispensing systems. Little opportunity for spillage or waste.	Waste through used containers (vials or specialist containers). Some containers are returned for recycling, but other disposed of as solid waste.
Evaporation / deposition stages	Use is typically in enclosed, controlled environments using automated equipment.	Little or no loss to the environment as a direct result of use.
Sputtering	Metal is vaporised and condensed onto the substrate to be coated. Some deposition can be expected on other surfaces in the vacuum chamber.	No emission from this process but waste metal will accumulate on non-target surfaces.
Disposal of waste	Many of the products used are unstable and are likely to degrade prior to disposal.	Substances are typically consumed during use and will lose their identity. The fate of degradation products will depend on the chemistry; some degrade to release volatile substances (such as amines) or non-water-soluble metal oxides. Processes are typically non-aqueous, but equipment and component cleaning may involve water.
	Degradation products may be removed in aqueous streams.	Water-soluble degradation products will potentially have a high rate of loss to waste water. Volatile degradation products will be released to the atmosphere.
	Unused product may be returned to supplier or disposed of as chemical waste. Some materials have very high value.	Controlled disposal should result in little loss to the environment.
End product	Deposited material, such as boron, silicon or other substances will remain on the components.	Solid waste from re-processing activities.

The rate of mass removal from the source material as a result of such evaporation increases with vapour pressure of the material to be evaporated and deposited on the target surface, which in turn increases with the applied heat. A vapour pressure greater than 1.5 Pa is needed in order to achieve deposition rates that are high enough for manufacturing purposes.

The substances used for this process will degrade during use, with loss of degradation products as vapours or as deposits on the target substrate and other surfaces. There is not considered to be any significant emission to the environment as a result of use. The manufactured components will include residues of the substance intended to be deposited during the process and will remain in the component during use until end of life.

3.7.2 Chemicals relevant to high vacuum evaporation/sputtering processes

3.7.2.1 Dopants

Doping, or deposition of particular atoms on silicon wafers, uses very specialist organo-metal, boron, silicon or phosphorus substances that will often functionally degrade as the intended 'dopant' atom is deposited. Many types of these materials will degrade to form water-soluble or volatile by-products such as amines, halides and water-soluble or insoluble salts.

Silicon products (such as silicon nitride and silane derivatives) are used to re-deposit silica on the treated wafers to form a new layer in semiconductor manufacture.

The level of chemical use for doping is very small, with only tens of kilos of certain types of specialist substance supplied in Europe. The high cost and instability of many of these chemicals will result in none of the parent materials being present after processing. Many such materials will degrade under atmospheric conditions, including residues in open containers.

Washing of semiconductors is a key part of the processing and will involve very large volumes of water in relation to the quantity of material used. The washings will include the degradation products of dopants, including amines, or metal salts. It appears that most waste from washing is discharged as waste water, and although the proportion of the metal or other functionally active components will be small (high costs will ensure good efficiency), up to 100 per cent of 'carrier' components, such as amines, may be lost to waste water. Volatile degradation products may be lost to the atmosphere.

Doping is also a colloquial term for any process of introducing a layer of substance onto a substrate. For organometallic dopants, the chemical vapour deposition method is most commonly used. For pure metal dopants, the high vacuum 'sputtering' method is used.

It is essential that the supplier or user of these reactive chemicals fully understands the rate of chemical degradation and the identity and properties of degradation products that are formed when considering a risk assessment for such substances.

3.7.2.2 Atmospheric gases

Atmospheric gases are defined as naturally occurring gaseous substances isolated from the atmosphere. Examples in the electronics industry include nitrogen as an inert carrier, a cooling medium (liquid form), or to provide an oxygen-free atmosphere for manufacture. Similarly, argon is used as an inert carrier for plasma process and sputtering in semiconductor manufacture. Carbon dioxide, in its solid form, has applications for abrasive cleaning of silicon wafers at very low temperatures.

Gases are supplied as pressurised liquids in the same manner as supplied to other industry sectors. It can be considered that use will result in 100 per cent loss to the atmosphere. There will be exceptions, such as the use of oxygen as an oxidising agent, that will lead to the formation of oxidised forms of the material being processed.

Neon and xenon gases are also used in plasma screen technology, which is discussed briefly in Section 2.7.3 on Displays.

Gases are not considered in Release Scenarios and Tables. It is assumed that there is 100 per cent loss to the atmosphere.

3.7.2.3 Metals

Metals in massive form (for example as wire or block for 'sputtering'), or that are a part of components (such as coated laminates), need to be considered in view of waste and disposal. Outer casings, wires, cables and batteries are excluded from this ESD and other sections deal with metal salts or organo-metal substances (dopants) and preparations. Solder is discussed in detail (see Section 3.10).

Other uses for metals include heat sinks or as substrate base for some hybrid circuits that use relatively thick copper coatings.

Commonly used metals are copper and tin, although specialist applications may require the use of gold, silver or rare metals. Metal, supplied in the massive form or coated to laminates, will either constitute part of the finished electronic component, or be lost as waste, either in solid particulate form, or in the form of dissolved salts formed during etching.

Metal remaining in the components will not be released during the service life phase of the components, but will make up a significant proportion of the waste generated at end-of-life. There is a market for recovered metals, although copper and tin are relatively low value and recovery may not be as thorough as work to recover silver, gold or other rare metals. The same recovery processes will extract lead from soldered components.

Metal lost as waste, through physical processes (such as waste wire, cuttings or drilling waste from laminate boards) will be collected and either disposed of as general waste (small scale operations), or collected for recovery as scrap. It is unlikely that solid metal will enter waste water systems and most sites will have a sump to collect solids before eventual discharge.

Metals reacted to form salts (for example through etching processes) will form solid waste (which will be taken for recovery or disposal as waste), or be taken in solution to waste water treatment. Most sites will have a consent order for certain metal waste.

3.7.2.4 Silicon

Silicon dioxide (silica) is reduced to form silicon that is supplied in massive form as 'ingots', made by melting the oxide and crystallising onto a 'seed', forming a single crystal of silicon. These are up to 30 cm in diameter and 20 – 30 cm long. Thin slices are prepared and duplicate patterns can etched before cutting the wafers into the familiar 'chip' size articles. These wafers can be up to 30 cm wide.

Under controlled conditions, using pure oxygen, a thin layer of oxide forms on the silicon wafers and this oxide layer is used as part of the photolithography and etching process.

Silicon waste is in the form of particulates and off-cuts from physical handling of the wafers. The silicon will quickly oxidise under atmospheric conditions and waste will be in the form of silicon dioxide. Although this may remain in suspension following washing phases with water, silica will be removed through settling or filtering processes during water treatment.

3.7.3 Release scenarios for high vacuum evaporation processes

3.7.3.1 Release scenario for high vacuum evaporation: metals

This process is also called ‘sputtering’ and involves heating metal at low pressure in an inert gas to enable vapours of the metal to condense on the target surface. The flow of ions is aided by application of a strong voltage. The process is similar to electroplating, but takes place in vapour form rather than solution.

Waste metal (metal residues) will condense on non-target areas, although this is minimised through application of the electric current. Any metal is collected for recovery, at both small- and large-scale sites. The total loss (wastage) from the process is typically zero. No release of waste solids (process sludges or solids from settled waste water) is estimated.

Table 3.53 Release table for high vacuum evaporation: metals

Description	Small scale	Large scale	Comments
Total use	< 10 kg/pa	> 10 kg/pa	Very low volume of use.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air	0%	0%	Only solid wastes are anticipated (metal residues).
% to waste water	0%	0%	

Release scenario for high vacuum evaporation: inorganic and organic solids, and non-aqueous liquids

Inorganic solids

This is very similar in activity to chemical vapour deposition. Users should refer also to Section 3.3.

Organic solids

Organic substances used in the process are expected to have similar release to inorganic solids. Organo-metallic substances will deposit metal onto the target surface and metal will also be lost as solid waste.

Non-aqueous liquids

This is a specialist process involving high value chemicals (very pure or with rare elements), and the release will be similar to that for organic and inorganic solids. The principle of processing is similarly irrespective of physical form – the substance is allowed to degrade so that one or more degradation products are deposited onto the target surface.

Table 3.54 Release table for high vacuum evaporation: inorganic and organic solids and non-aqueous liquids

Description	Small scale	Large scale	Comments
Total use	< 100 kg/pa	> 100 kg/pa	Very low volume of use.
Days in use	300	300	Continuous use.
% to air, starting materials	0%	0%	Dust will be trapped in filter systems[1].
% to air, gaseous degradation products	100%	100%	Vapour losses of volatile degradation products.
% to waste water, sol. > 1 mg/l	2%	2%	Water-soluble degradation products.

Note

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control

Total loss (wastage) from the process is estimated to be typically <50 per cent at small sites and <20 per cent at large sites; this is an inefficient process, despite high costs of the materials. Solid and liquid waste is to be expected at both large- and small-scale installations (solid waste and washings from process). Recovery of waste is likely for economic reasons because the metals and isotopes used are of high value. Some washings would pass to waste water (larger scale formulators may have waste disposal and treatment procedures in place). Note that materials may be unstable and breakdown products need to be considered.

The amount of waste solid is estimated (on the basis of metals/materials adsorbing to process sludges or solids from settled waste water) to be in the order of 2 per cent at small and large scale sites. These releases include solid degradation products of water solubility <1 mg/l.

3.7.4 Associated processes

3.7.4.1 Chemical handling by the user

The use of chemicals in the electronics industry is very often on a small scale when compared with other industry sectors, with a high reliance on manual handling and the subsequent use of small containers. Chemical suppliers re-package bulk products for use by small organisations, and some organisations will themselves decant from larger containers to smaller unit sizes for day-to-day use. This is common in small to medium enterprises.

During manufacturing processes for electronic components, the focus will be on the quality of the products being produced, with engineering designed to ensure quality of final products that may themselves be of high unit value. Less attention may be given to efficiency in the use of chemicals that, in some processes, may be a relatively low-cost element. This is particularly true for etching and cleaning processes. Conversely, certain fine chemicals and ultra-pure materials used in semiconductor manufacture will be very expensive, thus their cost will ensure careful handling.

Table 3.55 Summary of processes relevant to chemical handling

Life cycle stage	Description	Loss mechanisms
Storage and handling	Storage of substances and preparations prior to use. Transfer of substances and preparations into different containers. Dilution and mixing of substances and preparations at the point of use.	Surface contamination and emission to drain or ventilation resulting from leakage and spillage (not major accidents) or deliberate release. Disposal of container washings to drain or wastewater treatment plant. Disposal of used containers. Disposal of old material or products not meeting quality specifications.
Use	Application of substance or preparation to substrate or surface to be worked on. Cleaning or servicing of equipment after use.	Surface contamination and emission to drain or ventilation resulting from spillage or deliberate release. Liquid and solid wastes and emissions to drain or wastewater treatment plant arising from washing or servicing chemical plant areas and equipment.

The Electronics section of the Environment Agency NetRegs website (Environment Agency, 2005) makes recommendations to some areas of industry relevant to electronics manufacturing, with regard to prevention of pollution. The guidance is aimed at small and medium-sized enterprises (SMEs) not subject to IPPC/LAAPC. Mandatory requirements for handling and storage of chemicals include the following, for sites manufacturing CDs/DVDs:

- Contain any spilled chemicals to prevent them entering surface water drains, ditches, watercourses or soakaways. Do not hose spillages down drains.

- Regularly check pipe work for leaks. If leaks are identified, ensure that maintenance work is undertaken immediately and the extent and impact of any contamination assessed and cleaned up.

For sites manufacturing printed circuit boards, there are no mandatory requirements, but the following guidelines are included:

- Store all chemical barrels in a secure location which cannot leak. The base of these areas should be chemical resistant and must have secondary containment such as a bund or a drip tray of adequate size.

- Make sure that all unloading areas are away from storm drains and are hard surfaced to prevent water or ground contamination if there is a spill. If this is not possible, make sure that the drains are protected during delivery (for example by using suitably sized and correctly fitted drain covers).

- Storage areas and drip trays should drain to the plant's wastewater treatment plant, as long as the plant can process these wastes. On no account should these be permitted to drain to the storm system.

- Contain any spilled chemicals to prevent them entering surface water drains, ditches, watercourses or soakaways. Do not hose spillages down drains.

These guidelines have been prepared by industry for industry and take into consideration that the primary activities in most cases are the design, manufacture and assembly of electronic components and the sites are not regarded as chemical production or formulating plants.

3.7.4.1.1 Release scenarios for handling by the user: metals

Metals will be handled prior to use in assembly and soldering or prior to recovery activities. The processes to consider include drilling, cutting and grinding metals to create bases for assembly of components or melting and handling of molten metal such as solder.

Waste will comprise exclusively of solid metal that will either be sent for recovery or disposed as solid waste.

Table 3.56 Release scenarios for handling by the user: metals

Description	Small scale	Large scale	Comments
Total use	< 1,000 kg/y	> 1,000 kg/y	
Days in use	300	300	Continual use.
% to air	0%	0%	Only solid wastes are anticipated (wastage from the process).
% to waste water	0%	0%	

Total loss (wastage) from the process is estimated to be typically 5 per cent at small sites and 2 per cent at large sites. Solid wastes are to be expected (small particulates and fragments). The degree of recovery will reflect value of the waste, but in general at larger sites recovery and/or specialist disposal is to be expected. At small-scale sites this is less likely to be the case.

The amount of waste solid (process sludges or solids from settled waste water, in the form of non-water-soluble solid particulates) is estimated to be in the order of 5 per cent at small- and 2 per cent at large-scale sites.

3.7.4.2 Cleaning of components and equipment

3.7.4.2.1 Summary

Water rinsing, where it is an integral stage of other industrial processes, is considered as part of those processes. This section considers only cleaning using cleaning chemicals, such as detergents or solvents.

The amount of cleaning appears to vary within the electronics industry, with some component suppliers conducting very little cleaning and others cleaning all components at every stage. Cleaning adds costs to the process and the amount of cleaning may reflect the final value of the end products; examples where no cleaning takes place may include components for toys or household appliances and examples of cleaning will be for aerospace or defence industries.

Water is used for early stages of cleaning, either with or without surface-active agents (detergents). Large quantities of water are consumed in preparing silicon wafers and other substrates such as glass and ceramics. Rinsing after electroless plating, electroplating and etching is essential to remove potentially corrosive or otherwise detrimental chemical residues.

Equipment is often cleaned with water-based detergents as part of servicing and maintenance procedures.

Solvent cleaners tend to be used in the later stages of production, with the use of volatile substances such as acetone or alcohols, either as neat substances or as a component of aqueous solutions (or less commonly, with wetting agents). The use of specific types of solvents will be determined by the material to be removed, the rate of drying and suitability in terms of ensuring that the component being cleaned is not damaged.

Table 3.57 Summary of processes relevant to cleaning

Life cycle stage	Description	Loss mechanisms
Aqueous cleaning	Immersion or spraying of components in dilute aqueous preparations of detergents. Cleaning of equipment with water-based detergents. Water based cleaning is not suitable for many electronic components due to sensitivity to water.	Considered to be 100 per cent loss of detergents to waste water. There may be some carry-over onto finished components, but this is not considered significant. Waste water will include the materials being washed off components, such as oils, greases, flux residues, metal salts and so on. Note applicability of Detergents Regulation EC 648/2004 ensuring minimum standards of biodegradability for surface active components – this does not mitigate loss, but ensures that residues in effluent will not accumulate.
Solvent cleaning	Immersion or spraying of components in dilute solvents or solvent preparations. Most use is where non-water-soluble materials are to be removed (such as photoresist, films and so on), where there is sensitivity to water (for example in the final stages of PCB manufacture) or where quick drying is required.	Loss to atmosphere of volatile solvents (such as acetone, isopropyl alcohol, esters and so on) or as solvent waste for disposal. Some loss expected to waste water.

Cleaners (aqueous)

Aqueous and non-aqueous cleaning products are used in various stages of electronic component manufacture.

Examples of aqueous cleaners include dilute preparations of surface active agents (such as alkyl ethoxylates) and these will be subject to the Detergents Regulation (648/2004) that imposes a minimum standard of biodegradation Those failing the prescribed rate of biodegradation can be placed on the market for specialist uses subject to a risk assessment – specialist use in the electronics industry could be an example where a derogation is granted.

Many of the cleaning preparations marketed for the electronics sector will mirror formulations used in other industry sectors such as domestic applications, metalworking, and the motor industry.

Formulation of such cleaners will be through mixing at ambient or slightly elevated temperatures using processes common to the detergent and cleaning industry sector. Supply takes place in small containers of less than 25 kg, with many suppliers offering containers of one litre or less.

The level of component and surface cleaning in the industry varies, with the highest level of cleaning found in the production of high-value products for the aerospace and defence industries.

The use of ‘clean-room’ processes for semiconductor and other precision components should not be confused by the use of cleaning products. Clean-room processes describe the barrier methods used to prevent chemical contamination of micro-electronic components and not the cleaning processes employed during manufacture. Many cleaning products can themselves be considered as potential contaminants in the precision processes that require clean-room technology, and surface-active materials could interfere with subsequent processing of the electronic components. Exceptions to this are purified water and high-quality grade volatile solvents such as acetone.

The use of aqueous cleaners, by their nature, usually involves significant volumes of water as more products are supplied as concentrates to be diluted in water at the time of use. Although there may be isolated cases where waste water is collected for disposal as chemical waste, it is assumed that there is 100 per cent loss of the aqueous cleaning products to waste water discharge. Although the detergents themselves may meet biodegradation criteria, waste effluent will contain emulsified or suspended material that has been removed during the cleaning process.

A small proportion of the surface active agents may remain on the cleaned surfaces, but this will be negligible and is not considered further – any such residues are likely to either ultimately degrade during the life-time or disposal of the electronic component, or be removed in subsequent washing stages.

Solvents (including organic solvent-based cleaners)

Solvents as a class of substances are used as carriers and cleaners in a wide range of applications in the electronics industry, with functions that are comparable with uses in other industries. Solvents such as xylene are used as a diluent and viscosity reducer, for example in solder flux, in the same way that they will be used in paints, sealants or other applications.

Proprietary formulations will include mixtures with other solvents such as ethanol, iso-propyl alcohol, or methanol. Such preparations will contain polar water-soluble and volatile components. Blending with other solvents will be under ambient conditions with precautions in place in consideration of possible flammability and atmospheric concentration limits. Equipment would not require washing with water after use and there is considered to be a low risk of loss to waste water from formulation activities. Similar solvent preparation may be used in other sectors of industry as cleaning agents or thinners (paints and other surface coatings).

Solvent cleaning of printed circuit boards (PCBs) or other components involves spraying or dipping the components in the solvent to remove residues of flux, grease or other contaminants or for removing photoresist layers. The choice of solvent will depend on the required polarity or volatility.

The use of solvents is regulated by Directive 99/13/EC on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations.

Waste solvents are either disposed as hazardous waste or will be lost in use to the atmosphere. There is not considered to be residual solvents remaining on components after assembly.

3.7.4.2.2 Release scenarios for cleaning processes: aqueous and non-aqueous preparations

Aqueous preparations

Water-based cleaning with detergents, or water rinsing, takes place at the early stages of component manufacture. Due to the nature of water washing, large volumes of water may be involved and it is assumed that a high proportion will be discharged as waste water.

Many cleaning agents may themselves be subject to the Detergents Regulation (648/2004) and the biodegradation thresholds are a key factor in any risk assessment being carried out.

Type of waste will be liquid at both large and small scale installations (water-soluble aqueous waste with emulsified or suspended non-water-soluble materials that have been cleaned from components). This would pass to waste water from small scale operations and from larger sites with no specialist disposal methods, and will be discharged to either municipal or on-site waste water treatment plants.

Non-aqueous preparations

Solvent washing may take place at various stages of processing to remove non-water-soluble contaminants or residues, including later stages of assembly when use of water is not appropriate. Solvents are used to remove residues, for example of photoresists and flux, and although most solvent waste will be collected for disposal, some may evaporate from the surface of cleaned components or equipment or be rinsed to waste water.

The route and quantity of emission is proportional to the water solubility and vapour pressure of the solvent cleaners.

Table 3.58 Release table for cleaning of components: aqueous and non-aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/pa	> 1000 kg/pa	Aqueous preparations: Quantity of active detergent component and not water. Non-aqueous preparations: Quantity of solvent.
Days in use	250	300	Most processes are continuous and not based on campaigns.
Releases information			For non-aqueous preparations: Proportion lost to air, water and soil is variable and dependent upon chemical properties. Refer to TGD Table A4.1, cleaning products UC48 (solvents).
% to air	0%	0%	For aqueous preparations only.
% to waste water	100%	100%	For aqueous preparations only (TGD Table A4.1, cleaning products UC10).

Table 3.59 Extract from TGD A-tables

The following data are taken from TGD Table A4.1, cleaning products UC48 (solvents).

Vapour pressure Pa	Water solubility mg/l	% emission to air	% emission to waste water	% emission to soil
< 100 Pa	< 10 mg/l	1.5%	10%	20%
100 - 1000	“	15%	10%	20%
1000 – 10 0000	“	40%	10%	20%
> 10 000	“	60%	10%	20%
< 100 Pa	10 – 100 mg/l	7.5%	20%	10%
100 - 1000	“	12.5%	20%	10%
1000 – 10 0000	“	25%	20%	10%
> 10 000	“	40%	20%	10%
< 100 Pa	100 – 1000 mg/l	2.5%	40%	5%
100 - 1000		10%	40%	5%
1000 – 10 0000		15%	40%	5%
> 10 000		22.5%	40%	5%
< 100 Pa	> 1000 mg/l	3%	60%	0.5%
100 - 1000		7.5%	60%	0.5%
1000 – 10 0000		12.5%	60%	0.5%
> 10 000		17.5%	60%	0.5%

3.8 Laminate production and processing

3.8.1 Summary

The production steps involving the initial formation of polymer-based circuit board and the subsequent metal coating may take place at different locations. Multi-layer boards are made by taking suitable laminates and creating layers of non-conducting polymer interspersed with metal conductive layers. Specialist adhesives are used to bond the layers.

The initial process of forming the polymeric boards is similar to processes used for other laminates, such as protective coatings used in a wide variety of applications. The proportion of laminate production for the electronics industry is very small.

Metal coating processes will include electroless and electroplating methods.

During use, the solid laminate boards will be drilled and cut, leading to the formation of solid waste in the form of dust, drilling swarf and off-cuts. Larger users will send waste for recovery of metals, but this is not economic for smaller users and waste will be disposed as non-hazardous industrial waste.

Table 3.60 Summary of processes relevant to laminate production and processing

Life cycle stage	Description	Loss mechanisms
Laminate production	Epoxies, phenolic papers and other composite substrates. Similar to plastics (polymer) industry application.	Adhesive and polymer processes not considered further.
Coating	Coating with copper or other conductors. Multi-layer laminates.	(See plating methods, Sections 3.4-3.5). Adhesives (not considered further in this ESD).
Board preparation	Cutting and drilling boards.	Drilling and routing dust (copper, aluminium, and gold) are collected and recycled. Airborne particulates.
	Cleaning boards.	Waste water from rinsing. Sludge from wastewater treatment.
Waste	Disposal of off-cuts.	Scrap board materials recycled for metal recovery.

Laminate sheets are sourced from outside Europe, either direct or through import suppliers. There appears to be little primary production in the UK or other parts of Europe. Some products (such as multi-layer) can be produced to order by specialist EU companies, but these often use pre-formed composites as starting materials. The chemistry of the laminate boards used in the electronics industry is similar to other composite materials used for other engineering or manufacturing activities.

For the electronics industry, the laminate boards are coated with thin layers of copper or perhaps tin. Very rarely, other metals or alloys are used, but this is very limited.

These laminates are cut to size (preparation and etching tanks can handle up to 40 x 40 cm) and each sheet will normally comprise multiple circuit boards processed together (for obvious cost savings), with the final cut to size being at the end of the process or by the customer.

The laminates are drilled by semi-automatic machine working from computer-aided design (CAD).

Waste laminates are treated as non-hazardous waste with some recovery depending on the scrap metal value. Dust and powder are extracted or swept for solids disposal.

3.8.2 Release scenarios for laminate processing

3.8.2.1 Release scenario for laminate production: metals, organic solids

Metals

Metals used are deposited onto the surface of the laminate using electroless plating (refer also to Section 3.4). During preparation of the laminates for use, assembly processes take place, such as cutting and drilling (refer also to Section 3.2).

Total loss (wastage) from the process is estimated to be typically 5 per cent at small sites and 2 per cent at large sites. Solid, non-hazardous wastes are to be expected (small particles and fragments). The degree of recovery will reflect value of the waste, but in general recovery and/or specialist disposal is to be expected at larger sites. At small-scale sites this is less likely to be the case.

Organic solids

Organic solids include the laminate board itself, often made as a composite from different polymer layers. Waste will be solid off-cuts that will be collected and disposed of as non-hazardous trade waste.

Total loss (wastage) from the process is estimated to be typically 5 per cent at small sites and 2 per cent at large sites. Solid, non-hazardous wastes are to be expected (small particles, dusts and fragments). In general, specialist disposal is to be expected at larger sites. At small-scale sites this is less likely to be the case.

Table 3.61 Release Scenario for laminate production: metals, organic solids

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/y	> 1000 kg/y	
Days in use	300	300	Continuous use.
% to air	0%	0%	Only solid wastes are anticipated (wastage from the process).
% to waste water	0%	0%	

Note: Any use of inorganic solids can be considered to be an assembly process (see Section 3.2).

The amount of waste solid (process sludges or solids from settled waste water, in the form of non-water-soluble solid particulates) is estimated to be in the order of 5 per cent at small and 2 per cent at large scale sites.

3.8.3 Associated processes

3.8.3.1 Cleaning of components and equipment

3.8.3.1.1 Summary

Water rinsing, where it is an integral stage of other industrial processes, is considered as part of those processes. This section considers only cleaning using specific chemicals, such as detergents or solvents.

The amount of cleaning appears to vary within the electronics industry, with some component suppliers conducting very little cleaning and others cleaning all components at every stage. Cleaning adds costs to the process and the amount of cleaning may reflect the final value of the end products. Examples where no cleaning takes place may include components for toys or household appliances and examples of cleaning will be for aerospace or defence industries.

Table 3.62 Summary of processes relevant to cleaning

Life cycle stage	Description	Loss mechanisms
Aqueous cleaning	Immersion or spraying of components in dilute aqueous preparations of detergents. Cleaning of equipment with water-based detergents. Water-based cleaning is not suitable for many electronic components due to sensitivity to water.	100% loss of detergents to waste water is assumed. There may be some carry-over onto finished components, but this is not considered significant. Waste water will include the materials being washed off components, such as oils, greases, flux residues, metal salts and so on. Note applicability of Detergents Regulation EC 648/2004 ensuring minimum standards of biodegradability for surface active components – this does not mitigate loss, but ensures that residues in effluent will not accumulate in the environment.
Solvent cleaning	Immersion or spraying of components in dilute solvents or solvent preparations. Most use is where non-water-soluble materials are to be removed (such as photoresist, films and so on), where there is sensitivity to water (for example in the final stages of PCB manufacture) or where quick drying is required.	Loss to atmosphere of volatile solvents (such as acetone, isopropyl alcohol, esters and so on) or as solvent waste for disposal. Some loss expected to waste water.

Water is used for early stages of cleaning, either with or without surface-active agents (detergents). Large quantities of water are consumed in preparing silicon wafers and other substrates such as glass and ceramics. Rinsing after electroless plating, electroplating and etching is essential to remove corrosive or otherwise detrimental chemical residues.

Equipment is often cleaned with water-based detergents as part of servicing and maintenance procedures.

Solvent cleaners tend to be used in the later stages of production, with the use of volatile substances such as acetone or alcohols, either as neat substances or as a component of aqueous solutions (or less commonly, with wetting agents). The use of specific types of solvents will be determined by the material to be removed, the rate of drying and suitability in terms of ensuring the component being cleaned is not damaged.

Cleaners (aqueous)

Aqueous and non-aqueous cleaning products are used in various stages of electronic component manufacture.

Examples of aqueous cleaners include dilute preparations of surface active agents (such as alkyl ethoxylates) and these will themselves be subject to the Detergents Regulation (648/2004) that imposes a minimum standard of biodegradation. Those failing the prescribed rate of biodegradation can be placed on the market for specialist uses subject to a risk assessment – specialist use in the electronics industry could be an example where a derogation is granted.

Many of the cleaning preparations marketed for the electronics sector will mirror formulations used in other industry sectors such as domestic applications, metalworking, and the motor industry.

Formulation of such cleaners will be through mixing at ambient or slightly elevated temperatures using processes common to the detergent and cleaning industry sector. Supply takes place in small containers of less than 25 kg, with many suppliers offering containers of one litre or less.

The level of component and surface cleaning in the industry is variable, with the highest level of cleaning found in the production of high-value products for the aerospace and defence industries.

The use of 'clean-room' processes for semiconductor and other precision components should not be confused by the use of cleaning products. Clean room processes describe the barrier methods used to prevent chemical contamination of micro-electronic components and not the cleaning processes employed during manufacture. Many cleaning products can themselves be considered as potential contaminants in the precision processes that require clean-room technology and surface-active materials could interfere with subsequent processing of the electronic components. Exceptions to this are purified water and high-quality grade volatile solvents such as acetone.

The use of aqueous cleaners, by their nature, involves significant volumes of water as many products are supplied as concentrates to be diluted in water at the time of use. Although there may be isolated cases where waste water is collected for disposal as chemical waste, it is assumed that there is 100 per cent loss of the aqueous cleaning products to waste water discharge. Although the detergents themselves may meet biodegradation criteria, waste effluent will contain emulsified or suspended material that has been removed during the cleaning process.

A small proportion of the surface active agents may remain on the cleaned surfaces, but this will be negligible and is not considered further – any such residues are likely to either degrade completely during the life-time or disposal of the electronic component, or be removed in subsequent washing stages.

Solvents (including organic solvent-based cleaners)

Solvents as a class of substances are used as carriers and cleaners in a wide range of applications in the electronics industry, with functions that are comparable with uses in other industries. Solvents such as xylene are used as a diluent and viscosity reducer, for example in solder flux, in the same way that they will be used in paints, sealants or other applications.

Proprietary formulations will include mixtures with other solvents such as ethanol, iso-propyl alcohol, or methanol. Such preparations will typically contain polar, water-soluble and volatile components. Blending with other solvents will be under ambient conditions with precautions in place in consideration of possible flammability and atmospheric concentration limits. Equipment would not typically require washing with water after use and there is considered to be a low risk of loss to waste water from formulation activities. Similar solvent preparation may be used in other sectors of industry as cleaning agents or thinners (paints and other surface coatings).

Solvent cleaning of printed circuit boards (PCBs) or other components involves spraying or dipping the components in the solvent to remove residues of flux, grease or other contaminants or for removing photoresist layers. The choice of solvent will depend on the required polarity or volatility.

The use of solvents is regulated by Directive 99/13/EC on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations.

Waste solvents are either disposed as hazardous waste or will be lost in use to the atmosphere. There is not considered to be residual solvent remaining on components after assembly.

3.8.3.1.2 Release scenarios for cleaning processes: aqueous and non-aqueous preparations

Aqueous preparations

Water-based cleaning with detergents, or water rinsing, takes place at the early stages of component manufacture. Due to the nature of water washing, large volumes of water may be involved and it is assumed that a high proportion will be discharged as waste water.

Many cleaning agents may themselves be subject to the Detergents Regulation (648/2004) and the biodegradation thresholds are a key factor in any risk assessment being carried out.

Type of waste will be liquid at both large and small scale installations (water-soluble aqueous waste with emulsified or suspended non-water-soluble materials that have been cleaned from components). This would pass to waste water from small scale operations and from larger sites with no specialist disposal methods, and will be discharged to either municipal or on-site waste water treatment plants.

Non-aqueous preparations

Solvent washing may take place at various stages of processing to remove non-water-soluble contaminants or residues, including later stages of assembly when use of water is not appropriate. Solvents are used to remove residues, for example of photoresists and flux, and although most solvent waste will be collected for disposal, some may evaporate from the surface of cleaned components or equipment or be rinsed to waste water.

The route and quantity of emission is proportional to the water solubility and vapour pressure of the solvent cleaners.

Table 3.63 Release table for cleaning of components: aqueous and non-aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/pa	> 1000 kg/pa	Aqueous preparations: Quantity of active detergent component and not water. Non-aqueous preparations: Quantity of solvent.
Days in use	250	300	Most processes are continuous and not based on campaigns.
Releases information			For non-aqueous preparations: Proportion lost to air, water and soil is variable and dependent upon chemical properties. Refer to TGD Table A4.1, cleaning products UC48 (solvents).
% to air	0%	0%	For aqueous preparations only.
% to waste water	100%	100%	For aqueous preparations only (TGD Table A4.1, cleaning products UC10).

Table 3.64 Extract from TGD A-tables

The following data are taken from TGD Table A4.1, cleaning products UC48 (solvents).

Vapour pressure Pa	Water solubility mg/l	% emission to air	% emission to waste water	% emission to soil
< 100 Pa	< 10 mg/l	1.5%	10%	20%
100 - 1000	“	15%	10%	20%
1000 – 10 0000	“	40%	10%	20%
> 10 000	“	60%	10%	20%
< 100 Pa	10 – 100 mg/l	7.5%	20%	10%
100 - 1000	“	12.5%	20%	10%
1000 – 10 0000	“	25%	20%	10%
> 10 000	“	40%	20%	10%
< 100 Pa	100 – 1000 mg/l	2.5%	40%	5%
100 - 1000		10%	40%	5%
1000 – 10 0000		15%	40%	5%
> 10 000		22.5%	40%	5%
< 100 Pa	> 1000 mg/l	3%	60%	0.5%
100 - 1000		7.5%	60%	0.5%
1000 – 10 0000		12.5%	60%	0.5%
> 10 000		17.5%	60%	0.5%

3.9 Photolithography

3.9.1 Summary

Photolithography is a photochemical process used to imprint a pattern onto a metal surface by exposure of photosensitive materials (photoresists) to a pattern of light. The pattern, in the shape of the desired electrical circuit, is created by use of a template (mask). After exposure to light, certain areas of the metal surface are protected from chemical etching. Photolithography processes are used in the manufacture of printed circuit boards, semiconductors and cathode ray tubes. Photoresists used in semiconductor manufacture are covered in an existing OECD Emission Scenario Document (OECD, 2004b).

A thin layer of photoresist is deposited onto the surface of the laminate or other substrate by using a variety of techniques such as spin-coating, spray, rollers or application of a polymeric film. This can lead to significant quantities of photoresist not reaching the target surface.

A glass or plastic film mask is created with the required pattern. The pattern is created using computer aided design (CAD) and printed onto a transparent plastic film template. Durable glass or quartz plates can be prepared for multiple uses and are prepared by coating them in photosensitive compounds (including chromium compounds), then exposing them to UV light through the printed plastic template to fix the pattern. Alternatively, the pattern may be created using electron beams or lasers directly to quartz plates to give a high definition photomask for use in microscopic semiconductor circuitry. The quantities of chemical used in the creation of quartz plates is in gram quantities and are not considered further.

Table 3.65 Summary of processes relevant to photolithography

Life cycle stage	Description	Loss mechanisms
Preparation of photoresist	Chemical formulation of photoactive substances in solvents. Production of polymeric films.	See 3.9.4.1 (formulation).
Application of liquid photoresist	Spin coating or spraying of solvent preparations of photoresists to surface to be etched. Spraying, roller coating.	See 3.9.4.2 (chemical handling by user). Spin coating and spraying will lead to loss of materials not reaching target surface and evaporation of solvents. Cleaning of equipment with solvent cleaners. See 3.9.4.3 (cleaning).
Application of photoresist film	Cutting and placement of plasticised photoresist film on to surface to be etched.	Excess unused film disposed as solid waste.
Exposure to light source	Exposure to UV-light or other radiation to react positive or negative photoresist. Use of polymeric (plastic) template to create pattern.	Photoresist and other reactive components will lose their identity. No direct loss mechanism. Templates typically re-used a number of times, before disposal as non-hazardous solid waste.
Developing / removal in etching	Developing process (if used) involves removal of water-soluble photoresist (reacted or un-reacted depending on whether positive or negative system used) to prepare the surface for etching. Etching process removes remaining water-soluble residues.	Aqueous waste discharged from site together with etching and cleaning waste.
Cleaning	Non-water-soluble residues (reacted or un-reacted photoresist) removed by solvent cleaning. (Not always performed).	Solvent waste collected for disposal as chemical waste.

Due to the scale of the process, the light can be projected through lenses so that the template can be somewhat larger than the final pattern being made on the component to be etched.

Photoresists may be ‘positive’ or ‘negative’. A ‘positive’ photoresist substance is made more soluble in a given solvent following exposure, whereas a ‘negative’ photoresist is made less soluble by irradiation (due to polymerisation, for example). After the substrate has been irradiated, the pattern is ‘developed’ using the appropriate developer.

Developing (preparation of the surface to be etched) may be carried out using dip, immersion or spray techniques. For positive photoresists, the developer removes the exposed substance, while for negative photoresists, the developer removes the substance that was protected by the mask, or that was not exposed.

Chemical etching is then used to remove the surface layer not protected by photoresist and to create depressions on the surface. In PCB manufacture, the 'developing' stage may be omitted and the water-soluble photoresist fractions removed in the etching process itself.

After etching, there may be a cleaning stage using organic solvents, using proprietary blends of acetone, ethanol, isopropyl alcohol or methanol. Cleaning is not always conducted and the non-water-soluble fractions of photoresist may remain on the component.

For semiconductor etching, positive or negative photoresist films are deposited on the wafers and although the same types of product are used in PCB and semiconductor photolithography, the scale of the process is different.

3.9.2 Substances relevant to photolithography processes

3.9.2.1 Atmospheric gases

Atmospheric gases are defined as naturally occurring gaseous substances isolated from the atmosphere. Examples in the electronics industry include nitrogen as an inert carrier, a cooling medium (liquid form), or to provide an oxygen-free atmosphere for manufacture. Similarly, argon is used as an inert carrier for plasma process and sputtering in semiconductor manufacture. Carbon dioxide, in its solid form, has applications for abrasive cleaning of silicon wafers at very low temperatures.

Gases are supplied as pressurised liquids in the same manner as supplied to other industry sectors. It can be considered that use will result in the gases returning to the atmosphere with 100 per cent loss. There will be exceptions, such as the use of oxygen as an oxidising agent, that will lead to the formation of oxidised forms of the material being processed.

Neon and xenon gases are also used in plasma screen technology, which is discussed briefly in Section 2.7.3 on Displays.

Gases are not considered in Release Scenarios and Tables. It is assumed that there is 100 per cent loss to the atmosphere.

3.9.2.2 Inorganic salts

This category covers the generic group of inorganic salts that are used in a wide range of applications and not just etching (see Section 3.6) or plating (Sections 3.4-3.5). Inorganic salts will be supplied as solids or aqueous solutions and handled in aqueous 'wet-chemistry' systems with water washing of components after processing. The chemistry processes will not necessarily be unique to the electronics industry and may have more in common with metalworking or engineering applications.

Supply of inorganic metal salts for the electronics industry will be in relatively low quantities when compared with other industries, but use rates are still higher than for many other types of chemical. In some cases, the metal salts may be hazardous (such as cadmium) and may be subject to additional regulatory controls.

For electroless and electroplating, the metals are deposited on the component being produced and will form part of the final electronic article (although some may be removed in subsequent etching processes). There will be no release during service life, but the metals may be recovered at the end of life. Metals such as cadmium and lead will need particular attention at the end of life stage.

Waste from industrial processes is generated in the form of aqueous solutions (such as spent liquor, washings, and run-off) and solid waste (non-water-soluble sludge from tanks). Some of the solid waste will have a recovery value, but it is not generally economical to reprocess copper and tin salts, as recovery techniques from these salts are expensive. Most solid salts, especially from smaller organisations, will be disposed of as chemical waste to landfill or cement block production. Aqueous waste is discharged to waste water, with discharge consents based on pH and specific metal content.

Inorganic salts can be generated as a by-product of the etching process, and some can be used as etchants (see also Section 3.6).

3.9.2.3 Photoresists

An ESD already exists covering the use of Photoresists in the manufacture of semiconductors (OECD, 2004b).

The existing ESD is aimed at the use of photoresists in the manufacture of micro-electronic components and does not cover the use of photoresists in other applications in the industry, such as the manufacture of PCBs. The principles of use are similar in the different applications, but the exposure scenarios reflect the scale of operation in semiconductor and PBC manufacture. There is also a difference in the application method – in semiconductor manufacture, photoresist may be ‘spun’ coated onto the silicon wafers, but in PCB manufacture, application may be as a solvent-based spray or as a film. Pre-treated laminates, coated with photoresist, are also available.

Two types of photoresist are used and are classified according to how the chemical responds to light (typically UV-radiation); these are termed ‘positive’ or ‘negative’.

Positive photoresists are made more soluble upon exposure to radiation and the pattern of light maps out the area to be etched - the soluble ‘exposed’ photoresist is removed by washing or during the etching process exposing the areas of metal coating on the laminate to be removed. These photoresists will include photosensitive compounds embedded within polymeric films or resins, applied in solvent-based coatings or as plasticised films.

Negative photoresists are chemicals that polymerise into less soluble films or coating after exposure and the pattern of light used during exposure maps out the area that does not need to be removed during the etching process. As with positive photoresists, a variety of photosensitive substance is used, as well as inert substances, such as solvents, viscosity control agents, and pigments.

Irrespective on whether positive or negative photoresist products have been used, both photo-reacted and un-reacted photoresist will be present on the PCB immediately after exposure to light and developing. Depending on the system used, the reacted or un-reacted photoresist will be washed off the component before or during etching and will be lost to waste water with etchants and dissolved metal (see Section 3.6 on Etching).

Remaining etch-resistant photoresist may remain on the component as a hardened coating, but with certain production processes, this too may be removed with suitable solvent cleaners; waste solvent from cleaning is collected for recovery or as disposed as chemical waste.

3.9.2.4 Solvents (including organic solvent-based cleaners)

Solvents as a class of substances are used as carriers and cleaners in a wide range of applications in the electronics industry, with functions that are comparable with uses in other industries. Solvents such as xylene are used as a diluent and viscosity reducer, for example in solder flux, in the same way that they will be used in paints, sealants or other applications.

Proprietary formulations will include mixtures with other solvents such as ethanol, iso-propyl alcohol, or methanol. Such preparations will contain polar water-soluble and volatile components. Blending with other solvents will be under ambient conditions with precautions in place in consideration of possible flammability and atmospheric concentration limits. Equipment would not require washing with water after use and there is considered to be a low risk of loss to waste water from formulation activities. Similar solvent preparation may be used in other sectors of industry as cleaning agents or thinners (paints and other surface coatings).

Solvent cleaning of printed circuit boards (PCBs) or other components involves spraying or dipping the components in the solvent to remove residues of flux, grease or other contaminants or for removing photoresist layers. The choice of solvent will depend on the required polarity or volatility.

The use of solvents is regulated by Directive 99/13/EC on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations.

Waste solvents are either disposed as hazardous waste or will be lost in use to the atmosphere. There is not considered to be residual solvents remaining on components after assembly.

3.9.3 Release scenarios for photolithography and spin coating processes

3.9.3.1 Release scenario for photolithography: inorganic and organic solids and aqueous and non-aqueous preparations

For photolithography in semiconductor manufacture, refer to the ESD on Photoresists (OECD, 2004b).

Photolithography needs to consider the photo-reacted and un-reacted components of the photoresists used. Depending on whether the photoresists are ‘positive’ or ‘negative’, either the photoresist itself or the reacted product will be water-soluble and washed off prior to or during etching. The remaining material will stay on the printed circuit board (PCB) or other component or, exceptionally, will be washed off with appropriate solvent cleaners.

Inorganic solids

Application to the component to be processed is achieved by dissolving the photoresist in water and spraying or immersing the component.

It can be assumed that approximately 50 per cent of photoresist (reacted or un-reacted) applied to the PCB will be washed off in aqueous systems.

Organic solids

Application to the component to be processed is achieved by dissolving the photoresist in solvent or water and spraying, spin coating or immersing the component to be treated. Photoresist film may be applied directly to the components and perhaps heated gently to ensure that the film adheres to the component.

It can be assumed that approximately 50 per cent of photoresist (reacted or un-reacted) applied to the PCB will be washed off in aqueous systems and the remaining organic materials may be washed off as solvent solution. This estimate is based on an understanding of the process: the areas of the PCB exposed during the mapping process are approximately 50 per cent – that is, half the surface area conducting, and half not conducting.

Table 3.66 Release scenario for photolithography: inorganic and organic solids and aqueous and non-aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/y	> 1000 kg/y	Volume relates to quantity of photoresist used.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air	0%	0%	Photoresist materials typically non-volatile. Solvent cleaners discussed in Section 3.9.4.3.
% to waste water	50%	50%	Based on aqueous washing or during etching process.

Total loss (wastage) from the process is estimated to be typically 50 per cent based on 50 per cent photo-reaction. Liquid wastes (liquid washings; aqueous or solvents) are to be expected. Aqueous wastes would pass to waste water. Solvent-based wastes (including some wastes from processes using organic solids and non-aqueous preparations) would be collected for chemical waste disposal at both small- and large-scale sites. Some larger scale users have on-site waste water treatment but at small-scale sites this would not be expected.

No release to waste solid (process sludges or solids from settled waste water) is estimated.

3.9.4 Associated processes

3.9.4.1 Chemical formulation

Table 3.67 Summary of processes relevant to chemical formulation

Life cycle stage	Description	Loss mechanisms
Formulation	Mixing of substances to produce a preparation. There is often more than one formulation stage.	Surface contamination and emission to drain or ventilation resulting from leakage and spillage (not major accidents) or deliberate release. Liquid and solid wastes, emissions to drain or wastewater treatment plant arising from washing or servicing chemical plant areas and equipment. Disposal of container washings to drain or wastewater treatment plant. Disposal of used containers. Disposal of off-specification product.

The processes used to mix substances to make chemical products for supply to the electronics industry do not involve processing techniques that are unique or specific to this industry. Similar processes for manufacturing or preparing chemical products for supply are used in a wide range of industry sectors. Indeed, it is noted that many chemical products used by the electronics industry are purchased from suppliers who also supply other sectors.

The only significant difference in the supply to the electronics industry, when compared with some other industry sectors, appears to be scale of use – supply of chemicals in containers greater than 25 litres or kilograms is unusual. There is perhaps also a greater degree of manual handling involved in the small-scale use of chemicals when compared with larger chemical users and small pack sizes are normal.

With the exception of certain highly specialised deposition chemicals (dopants) in the semiconductor manufacturing process (such as organo-metals), there are not many chemical substances used exclusively in the electronics industry. However, some of the handling and exposure scenarios may be unique to the industry and must be considered in detail.

3.9.4.1.1 Release scenarios for Formulation processes

Release scenario for chemical formulation; inorganic and organic solids

Preparation of organic materials for supply includes blending and drying processes for solids. The TGD Industry Category (IC) 2 General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenarios, with Table A2.1 being used as a basis for these estimates.

Inorganic solids

Poorly water-soluble solid waste is expected to be removed during initial settling from waste water, leading to a low level of entry to sludge and subsequent application to agricultural soil. Water-soluble waste will either remain in solution and be discharged (for example nitrates or sulfates), or in some cases (such as certain metal ions such as copper or tin) will adsorb onto sludge. The proportions reaching water or soil must be estimated in accordance with the known properties of the solid.

Organic solids

This category is also used to cover handling of polymeric materials such as films (but not production of polymers, which are outside the scope of this ESD).

Poorly water-soluble solid waste is expected to be removed during initial settling from waste water, leading to a low level of entry to sludge and subsequent application to agricultural soil. However, water-soluble waste will either biodegrade or remain in solution and be discharged. Biodegradability should be considered when preparing a risk assessment for organic solids.

Table 3.68 Release Scenario for chemical formulation; inorganic and organic solids

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	30	50	Production campaigns may be used for formulating.
% to air, vp < 100 Pa and	0%	0%	Dust will be trapped in filter systems[1].

Description	Small scale	Large scale	Comments
for all inorganic solids			
% to air, vp > 100 Pa for organic solids	1%	1%	Estimate based on TGD Table A2.1.
% to waste water	2%	2%[2]	Estimate based on TGD Table A2.1.

Note

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control.

2. At greater than 1,000t/y formulated product a more typical loss rate would be 0.3 per cent (estimate based on TGD Table A2.1).

Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Solid and liquid wastes are to be expected (solid residues from formulation removed when cleaning equipment, and water or solvent washings from the process). These wastes pass to landfill or waste water from small-scale sites. If solvent cleaners are used, waste may be collected. From large-scale sites the wastes may pass to waste water, recovery, chemical waste or landfill. Larger scale formulators may have waste disposal and treatment procedures in place.

The amount of waste solid (based on metals/materials adsorbing to process sludges or solids from settled waste water) is estimated to be in the order of 2 per cent at small and large scale sites.

Release scenario for chemical formulation; non-aqueous preparations

Preparation of non-aqueous mixtures for supply, including blending, dilution and packaging processes with solvents and other liquids, and blending of non-aqueous suspensions or pastes (such as solder paste). Particular attention should be given to volatile components (such as solvents), though other properties are of course more generally relevant to risk assessment.

Table 3.69 Release table for chemical formulation; non-aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulation produced.
Days in use	30	50	Production campaigns may be used for formulating.
% to air, vp < 100 Pa	0%	0%	Estimate based on TGD Table A2.1.
% to air, vp 100 - 1000 Pa	1%	1%	Estimate based on TGD Table A2.1.
% to air, vp > 1000 Pa	2.5%	2.5%	Estimate based on TGD Table A2.1.
% to waste water, sol. > 1 mg/l	2%	2%[1]	Estimate based on TGD Table A2.1.

1. At greater than 1,000t/y formulated product a more typical loss rate would be 0.3 per cent (estimate based on TGD Table A2.1).

Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Solid and liquid wastes are to be expected (solid residues from formulation removed when cleaning equipment, and water or solvent washings from the process). These wastes pass to landfill or waste water from small-scale sites. If solvent cleaners are used, waste may be collected. From large-scale sites the wastes may pass to waste water, recovery, chemical waste or landfill. Larger scale formulators may have waste disposal and treatment procedures in place.

The amount of waste solid (based on materials of solubility <1 mg/l adsorbing to process sludges or solids from settled waste water) is estimated to be in the order of 2 per cent at small and large scale sites.

3.9.4.2 Chemical handling by the user

Table 3.70 Summary of processes relevant to chemical handling

Life cycle stage	Description	Loss mechanisms
Storage and handling	Storage of substances and preparations prior to use. Transfer of substances and preparations into different containers. Dilution and mixing of substances and preparations at the point of use.	Surface contamination and emission to drain or ventilation resulting from leakage and spillage (not major accidents) or deliberate release. Disposal of container washings to drain or wastewater treatment plant. Disposal of used containers. Disposal of old material or products not meeting quality specifications.
Use	Application of substance or preparation to substrate or surface to be worked on. Cleaning or servicing of equipment after use.	Surface contamination and emission to drain or ventilation resulting from spillage or deliberate release. Liquid and solid wastes and emissions to drain or wastewater treatment plant arising from washing or servicing chemical plant areas and equipment.

The use of chemicals in the electronics industry is very often on a small scale when compared with other industry sectors, with a high reliance on manual handling and the subsequent use of small containers. Chemical suppliers re-package bulk products for use by small organisations, and some organisations will themselves decant from larger containers to smaller unit sizes for day-to-day use. This is common in small to medium enterprises.

During manufacturing processes for electronic components, the focus will be on the quality of the products being produced, with engineering designed to ensure quality of final products that may themselves be of high unit value. Less attention may be given to efficiency in the use of chemicals that, in some processes, may be a relatively low-cost element. This is particularly true for etching and cleaning processes, but conversely, certain fine chemicals and ultra-pure materials used in semiconductor manufacture will be very expensive, thus their price will ensure careful handling.

The Electronics section of the Environment Agency NetRegs website (Environment Agency, 2005) makes recommendations to some areas of industry relevant to electronics manufacturing, with regard to prevention of pollution. The guidance is aimed at small and medium-sized enterprises (SMEs) not subject to IPPC/LAAPC. Mandatory requirements for handling and storage of chemicals include the following, for sites manufacturing CDs/DVDs:

- Contain any spilled chemicals to prevent them entering surface water drains, ditches, watercourses or soakaways. Do not hose spillages down drains.

- Regularly check pipe work for leaks. If leaks are identified, ensure that maintenance work is undertaken immediately and the extent and impact of any contamination assessed and cleaned up.

For sites manufacturing printed circuit boards, there are no mandatory requirements, but the following guidelines are included:

- Store all chemical barrels in a secure location which cannot leak. The base of these areas should be chemical resistant and must have secondary containment such as a bund or a drip tray of adequate size.
- Make sure that all unloading areas are away from storm drains and are hard surfaced to prevent water or ground contamination if there is a spill. If this is not possible, make sure that the drains are protected during delivery (for example by using suitably sized and correctly fitted drain covers).
- Storage areas and drip trays should drain to the plant's wastewater treatment plant, as long as the plant can process these wastes. On no account should these be permitted to drain to the storm system.
- Contain any spilled chemicals to prevent them entering surface water drains, ditches, watercourses or soakaways. Do not hose spillages down drains.

These guidelines have been prepared by industry for industry and take into consideration that the primary activities in most cases are the design, manufacture and assembly of electronic components and the sites are not regarded as chemical production or formulating plants.

3.9.4.2.1 Release scenarios for handling processes

Release scenario for handling by the user: inorganic and organic solids

Inorganic solids

Handling of inorganic solids by the user includes direct addition to production process or on-site dilution prior to use, disposal of packaging and servicing equipment that may contain dried residues of solids.

The TGD Industry Category (IC) 2: General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenario, with Table A2.1 being used as a basis for these estimates. Poorly-soluble solid waste is expected to be removed during initial settling from waste water, leading to a low level of entry to sludge and subsequent application to agricultural soil. Water-soluble waste will either remain in solution and be discharged (for example nitrates or sulfates), or in some cases (for example certain metal ions such as copper or tin) will adsorb onto sludge. The proportions reaching water or soil must be estimated in accordance with the known properties of the solid.

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). The type of waste will be solid and liquid at both large and small scale installations (solid waste and washings from process). These wastes (including solid residues from formulation removed when cleaning equipment) would go to waste water or landfill from small scale operations (no specialist disposal methods) and to waste water, recovery, chemical waste or landfill from larger sites (specialist disposal methods). Larger scale formulators may have waste disposal and treatment procedures in place.

The amount of waste solid is estimated (on the basis of metals/materials adsorbing to process sludges or solids from settled waste water) to be in the order of 2 per cent at small and large scale sites.

Organic solids

Handling of organic solids by the user includes direct addition to production process or on-site dilution prior to use, disposal of packaging and servicing equipment. This category is also used to cover handling of polymeric materials such as films.

The TGD Industry Category (IC) 2: General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenario, with Table A2.1 being used as a basis for these estimates. Poorly-soluble solid waste is expected to be removed during initial settling from waste water, leading to a low level of entry to sludge and subsequent application to agricultural soil. However, water-soluble waste will either biodegrade or remain in solution and be discharged. Biodegradability should be considered when preparing a risk assessment for organic solids.

Other information: as for inorganic solids. If solvent cleaners are used, waste may be collected. Releases to waste solids include substances of water solubility <1 mg/l.

Table 3.71 Release table for handling by the user: inorganic and organic solids

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air, vp < 100 Pa and all inorganic solids	0%	0%	Dust will be trapped in filter systems[1].
% to air, vp > 100 Pa	1%	1%	For organic solids only: Estimate based on TGD Table A2.1.
% to waste water	2%	2%	Estimate based on TGD Table A2.1.

Note

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control.

Release scenario for handling by the user; non-aqueous liquids

Handling of non-aqueous liquid substance and preparations by the user includes direct addition to production process or on-site decanting to smaller container prior to use, disposal of packaging and servicing equipment. Particular attention should be given to volatile components (such as solvents).

Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Solid and liquid wastes are to be expected at both large and small scale installations (solid waste and water or solvent washings from process). These wastes (including solid residues from formulation removed when cleaning equipment) would go to waste water or landfill from small scale operations. If solvent cleaners are used, waste may be collected. Wastes would pass to waste water, recovery, chemical waste or landfill from larger sites. Larger scale formulators may have waste disposal and treatment procedures in place.

The amount of waste solid (based on materials of solubility <1 mg/l adsorbing to process sludges or solids from settled waste water) is estimated to be in the order of 2 per cent at small and large scale sites.

Table 3.72 Release table for handling by the user; non-aqueous liquids

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated matter produced.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air, vp < 100 Pa	0%	0%	Dust will be trapped in filter systems[1].
% to air, vp 100 - 1000 Pa	1%	1%	Estimate based on TGD Table A2.1.
% to air, vp > 1000 Pa	2.5%	2.5%	Estimate based on TGD Table A2.1.
% to waste water, sol. > 1 mg/l	2%	2%	Estimate based on TGD Table A2.1.

Note

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control.

3.9.4.3 Cleaning of components and equipment

3.9.4.3.1 Summary

Water rinsing, where it is an integral stage of other industrial processes, is considered as part of those processes. This section considers only cleaning using cleaning chemicals, such as detergents or solvents.

Table 3.73 Summary of processes relevant to cleaning

Life cycle stage	Description	Loss mechanisms
Aqueous cleaning	Immersion or spraying of components in dilute aqueous preparations of detergents. Cleaning of equipment with water-based detergents. Water based cleaning is not suitable for many electronic components due to sensitivity to water.	Considered to be 100 per cent loss of detergents to waste water. There may be some carry-over onto finished components, but this is not considered significant. Waste water will include the materials being washed off components, such as oils, greases, flux residues, metal salts and so on. Note applicability of Detergents Regulation EC 648/2004 ensuring minimum standards of biodegradability for surface active components – this does not mitigate loss, but ensures that residues in effluent will not accumulate.
Solvent cleaning	Immersion or spraying of components in dilute solvents or solvent preparations. Most use is where non-water-soluble materials are to be removed (such as photoresist, films and so on), where there is sensitivity to water (for example in final stages of PCB manufacture) or where quick drying is required.	Loss to atmosphere of volatile solvents (such as acetone, isopropyl alcohol, esters and so on) or as solvent waste for disposal. Some loss expected to waste water.

The amount of cleaning appears to vary within the electronics industry, with some component suppliers conducting very little cleaning and others cleaning all components at every stage. Cleaning adds costs to the process and the amount of cleaning may reflect the final value of the end products. Examples where no cleaning takes place may include components for toys or household appliances and examples of cleaning will be for aerospace or defence industries.

Water is used for early stages of cleaning, either with or without surface-active agents (detergents). Large quantities of water are consumed in preparing silicon wafers and other substrates such as glass and ceramics. Rinsing after electroless plating, electroplating and etching is essential to remove potentially corrosive or otherwise detrimental chemical residues.

Equipment is often cleaned with water-based detergents as part of servicing and maintenance procedures.

Solvent cleaners tend to be used in the later stages of production, with the use of volatile substances such as acetone or alcohols, either as neat substances or as a component of aqueous solutions (or less commonly, with wetting agents). The use of specific types of solvents will be determined by the material to be removed, the rate of drying and suitability for not damaging the component being cleaned.

Cleaners (aqueous)

Aqueous and non-aqueous cleaning products are used in various stages of electronic component manufacture.

Examples of aqueous cleaners include dilute preparations of surface active agents (such as alkyl ethoxylates) and these will themselves be subject to the Detergents Regulation (648/2004) that imposes a minimum standard of biodegradation; those failing the prescribed rate of biodegradation can be placed on the market for specialist uses subject to a risk assessment – specialist use in the electronics industry could be examples where derogations are granted.

Many of the cleaning preparations marketed for the electronics sector will mirror formulations used in other industry sectors such as domestic applications, metalworking, and the motor industry.

Formulation of such cleaners will be through mixing at ambient or slightly elevated temperatures using processes common to the detergent and cleaning industry sector. Supply takes place in small containers of less than 25 kg, with many suppliers offering containers of one litre or less.

The level of component and surface cleaning in the industry is variable, with the highest level of cleaning found in the production of high-value products for the aerospace and defence industries.

The use of ‘clean-room’ processes for semiconductor and other precision components should not be confused by the use of cleaning products. Clean room processes describe the barrier methods used to prevent chemical contamination of micro-electronic components and not the cleaning processes employed during manufacture. Many cleaning products can themselves be considered as potential contaminants in the precision processes that require clean-room technology, and surface-active materials could interfere with subsequent processing of the electronic components. Exceptions to this are purified water and high-quality grade volatile solvents such as acetone.

The use of aqueous cleaners, by their nature, usually involves significant volumes of water as more products are supplied as concentrates to be diluted in water at the time of use. Although there may be isolated cases where waste water is collected for disposal as chemical waste, it is assumed that there is 100 per cent loss of the aqueous cleaning products to waste water discharge. Although the detergents themselves may meet biodegradation criteria, waste effluent will contain emulsified or suspended material that has been removed during the cleaning process.

A small proportion of the surface active agents may remain on the cleaned surfaces, but this will be negligible and is not considered further – any such residues are likely to either ultimately degrade during the life-time or disposal of the electronic component, or be removed in subsequent washing stages.

Solvents (including organic solvent-based cleaners)

Solvents as a class of substances are used as carriers and cleaners in a wide range of applications in the electronics industry, with functions that are comparable with uses in other industries. Solvents such as xylene are used as a diluent and viscosity reducer, in solder flux for example, in the same way that they will be used in paints, sealants or other applications.

Proprietary formulations will include mixtures with other solvents such as ethanol, iso-propyl alcohol, or methanol. Such preparations will contain polar water-soluble and volatile components. Blending with other solvents will be under ambient conditions with precautions in place in consideration of possible flammability and atmospheric concentration limits. Equipment would not require washing with water after use and there is considered to be a low risk of loss to waste water from formulation activities. Similar solvent preparation may be used in other sectors of industry as cleaning agents or thinners (paints and other surface coatings).

Solvent cleaning of printed circuit boards (PCBs) or other components involves spraying or dipping the components in the solvent to remove residues of flux, grease or other contaminants or for removing photoresist layers. The choice of solvent will depend on the required polarity or volatility.

The use of solvents is regulated by Directive 99/13/EC on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations.

Waste solvents are either disposed as hazardous waste or will be lost in use to the atmosphere. There is not considered to be residual solvents remaining on components after assembly.

3.9.4.3.2 Release scenarios for cleaning processes: aqueous and non-aqueous preparations

Aqueous preparations

Water-based cleaning with detergents, or water rinsing, takes place at the early stages of component manufacture. Due to the nature of water washing, large volumes of water may be involved and it is assumed that a high proportion will be discharged as waste water.

Many cleaning agents may themselves be subject to the Detergents Regulation (648/2004) and the biodegradation thresholds are a key factor in any risk assessment being carried out.

Type of waste will be liquid at both large and small scale installations (water-soluble aqueous waste with emulsified or suspended non-water-soluble materials that have been cleaned from components). This would pass to waste water from small scale operations and from larger sites with no specialist disposal methods, and will be discharged to either municipal or on-site waste water treatment plants.

Non-aqueous preparations

Solvent washing may take place at various stages of processing to remove non-water-soluble contaminants or residues, including later stages of assembly when use of water is not appropriate. Solvents are used to remove residues, for example, of photoresists and flux, and although most solvent waste will be collected for disposal, some may evaporate from the surface of cleaned components or equipment or be rinsed to waste water.

The route and quantity of emission is proportional to the water solubility and vapour pressure of the solvent cleaners.

Table 3.74 Release table for cleaning of components: aqueous and non-aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/pa	> 1000 kg/pa	Aqueous preparations: Quantity of active detergent component and not water. Non-aqueous preparations: Quantity of solvent.
Days in use	250	300	Most processes are continuous and not based on campaigns.
Releases information			For non-aqueous preparations: Proportion lost to air, water and soil is variable and dependent upon chemical properties. Refer to TGD Table A4.1, cleaning products UC48 (solvents).
% to air	0%	0%	For aqueous preparations only.
% to waste water	100%	100%	For aqueous preparations only (TGD Table A4.1, cleaning products UC10).

Table 3.75 Extract from TGD A-tables

The following data are taken from TGD Table A4.1, cleaning products UC48 (solvents).

Vapour pressure Pa	Water solubility mg/l	% emission to air	% emission to waste water	% emission to soil
< 100 Pa	< 10 mg/l	1.5%	10%	20%
100 - 1000	“	15%	10%	20%
1000 – 10 0000	“	40%	10%	20%
> 10 000	“	60%	10%	20%
< 100 Pa	10 – 100 mg/l	7.5%	20%	10%
100 - 1000	“	12.5%	20%	10%
1000 – 10 0000	“	25%	20%	10%
> 10 000	“	40%	20%	10%
< 100 Pa	100 – 1000 mg/l	2.5%	40%	5%

Vapour pressure Pa	Water solubility mg/l	% emission to air	% emission to waste water	% emission to soil
100 - 1000		10%	40%	5%
1000 – 10 0000		15%	40%	5%
> 10 000		22.5%	40%	5%
< 100 Pa	> 1000 mg/l	3%	60%	0.5%
100 - 1000		7.5%	60%	0.5%
1000 – 10 0000		12.5%	60%	0.5%
> 10 000		17.5%	60%	0.5%

3.10 Soldering

3.10.1 Summary

Soldering is considered to be a distinct process used in the electronics industry to attach components to printed circuit boards. Solder itself is a metal alloy, usually predominantly tin, mixed with lead or, more recently, other metals such as silver (lead-free solder). In addition, flux and cleaning agents (both organic solvents and aqueous-based cleaners) are used in the soldering process. Flux is used to clean surfaces and remove oxides before soldering as well as to prevent oxidation during the soldering process, to ensure that secure joints are obtained. It is composed of rosin with wetting agents, viscosity adjusters, organic acids and halides in preparations up to five per cent in water or isopropyl alcohol. Rosin-free preparations are also available, although these are less common.

A number of different soldering techniques may be used, such as wave, dip or drag soldering and use of solder pastes.

The ‘traditional’ spot soldering method, often using solder wire, uses a small amount of alloy placed on the parts to be joined with heat applied directly to that position. The method of applying solder to specific connections is common in all sectors of industry, including automotive, aerospace, and toys and uses similar technology as methods used in plumbing. Since these are assembly processes, they are not considered further in this ESD. In the UK electronics industry wave soldering and solder pastes are most common, and these processes are described in more detail.

Table 3.76 Summary of processes relevant to soldering

Life cycle stage	Description	Loss mechanisms
Application to printed circuit board (PCB)	Wave soldering	Carry over of solder after application to PCB. High rate of loss reported, but most recovered on-site and re-introduced to solder tank.
	Solder paste	Unused material on equipment and in opened containers (short-shelf life once opened due to solvent evaporating and paste drying).
	Hot air solder levelling (HASL)	Low level of waste as excess solder blown off bank into immersion tank.
Component Assembly	Use of solder wire, spot	Small sections of wire or dripped solid waste.

Life cycle stage	Description	Loss mechanisms
	soldering	
Recovery		Some on-site recovery of solder. End-of-life recovery from electronic equipment to recover metals. Lead-free solder with significant levels of silver present has the greatest value. See Section 3.13 (Recovery).

Wave soldering

Wave soldering, using machines that apply molten solder to all connections on a circuit board. This type of solder is typically >95 per cent tin, with small amounts of silver, copper and other speciality metals in low concentrations. Solder is supplied as metal ingots, although up to 5 per cent rosin flux may be included within the solder.

The printed circuit assembly (that is, the PCB and components) is passed over the crest of a wave of molten solder (US EPA, 1995), which adheres to the copper wiring or other metal parts to be joined. The unit is then heated and excess solder is scraped off after cooling. Only a small amount of solder is removed as waste.

Components are sometimes washed in alcohol after manufacture to remove excess flux and combustion products. This washing does not remove metal.

Solder pastes

Solder paste is produced by atomising solder alloy and combining in a paste with flux and a suitable solvent. The paste may contain 70 – 80 per cent solder (>95 per cent of which is tin and the remainder silver, copper or similar), plus 5 – 10 per cent rosin flux and other wetting agents with viscosity adjusters. Solder paste accounts for about 20 per cent of solder use.

Solder paste ‘screen printing’ systems are used, where solder paste is extruded through holes in a template, placing the sticky paste onto the surface where components are to be placed.

The paste is applied to a metal template and wiped with a rubber blade. Excess paste is kept to a minimum as the device can wipe backwards and forwards, adding a small amount of paste each time. Any paste left at the end of production is collected and taken for recovery – removal is done by hand.

The whole unit is subsequently heated to set the paste and fix the connections in place.

Other soldering techniques

Dip soldering, also referred to as hot air solder levelling (HASL) is commonly used in the manufacture of PCBs. Here, the board or other component is dipped in a tank of molten solder. Excess is removed by blowing off with a hot air “knife”. Cold air processes may also be used.

Recovery

There is significant recovery of used solder by either just re-melting and forming into ingots or other usable physical form, or by separating the metal components of solder through making use of different melting points. There is more commercial interest in recovering used lead-free solder in view of the level of high value metals such as silver. (See Section 3.13 on Recovery).

3.10.2 Substances relevant to soldering

3.10.2.1 Solder

Solder is used to provide an electrically conductive join between electronic components during assembly or to provide pathways for electric current between components.

Solder alloy is made by melting and blending together tin with other metals using processes common to the metal industry. There is close control of exposure to lead fumes to protect health and these controls will also reduce exposure to the higher melting point metals being used. The solder is supplied either as ingots, which are melted during use, as solder paste or solder wire.

Solder paste is an amalgam of solder particles with flux (rosin, organic acids and halides) plus high flash point solvents to control viscosity. Solder paste will contain at least 90 per cent metal, 5 per cent flux (of which <1 per cent is acid or halide), and the remainder solvent. Other speciality chemicals, such as wetting agents may be used, but at <1 per cent by weight of solder.

Solder paste is made by atomising solder alloy into <100 μm particles and blending with flux and high-flash point solvents to modify viscosity.

Solder wire, often with up to 5 per cent flux embedded within it (multi-core), is used mainly for precision joining of individual components.

It is difficult to quantify level of waste from production, but most waste is recycled due to the value of the alloys and starting metals. For example, floor sweepings and dust removed from air extraction filters are collected and returned to the suppliers of metals or for scrap. Water washing systems include a settlement treatment stage that will collect metal solids.

Solder paste manufacturing equipment is washed with the solvent used in the paste and either re-used if 'fresh' or disposed of as hazardous waste. The metal is not always recovered as old waste can contain oxides. The level of solder recovery is currently less clear than for precious metals and other matierials used in circuit boards. Washing of equipment with water or proprietary aqueous cleaners will involve discharge of waste water for treatment or for collection at chemical waste, depending on the level of contamination.

Despite the aqueous washing of equipment, it is considered that the default release rate of 2 per cent is a high figure for loss to waste water treatment or other 'uncontrolled' loss. However, in the absence of quantified reports, the figure of 2 per cent waste is considered to be appropriate.

3.10.2.2 Flux

Flux works by providing better adhesion of solder to metal surfaces, specifically by penetrating and lifting off thin layers of metal oxides on the components being soldered and on the solder surface itself.

Flux preparations

Flux is made by blending rosin acid with proprietary additives at elevated temperatures to reduce viscosity. The flux is dispersed or dissolved in water or alcohol (such as isopropyl alcohol) at ambient or slightly elevated temperatures to make preparations containing typically 2 – 5 per cent rosin. Formulation takes place batch-wise in dedicated vessels. The process is regular throughout the year, although there may be certain changes in the precise formulation details. Equipment is periodically serviced and cleaned with water. If it is not possible to use the water in the next batch, it may be discharged to waste water treatment.

Rosin itself, and some additives (such as inorganic and organic acids, and halides), are potentially hazardous. The finished preparations are classified and labelled accordingly in some cases. Rosin acids are under investigation by the UK HSE with a specific concern about potential sensitisation, and some rosin-free fluxes are on the market, which use other forms of fatty acid. Rosin acid-based flux is subject to a worker exposure limit - WEL - (HSE, 2004), and the use of flux should therefore monitored by users.

The formulation of flux is no different, in terms of potential exposure, to other aqueous mixing and blending processes and the default release rate of 2 per cent to waste water is considered to be an acceptable figure.

Fluid flux preparations are supplied in containers of up to 25 litres.

Solder paste

Solder paste is made by mixing flux with solder metal and high flash point solvents to make solder paste formulations. The paste is dispensed into buckets of up to 25 kg. Smaller containers may also be used, in view of the potential for metal to oxidise or for the solvents to evaporate once the containers have been opened.

Equipment is periodically serviced and cleaned with water. If it is not possible to use the water in the next batch formulated, it may be discharged to waste water treatment. Solvents will be used for cleaning production equipment and solvent waste will be sent for disposal. Metals will usually be recovered by specialist organisations and organic components will be disposed of as chemical waste or possibly incinerated.

Other forms of flux

Flux (rosin acids) is also used by incorporating into multi-core solder (and other compositions) for specialist uses such as assembly of components, and to a lesser degree for the DIY market.

Use of flux

Most use (>90 per cent) is in wave soldering or Hot Air Solder Levelling (HASL) processes.

In wave soldering, the components are sprayed or dipped in the flux solutions, and with HASL, flux is added to the solder bath, forming a layer on the surface that components must pass through. This layer of flux also protects the hot solder from oxidation.

Solder paste, containing a few percent flux, is spread onto screens with holes that allow a small amount of solder to be forced onto a PCB or other components using a rubber blade. The components are then heated to melt the solder/flux mixture allowing the components to be joined to the circuit board when cooled. The flux present will remain on the components, floating to the surface of the solder joints.

With all processes, flux will remain on the components, or perhaps volatilise at the high temperatures of the process, leading to emissions to the local air compartment. In some cases, components are washed with alcohol preparations to remove excess flux before further assembly and the waste liquor, containing flux, will be disposed of as chemical waste or to waste water.

Once components are joined and assembled into products, it is not expected that there will be exposure to flux residues, unless components are removed during servicing or for disassembly at end of life. Soldered articles, used solder and waste solder paste will contain rosin acids and this may remain in waste from metal recovery processes at end-of-life recovery.

3.10.3 Release scenarios for soldering processes

3.10.3.1 Release scenario for soldering: metals

Soldering involves the use of specific alloys that are melted, applied to the target surface and allowed to cool and solidify. Most soldering methods result in a significant level of waste, but solder can be easily recovered and either re-used *in situ*, or sent for recovery at specialist organisations.

Waste solder not sent for recovery is disposed of as scrap metal waste or as low-hazard solid waste. There is no release to air or water.

Total loss (wastage) from the process is estimated to be typically 10 per cent (based on industry practice). Solid metal waste from this process may be recovered or disposed of in other ways (off-site) for both large and small scale sites. The degree of recovery will reflect the value of the metal waste. Waste metals will be disposed of through specialist handlers for recovery at both large and small scale sites.

Table 3.77 Release table for soldering: metals

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/y	> 1000 kg/y	
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air	0%	0%	Only solid wastes are anticipated (wastage from the process).
% to waste water	0%	0%	

3.10.3.2 Release scenario for soldering: aqueous preparations

Flux is supplied in aqueous suspensions containing a low level of rosin and other organic or inorganic components. The level of waste is difficult to determine, with unused flux remaining on components and possibly removed in subsequent solvent washes. Water will evaporate during the high temperature process of applying the liquid solder.

Waste residues of liquid flux from containers, spills and other handling are considered to be equivalent to the release scenario for handling of aqueous preparations.

Table 3.78 Release table for soldering: aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air, vp < 100 Pa	0%	0%	Estimate based on TGD Table A2.1.
% to air, vp > 100 Pa	1%	1%	Estimate based on TGD Table A2.1.
% to waste water	2%	2%	Estimate based on TGD Table A2.1.

Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Solid and liquid wastes are to be expected (water-soluble solid wastes, and aqueous preparations and washings). These wastes pass to waste water from small scale sites. From large scale sites the wastes may pass to waste water, recovery, or as chemical waste for specialist treatment. Level of discharge to waste water relates to local discharge consent for specific dangerous components, such as metal salts. Other aqueous waste may only be subject to cursory control, such as pH. Larger scale formulators may have waste disposal and treatment procedures in place and it has been indicated (pers. comm., 17/03/2008) that 2 per cent may be a cautious estimate.

No release to waste solids is estimated at large or small sites (on the basis of water-soluble material not adsorbing to process sludges or solids from settled waste water). Certain metal salts may adsorb.

3.10.3.3 Release scenario for soldering: non-aqueous preparations

Non-aqueous liquids include solder paste and non-water based flux preparations.

Flux does not contain volatile solvents, but some solder paste preparations include xylene or other solvents to keep the paste workable.

Some loss to waste water is possible from cleaning of equipment or components.

Table 3.79 Release table for soldering: non-aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/y	> 1000 kg/y	Volume relates to quantity of solder paste used.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air	0%	0%	Non-volatile.
% to waste water	2%	2%	Estimate based on TGD Table A2.1.

Total loss (wastage) from the process is estimated to be typically 10 per cent (based on industry practice). Liquid wastes are to be expected (solvent washings from the process). These wastes would be treated as hazardous liquid waste at both large and small scale sites. At larger sites recovery may take place and it has been indicated (pers. comm., 17/03/2008) that 2 per cent may be a cautious estimate.

The amount of waste solid (based on materials adsorbing to process sludges or solids from settled waste water) is estimated to be in the order of 2 per cent at small and large scale sites.

3.10.4 Associated processes

3.10.4.1 Chemical formulation

Table 3.80 Summary of processes relevant to chemical formulation

Life cycle stage	Description	Loss mechanisms
Formulation	Mixing of substances to produce a preparation. There is often more than one formulation stage.	Surface contamination and emission to drain or ventilation resulting from leakage and spillage (not major accidents) or deliberate release. Liquid and solid wastes, emissions to drain or wastewater treatment plant arising from washing or servicing chemical plant areas and equipment. Disposal of container washings to drain or wastewater treatment plant. Disposal of used containers. Disposal of off-specification product.

The processes used to mix substances to make chemical products for supply to the electronics industry do not involve processing techniques that are unique or specific to this industry. Similar processes for manufacturing or preparing chemical products for supply are used in a wide range of industry sectors. Indeed, it is noted that many chemical products used by the electronics industry are purchased from suppliers who also supply other sectors.

The only significant difference in the supply to the electronics industry, when compared with some other industry sectors, appears to be scale of use – supply of chemicals in containers greater than 25 litres or kilograms is unusual. There is perhaps also a greater degree of manual handling involved in the small-scale use of chemicals when compared with larger chemical users and small pack sizes are normal.

With the exception of certain highly specialised deposition chemicals (dopants) in the semiconductor manufacturing process (such as organo-metals), there are not many chemical substances used exclusively in the electronics industry. However, some of the handling and exposure scenarios may be unique to the industry and must be considered in detail.

3.10.4.1.1 Release scenarios for Formulation processes

Preparation of inorganic and organic materials for supply includes blending and drying processes. The TGD Industry Category (IC) 2 General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenarios, with Table A2.1 being used as a basis for these estimates.

Release scenario for chemical formulation: metals, inorganic and organic solids

Metals

Formulation of metals for supply considers primarily the preparation of alloys for use as solder or other specialist connectors. TGD Industry Category (IC) 8 Metal Processing is considered to be the most appropriate to follow as a basis for emission release scenarios. However, solder manufacturers and other specialist metal processors for the electronics industry appear to have no loss of metal to the environment.

More generally, the degree of recovery will reflect value of metal waste. Use is continuous. Waste metals will be disposed of through specialist handlers for recovery.

There is considered to be no loss to the environment. It has been indicated that research by the tin industry suggests that total loss of tin may be low. However, further information is not available and the relevance of this research to solder is not fully clear.

Inorganic solids

Poorly water-soluble solid waste is expected to be removed during initial settling from waste water, leading to a low level of entry to sludge and subsequent application to agricultural soil. Water-soluble waste will either remain in solution and be discharged (such as nitrates or sulfates), or in some cases (for example certain metal ions such as copper or tin) will adsorb onto sludge. The proportions reaching water or soil must be estimated in accordance with the known properties of the solid.

Organic solids

This category is also used to cover handling of polymeric materials such as films (but not production of polymers, which are outside the scope of this ESD).

Poorly water-soluble solid waste is expected to be removed during initial settling from waste water, leading to a low level of entry to sludge and subsequent application to agricultural soil. However, water-soluble waste will either biodegrade or remain in solution and be discharged. Biodegradability should be considered when preparing a risk assessment for organic solids.

Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Solid and liquid wastes are to be expected (solid residues from formulation removed when cleaning equipment, and washings from the process). These wastes pass to landfill or waste water respectively from small scale sites. If solvent cleaners are used, waste may be collected. From large scale sites the wastes may pass to waste water, recovery, chemical waste or landfill. Larger scale formulators may have waste disposal and treatment procedures in place.

Table 3.81 Release table for chemical formulation: inorganic and organic solids (not metals)

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	30	50	Production campaigns may be used for formulating.
% to air, vp < 100 Pa for organic solids and for all inorganic solids	0%	0%	Dust will be trapped in filter systems[1].
% to air, vp > 100 Pa	1%	1%	Estimate based on TGD Table A2.1.
% to air	0%	0%	Dust will be trapped in filter systems.
% to waste water	2%	2%[2]	Estimate based on TGD Table A2.1.

Note

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control.

2. At greater than 1,000t/y formulated product a more typical loss rate would be 0.3 per cent (estimate based on TGD Table A2.1).

The amount of waste solid (based on metals/materials adsorbing to process sludges or solids from settled waste water) is estimated to be in the order of 2 per cent at small and large scale sites.

Release scenario for chemical formulation: aqueous preparations

Preparation of aqueous mixtures for supply includes blending, dilution and packaging processes.

The TGD Industry Category (IC) 2: General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenarios, with Table A 2.1 being used as a basis for these estimates. Being water-soluble or miscible, liquid and solid waste from formulating aqueous preparations is expected to result in waste that does not separate out during initial stages of treatment, or result in significant loss to sludge.

Biodegradability should be considered when preparing a risk assessment for organic solids formulated as aqueous preparations.

Table 3.82 Release table for chemical formulation; aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	30	50	Production campaigns may be used for formulating.
% to air, vp < 100 Pa	0%	0%	Dust will be trapped in filter systems[1].
% to air, vp > 100 Pa	1%	1%	Estimate based on TGD Table A2.1.
% to waste water	2%	2%[2]	Estimate based on TGD Table A2.1.

Note

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control.

2. At greater than 1,000 t/y formulated product a more typical loss rate would be 0.3 per cent (estimate based on TGD Table A2.1).

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Solid and liquid wastes are to be expected (water-soluble solid wastes, and aqueous preparations and washings). These wastes pass to waste water from small-scale sites. From large-scale sites the wastes may pass to waste water, recovery, or as chemical waste for specialist treatment. Level of discharge to waste water relates to local discharge consent for specific dangerous components, such as metal salts. Other aqueous waste may only be subject to cursory control, such as pH. Larger scale formulators may have waste disposal and treatment procedures in place.

No release of waste solid is estimated (on the basis of water-soluble material not adsorbing to process sludges or solids from settled waste water). Certain metal salts may adsorb.

Release scenario for chemical formulation; non-aqueous preparations

Preparation of non-aqueous mixtures for supply including blending, dilution and packaging processes with solvents and other liquids, and blending of non-aqueous suspensions or pastes (such as solder paste). Particular attention should be given to volatile components (such as solvents), the octanol-water partition coefficient and biodegradation of organic constituents.

Table 3.83 Release table for chemical formulation; non-aqueous preparations

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulation produced.
Days in use	30	50	Production campaigns may be used for formulating.
% to air, vp < 100 Pa	0%	0%	Estimate based on TGD Table A2.1.
% to air, vp 100 - 1000 Pa	1%	1%	Estimate based on TGD Table A2.1.
% to air, vp > 1000 Pa	2.5%	2.5%	Estimate based on TGD Table A2.1.
% to waste water, sol. > 1 mg/l	2%	2%[1]	Estimate based on TGD Table A2.1.

1. At greater than 1,000t/y formulated product a more typical loss rate would be 0.3 per cent (estimate based on TGD Table A2.1).

Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Solid and liquid wastes are to be expected (solid residues from formulation removed when cleaning equipment, and water or solvent washings from the process). These wastes pass to landfill or waste water from small scale sites. If solvent cleaners are used, waste may be collected. From large scale sites the wastes may pass to waste water, recovery, chemical waste or landfill. Larger scale formulators may have waste disposal and treatment procedures in place.

The amount of waste solid (based on materials of solubility <1 mg/l adsorbing to process sludges or solids from settled waste water) is estimated to be in the order of 2 per cent at small and large scale sites.

3.10.4.2 Chemical handling by the user

Table 3.84 Summary of processes relevant to chemical handling

Life cycle stage	Description	Loss mechanisms
Storage and handling	Storage of substances and preparations prior to use. Transfer of substances and preparations into different containers. Dilution and mixing of substances and preparations at the point of use.	Surface contamination and emission to drain or ventilation resulting from leakage and spillage (not major accidents) or deliberate release. Disposal of container washings to drain or wastewater treatment plant. Disposal of used containers. Disposal of old material or products not meeting quality specifications.
Use	Application of substance or preparation to substrate or surface to be worked on. Cleaning or servicing of equipment after use.	Surface contamination and emission to drain or ventilation resulting from spillage or deliberate release. Liquid and solid wastes and emissions to drain or wastewater treatment plant arising from washing or servicing chemical plant areas and equipment.

The use of chemicals in the electronics industry is very often on a small scale when compared with other industry sectors, with a high reliance on manual handling and the subsequent use of small containers. Chemical suppliers re-package bulk products for use by small organisations, and some organisations will themselves decant from larger containers to smaller unit sizes for day-to-day use. This is common in small to medium enterprises.

During manufacturing processes for electronic components, the focus will be on the quality of the products being produced, with engineering designed to ensure quality of final products, that may themselves be of high unit value. Less attention may be given to efficiency in the use of chemicals that, in some processes, may be a relatively low-cost element. This is particularly true for etching and cleaning processes. Conversely, certain fine chemicals and ultra-pure materials used in semiconductor manufacture will be very expensive, thus their price will ensure careful handling.

The Electronics section of the Environment Agency NetRegs website (Environment Agency, 2005) makes recommendations to some areas of industry relevant to electronics manufacturing, with regard to prevention of pollution. The guidance is aimed at small and medium-sized enterprises (SMEs) not subject to IPPC/LAAPC. Mandatory requirements for handling and storage of chemicals include the following, for sites manufacturing CDs/DVDs:

- Contain any spilled chemicals to prevent them entering surface water drains, ditches, watercourses or soakaways. Do not hose spillages down drains.

- Regularly check pipe work for leaks. If leaks are identified, ensure that maintenance work is undertaken immediately and the extent and impact of any contamination assessed and cleaned up.

For sites manufacturing printed circuit boards, there are no mandatory requirements, but the following guidelines are included:

- Store all chemical barrels in a secure location which cannot leak. The base of these areas should be chemical resistant and must have secondary containment such as a bund or a drip tray of adequate size.

- Make sure that all unloading areas are away from storm drains and are hard surfaced to prevent water or ground contamination if there is a spill. If this is not possible, make sure that the drains are protected during delivery (for example by using suitably sized and correctly fitted drain covers).

- Storage areas and drip trays should drain to the plant's wastewater treatment plant, as long as the plant can process these wastes. On no account should these be permitted to drain to the storm system.

- Contain any spilled chemicals to prevent them entering surface water drains, ditches, watercourses or soakaways. Do not hose spillages down drains.

These guidelines have been prepared by industry for industry and take into consideration that the primary activities in most cases are the design, manufacture and assembly of electronic components and the sites are not regarded as chemical production or formulating plants.

3.10.4.2.1 Release scenarios for handling processes

Release scenario for handling by the user: metals

Metals will be handled for use in assembly and soldering or prior to recovery activities. The processes to consider are melting and handling of molten metal (solder).

Waste will comprise exclusively of solid metal that will either be sent for recovery or disposed as solid waste.

Table 3.85 Release scenarios for handling by the user: metals

Description	Small scale	Large scale	Comments
Total use	< 1000 kg/y	> 1000 kg/y	
Days in use	300	300	Continual use.
% to air	0%	0%	Only solid wastes are anticipated (wastage from the process).
% to waste water	0%	0%	

Total loss (wastage) from the process is estimated to be typically 5 per cent at small sites and 2 per cent at large sites. Solid wastes are to be expected (small particulates and fragments). The degree of recovery will reflect the value of the waste, but in general at larger sites recovery and/or specialist disposal is to be expected. At small scale sites this is less likely to be the case.

The expected amount of waste solid (process sludges or solids from settled waste water, in the form of non-water-soluble solid particulates) is estimated to be of the order of 5 per cent at small scale sites and 2 per cent at large scale sites.

Release scenario for handling by the user: inorganic and organic solids

Inorganic solids

Handling of inorganic solids by the user includes direct addition to production process, on-site dilution prior to use, disposal of packaging and servicing equipment that may contain dried residues of solids.

The TGD Industry Category (IC) 2: General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenarios, with Table A2.1 being used as a basis for these estimates. Poorly water-soluble solid waste is expected to be removed during initial settling from waste water, leading to a low level of entry to sludge and subsequent application to agricultural soil. Water-soluble waste will either remain in solution and be discharged (for example nitrates or sulfates), or in some cases (for example certain metal ions such as copper or tin) will adsorb onto sludge. The proportions reaching water or soil must be estimated in accordance with the known properties of the solid.

Organic solids

The TGD Industry Category (IC) 2: General Chemicals is considered to be the most appropriate to follow as a basis for emission release scenarios, with Table A2.1 being used as a basis for these estimates. Poorly water-soluble solid waste is expected to be removed during initial settling from waste water, leading to a low level of entry to sludge and subsequent application to agricultural soil. However, water-soluble wastes will either biodegrade or remain in solution and be discharged.

Table 3.86 Release table for handling by the user: inorganic and organic solids

Description	Small scale	Large scale	Comments
Total use	< 10 t/y	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	250	300	Most processes are continuous and not based on campaigns.
% to air (inorganic solids) and % to air, vp < 100 Pa (organic solids	0%	0%	Dust will be trapped in filter systems[1].
% to air, vp > 100 Pa	1%	1%	For organic solids only: Estimate based on TGD Table A2.1.
% to waste water	2%	2%	Estimate based on TGD Table A2.1.

Note

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control.

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). The type of waste will be solid and liquid at both large and small scale installations (solid waste and washings from process). These wastes (including solid residues from formulation removed when cleaning equipment) would go to waste water or landfill from small scale operations (if solvent cleaners are used, waste may be collected) and to waste water, recovery, chemical waste or landfill from larger sites (specialist disposal methods). Larger scale formulators may have waste disposal and treatment procedures in place.

The expected amount of waste solid (process sludges or solids from settled waste water, in the form of non-water-soluble solid particulates) is in the order of 2 per cent at small and large scale sites. These amounts are estimates.

3.11 Other industrial processes

3.11.1 Liquid crystals

This grouping of chemicals is defined as those required in the manufacture of Liquid Crystal Displays (LCD). The scale of use in the UK is uncertain, although synthesis of chemicals (polymers) for use in LCD displays is conducted by European chemical manufacturers. Most LCD production takes place in the Far East and processes in the UK are limited to assembly of units or small-scale development work.

The chemical properties of liquid crystals in display units remain unchanged during use and although in-life activities should not lead to the release of such chemicals, breakages and end of life disposal will result in the release of the liquid crystals.

It can be assumed that there is 100 per cent release of the chemicals used in LCDs during end of life processes. The fate of material released on disposal will depend on the items incorporating the LCD – domestic products such as watches, calculators and toys will be predominantly disposed of as domestic waste through incineration or landfill. Whereas computers and television monitors will be disposed of in accordance with WEEE Directive, larger industrial displays will probably be dismantled and in part recycled.

3.11.2 Speciality gases

Speciality gases (those not naturally occurring in the atmosphere) are used for a number of applications in the production of semiconductors. For the purposes of this document, the term ‘gas’ refers to substances supplied and used in the gaseous phase and not substances that are vaporised during application.

The main application for speciality gases is in deposition or dry-etching in semiconductor manufacture, although there are also applications in optical display systems and lasers.

Examples of substances in this category include amines, boron compounds, silanes and phosphorus-based materials. These materials are supplied in sealed containers as liquids and many are sensitive to atmospheric moisture. Their use needs to be in specialist equipment under controlled conditions. These substances will lose their identity during use and degradation products will form solid residues or will remain in vapour form.

Many of these substances are extremely expensive and will be used at very low levels of supply, typically at less than 100 kg per annum by European users.

Due to rapid degradation and low rates of use in highly controlled conditions, environmental exposure is expected to be very low.

3.12 Service life

Table 3.87 Summary of processes relevant to service life

Life cycle stage	Description	Loss mechanisms
Use	In-use service life considers release of substances from components during their normal use.	It is not envisaged that there is significant emission of substances during use of electronic components. Residues of volatile solvents or other substances present on un-washed components (such as photoresists) may volatilise from warm surfaces, but this would be a minor release and is transient for new components.
'Consumable' components	Certain electronic components are either deliberately left in the environment (military hardware and ordinance) or are unintentionally discarded in an uncontrolled manner.	Articles discarded in the environment will slowly degrade. Organic components such as plastics and insulating materials will slowly biodegrade, but metals and inorganic materials will oxidise and if soluble, leach into ground water.

Release of chemicals from normal in-service life use of electronic components is minimal, but articles abandoned or deliberately placed in the environment will only slowly degrade. The mobility of degradation products in the environment will vary depending on the characteristics of the degradation products.

Special consideration must be made in preparing risk assessments to consider the fate of materials in the environment if discarded. Release during service would usually be a regional-scale scenario. However, the quantity of material entering the environment in this way is only a small proportion of electronic equipment.

It is noted that a research paper (McPherson *et al*., 2004) reported significant levels of certain flame retardants on monitors and computer casings. It was also noted that many major suppliers of computers had already phased out such chemicals or were planning to do so. However, the report was not considered impartial and from the limited technical details on methodology available, sampling methods appeared significantly flawed. Samples of dust were collected from monitors and casings that were perhaps attracting dust through electro-static charging and there is no evidence to suggest that the electronic items themselves generate the dust. Ideally, other surfaces in the vicinity of the computers should have been compared.

3.12.1 Release scenarios for service life

3.12.1.1 Release scenario for service life; organic solid

It is not possible to present a generic Release Table that covers organic solids released from electronic components during their normal use.

Whilst it is possible that residues of organic substances not removed during processing (such as photoresists) may volatilise from components when used, in general the use of electronic equipment does not normally result in the release of these substances. Releases would be very variable and dependent on specific substance properties and life cycle. Release in service would probably be a regional-scale scenario.

With regard to release of plastics additives (such as flame retardants) from plastic components of electronics products during service life, risk assessors should refer to the Emission Scenario Document for plastics additives (OECD, 2004a).

3.12.1.2 Release scenario for service life; non-aqueous liquids

It is not possible to present a generic Release Table that covers organic liquids released from electronic components during their normal use.

Whilst it is possible that residues of organic substances not removed during processing (such as solvent) may volatilise from components when used, in general the use of electronic equipment does not normally result in the release of substances. Releases would be very variable and dependent on specific substance properties and life cycle. Release in service would probably be a regional-scale scenario.

3.13 Recovery from waste

The WEEE Directive (see Section 2.1.1) concerning the disposal of Waste Electrical and Electronic Equipment has led to a degree of compulsion over the disposal and recovery of constituents of electrical equipment at their end-of-life. However, economics is also an important factor and the greater the value of waste that can be recovered, the more effort is placed into recovery. For example, with the move away from lead-based solder to solder with significant levels of silver and other more expensive metals, the scrap value of many components has increased.

Table 3.88 Summary of processes relevant to recovery

Life cycle stage	Description	Loss mechanisms
Collection and separation of waste material	Disassembly of electrical goods and removal of non-recoverable components.	Small components not worth processing will be discarded with low-hazard waste. Disposal of packaging and plastic waste with other domestic and low-hazard plastics, perhaps including recycling of plastics.
Treatment of waste and collection of recovered material	Heating of recovered metals to separate from non-metal solids. Heating of metal to separate metals.	Molten part-combusted plastics and solid ceramics removed and disposed of as waste. Metals separated to sufficient purity to have commercial value.
Collection and recovery or disposal of plastics	Plastic / polymeric components stripped from the electronic items when sent for recycling	Waste plastic and non-metal solids are disposed of with plastics from other domestic and industrial sources.
Disposal of remaining waste	Solid waste residues of mixed materials not possible to separate.	Disposal to landfill or other waste disposal depending on the nature of the waste.

The requirements of the WEEE Directive include a number of substances, preparations and components that must be removed from any separately collected WEEE (see Annex I for a list). In addition, it is stipulated that fluorescent coatings must be removed from cathode ray tubes, and mercury from gas discharge lamps.

Recovery can be considered in the form of scrap base metals (such as casings, wires, cables) and of more exotic metals used in solder, PCBs and other specialist components. Scrap base metal recovery will be no different to processes used for metal recovery from other industries, but recovery from electronic components will require specialist processes involving separation of metal from laminates, insulating materials, semi-conducting materials.

A major concern in the recycling process is the heating of plastics and other organic materials that can partially degrade or release hazardous by-products. The waste residues from recovery processes are considered hazardous waste and are collected for safe disposal. Waste solder recovery will result in residues of flux and 'dross' (oxides) that need to be disposed of as hazardous waste.

Two trials have been conducted on behalf of Defra to establish WEEE protocols (Defra 2007a and b). The first looked at all WEEE (small mixed WEEE, arising from Civic Amenity sites), and established proportions of the different categories of products. 125 tonnes of small mixed WEEE (SMW) made up of 16,401 individual items were hand-sorted. The items were segregated into 10 categories, provided in the WEEE Regulations, and counted and weighed. A detailed compositional breakdown of each category (proportion of metal, plastic, other and PCB) was provided in the report (Defra, 2007a). A separate trial focussing on Category 1 waste (large domestic appliances) assessed the proportion of different types of material, and the average composition of appliances in terms of proportions of plastics, metals, other and non-WEEE materials. This has resulted in publication of a further protocol (Defra, 2007b).

Plastic waste from casings, structural parts of equipment and from packaging is sent for recycling or disposal with other plastic waste from industrial and domestic sources. Although this waste is considered to be of low hazard, some plastic will contain potentially hazardous chemical substances such as brominated flame retardants. The ESD for plastics additives (OECD, 2004a) covers end of life plastics.

Laminates used in PCBs and other small components are not recovered and it is understood that once they have been heated to strip off solder and to release other components, the solid waste is disposed to landfill or incineration with other non-hazardous solid industrial waste. There is no evidence to suggest that the physical handling of laminates is in any way different for plastics originating in the electronics industries compared to other plastics.

The use of physical processes (including grinding and density separation) to recover resin in powder form from PCB has been demonstrated, as reported by Mou *et al.* (2004). This paper showed the resulting powdered resin to have several potential uses, including as filler in construction and building related applications, and in manufacture of resin shell (flat board).

It is also noted that some mixed plastic waste, including laminates, can be converted to fuels for energy (Cynar PLC, undated). One organisation carrying out such activities is UK-based firm Cynar PLC.

Other than washing of equipment or perhaps cleaning of recovered materials, there is limited use of process water.

Note: processes associated with recovery from wastes refer to both process wastes and end-of-life wastes (see Section 3.14 on Waste). Risk assessors should therefore consider the scenario for the substance(s) of interest where recovery from wastes is relevant, to assess the life cycle correctly and avoid double accounting of potential releases.

3.13.1 Release scenarios for recovery from waste

3.13.1.1 Release scenario for recovery: metals

The degree of recovery reflects the value of the metal. Recovery will involve heating to allow separation of metals in accordance with their melting points following metal purification steps common with metal refining. Metal from other industrial sources may be recovered on the same site. TGD Industry Category (IC) 8: Metal Processing is considered to be the most appropriate to follow as a basis for emission release scenarios.

Total loss (wastage) from the process is estimated to be typically zero. Waste will comprise exclusively of solid metal that will either be sent for recovery or disposed of as solid waste. The degree of recovery will reflect the value of metal waste. Waste metals will be disposed of through specialist handlers for recovery. No release to waste solid (process sludges or solids from settled waste water) is estimated.

Table 3.89 Release table for recovery: metals

Description	Any scale	Comments
Total use	Any	
Days in use	300	Continuous use.
% to air	0%	Only solid wastes are anticipated (wastage from the process).
% to waste water	0%	

3.13.1.2 Release scenario for recovery; organic solids

It has been noted that plastics (non-metallic, organic solids) are generally disposed with other plastics from domestic or industrial applications. These are covered by other emission scenario documents, but it is worth noting that some of this plastic waste is recovered for use as low-grade materials such as building materials, garden products (planters), street furniture or even as chippings for sports surfaces or horse exercise yards. It is estimated that 8 per cent of UK plastic waste is from electrical and electronic goods (Waste Online, 2006).

Although the plastics themselves are not considered hazardous, degradation may lead to the release of chemicals within them, including flame retardants or other substances that may be of potentially high concern.

With regard to release of plastics additives (such as flame retardants) from plastic components of electronics products during recovery processes, risk assessors should refer to the Emission Scenario Document for plastics additives (OECD, 2004a).

3.14 Waste

Table 3.90 Summary of processes relevant to waste

Life cycle stage	Description	Loss mechanisms
Disposal / destruction	The substance moves out of active control or is destroyed.	Incineration of waste is becoming more common. Chemical transformation to destroy a substance is often used at chemical facilities prior to release to the drainage system. Sewage sludge containing a substance may arise at any of the above stages, via the waste water treatment plant. This sludge may be incinerated, disposed to landfill, or spread onto agricultural land.

All processes will produce some form of waste and the methods for waste disposal will depend on the nature of the material being disposed of.

Waste from electronic component manufacture takes the form of non-hazardous solids (laminates, plastic films), low-hazard solids (metal salts from etching, rejected components), waste water and hazardous chemical waste. Some volatile processing and cleaning chemicals may be lost to the atmosphere during use.

In terms of environmental impact, waste water poses the highest risk and operating units will work to levels set for discharge consents, measuring pH, total dissolved carbon and perhaps levels of controlled metals.

High levels of waste cleaning materials, water-soluble photoresist components and etching solutions will be lost to waste water. Metals and organic substances may be removed from waste water during treatment and may adsorb into sludge that in turn could be applied to agricultural land.

However, please note that process wastes such as these are not dealt with in the release scenarios for 'waste', but rather as part of the release inherent in the process itself. For example, process wastes associated with etching are dealt with as part of the release to environment in the release scenarios for the etching process.

Waste from end-of-life (see Section 3.13 on Recovery) may contain hazardous chemicals, but the RoHS Directive (2002/95/EC) will limit the use of dangerous substances in electronic components that can cause long-term environmental impact. However, there are still many electronic components nearing the end of life still in use that will need to be carefully disposed of as potentially hazardous waste.

3.14.1 Release scenarios for waste processing

Note regarding dismantling processes: in England and Wales, sites undertaking WEEE treatment are subject to Authorisation by the Environment Agency. To act as an Authorised Treatment Facility (ATF), a site undertaking "sorting, dismantling, separation, shredding, screening, grading, baling, shearing, compacting, crushing, granulation, or cutting of waste into different components for recovery" must comply with standard rules established by the Environment Agency (2007b). A list of ATFs is available from the Environment Agency (undated).

3.14.1.1 Release scenario for waste processing: metals

Waste metals include scrap casing, conductive wires, heat sinks, joining mechanisms, coated laminates, and solder. Some of these are described in separate sections, and metals will usually be recovered. The degree of recovery will relate to the value of the metal. The level of solder recovery is currently less clear than for precious metals and other materials used in circuit boards.

The Release Scenario is considered to be similar to that for recovery of metals from waste. Total loss (wastage) from the process is estimated to be typically zero. Waste will comprise exclusively of solid metal that will be disposed of as solid waste. Waste metals will be disposed of through specialist handlers for recovery. No release to waste solid (process sludges or solids from settled waste water) is estimated.

Table 3.91 Release table for waste: metals

Description	Any scale	Comments
Total use	Any	
Days in use	300	Continual use.
% to air	0%	Only solid wastes are anticipated (wastage from the process).
% to waste water	0%	

3.14.1.2 Release scenario for waste processing: inorganic solids

There is little economic incentive to recover waste inorganic solids and those collected for disposal will often be sent to cement works for disposal or sent to suitable landfill.

It is not possible to prepare a Release Scenario for disposal of inorganic waste specifically from the electronics industry. For a general discussion of waste disposal, the draft IPPC reference documents on Best Available Techniques for waste treatment and incineration may be of interest (EC, 2005a, b).

3.14.1.3 Release scenario for waste processing: organic solids

Organic solids may be disposed of either by incineration or landfill. It is not possible to prepare a Release Scenario for disposal of organic waste specifically from the electronics industry. For a general discussion of waste disposal, the draft IPPC reference documents on Best Available Techniques for waste treatment and incineration may be of interest (EC, 2005a, b).

It has been noted that plastics (non-metallic, organic solids) are generally disposed of with other plastics from domestic or industrial applications. These are covered by other emission scenario documents, but it is worth noting that some of this plastic waste is recovered (refer to Section 3.12). It is estimated that 8 per cent of UK plastic waste is from electrical and electronic goods (Waste Online, 2006).

Although the plastics themselves are not considered hazardous, degradation may lead to the release of chemicals within them, including flame retardants or other substances that may be of potentially high concern.

With regard to release of plastics additives (such as flame retardants) from plastic components of electronics products at end-of-life, risk assessors should refer to the Emission Scenario Document for plastics additives (OECD, 2004a).

3.14.1.4 Release scenario for waste processing: aqueous liquids

Electronics components do not contain aqueous liquids at the stage of disposal of the unit.

Process wastes are considered within the relevant section for the process.

3.14.1.5 Release scenario for waste processing: non-aqueous liquids

Lubricants and oils present in components may require consideration at the stage of disposal of the unit but are not covered by this ESD.

Process wastes are considered within the relevant section for each process.

4. EXAMPLES

A series of worked examples is provided to give an indication of how to find the correct Release Scenario tables from the starting point of chemical supply type.

Covering a range of chemical types, each example describes and discusses the typical applications to reflect the level of information found elsewhere in the ESD. References are given to help find the most relevant Release Scenarios and application of the scenarios to determine releases is then demonstrated.

These examples describe the starting points for a risk assessment, but can only provide a sample of generic details. Those preparing risk assessments will need to explore each area in more detail and apply volumes supplied.

Users of this ESD must clearly understand that the scenarios described in this section are illustrative examples based on fictitious sites, designed to help readers use the ESD correctly, together with other information that may be available from other sources. In particular, please note that the information presented relating to quantities consumed at specific sites is illustrative only.

For sites at which multiple processes take place, the releases could be summed to give total kg/d for the relevant site. The release scenarios are process scenarios for specific substances, and if more than one process takes place on any site they should be added together, calculating according to the actual substance in use.

4.1 Notes on risk assessment for electronics chemicals

It is important to consider the following sections in the context of the end-point of this ESD, which is the preparation of a relevant exposure assessment for the purposes of making a realistic risk characterisation. This ESD is only a part of the exposure assessment process and the following points must also be assessed:

- Daily quantities associated with a task: these are estimated by considering annual quantities and dividing by the number of days the process takes place.

- Industry process: details such as batch size, closed or open vessels, cleaning regime, temperature of process, degree of automation and so on are important factors that may vary between users.

- Value of chemicals: in a low value industry, the losses are likely to be much higher than specialist operations where the cost of chemicals makes loss an unacceptable expense.

- The physical form and physicochemical properties of the substance or preparation: these will influence the risk of loss during processing through evaporation, dissolving in water or adsorbing to sediments. The Release Scenarios can only give a general indication of the rate of loss. Once the rates of loss are fully understood, physicochemical properties and the rate of degradation will determine the ultimate fate of the substance. Risk Assessment models often use the SimpleTreat method to estimate the fate of substances in waste water treatment processes.

- Local factors at electronic component production sites: specific volume of effluent, size of local waste treatment plant and points of discharge are important when considering the ultimate risk of substances entering the environment

This ESD has considered these generic factors for various process types and groups of chemical products. However, the user of the ESD is encouraged to confirm that the general scenarios described are correct for their specific application.

4.2 Worked example: Solvent used in spin coating

A solvent (acetone is used as an example) is known to be used in spin coating processes. Risk assessment for the environment is required.

Approach:

- Refer to section on spin coating (Section 3.9) and particularly the section on use of solvents in this industry (Section 3.9.2.4).
- Identify relevant life cycle stages (from the Summary given in Section 3.9.1).
- Refer to the Sections describing release scenarios for the process itself (Section 3.9.3) and from associated processes such as formulation, handling and cleaning (Section 3.9.4).
- Consider physicochemical properties.
- Consider whether large or small site scenario is more relevant.
- Calculate releases.

Overview of life cycle

Chemical type: organic liquid

Processes: formulation, chemical handling, spin coating, cleaning of components

Consider that the usage of the solvent at the main site for this purpose is 50 tonnes per year in formulations for spin coating, plus a further 15 tonnes used in solvent cleaning blends.

Overview of chemical properties

Acetone is a polar solvent, freely soluble in water and most organic solvents with a high vapour pressure, leading to a high rate of evaporation. Acetone is classified as Highly Flammable and Irritant, with R11, R36, R66, R67. Vapour pressure is reported as 24,000 Pa. Acetone is expected to biodegrade rapidly.

4.2.1 Process details

Formulation (refer to Section 3.9.4.1)

Acetone is one of several solvents used in cleaning components such as printed circuit boards or semiconductors.

Proprietary formulations will include mixtures with other solvents such as ethanol, iso-propyl alcohol, or methanol, or acetone may be used alone. Such preparations will contain polar, water-soluble and volatile components. Blending with other solvents will be under ambient conditions with precautions taken for flammability and loss to atmosphere. Equipment would not require washing with water after use and there is considered to be a low risk of significant loss to waste water from formulation activities.

Similar solvent preparation may be used in other sectors of industry as cleaning agents or thinners (paints and other surface coatings).

Release scenario for chemical formulation; non-aqueous preparations applies. Usage of 50 tonnes/year shows that we should refer to the scenario for large-scale sites, and consideration of the chemical properties of acetone allows us to identify the relevant release rates.

Description	**Large scale**	**Comments**
Total use	50 t/y	Volume relates to quantity of formulation produced.
Days in use	50	Production campaigns may be used for formulating.
% to air, vp > 1000 Pa	2.5%	Estimate based on TGD Table A2.1.
% to waste water, sol. > 1 mg/l	2%	Estimate based on TGD Table A2.1.

Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). This demonstrates that the process is relatively efficient.

Solid and liquid wastes that arise pass to waste water, recovery, chemical waste or landfill. Larger scale formulators may have waste disposal and treatment procedures in place (in refining a site-specific assessment this possibility should be explored). In the worst case, release could be to waste water.

Release via waste solids (adsorbing to process sludges or solids from settled waste water) is expected to be zero due to the solubility of acetone.

Overall daily release to air is calculated as follows:

Daily usage * % release rate to air

(50 t / 50 days) * 2.5% = 25 kg/d to air

Overall daily release to waste water is calculated as follows:

Daily usage * % release rate to waste water

(50 t / 50 days) * 2% = 20 kg/d to waste water

Applying the SimpleTreat model for distribution from waste water treatment, a high level of removal by volatilisation and biodegradation in the waste water treatment plant would be predicted. It is beyond the scope of this ESD to explore such issues further.

Chemical handling (refer to Section 3.9.4.2)

Supply can be in containers up to 25 litres, but are often in easier to handle containers of five to 10 litres. The pack sizes may be smaller than containers supplied to other sectors, and supply may take place through a series of traders and re-packaging activities. Handling losses during re-packaging could be considered equivalent to those for formulation.

Release scenario for handling by the user; non-aqueous liquids applies. Usage of 50 tonnes/year shows that we should refer to the scenario for large-scale sites, and consideration of the chemical properties of acetone allows us to identify the relevant release rates.

Description	**Large scale**	**Comments**
Total use	50 t/y	Volume relates to quantity of formulated matter produced.
Days in use	300	Most processes are continuous and not based on campaigns.
% to air, vp > 1000 Pa	2.5%	Estimate based on TGD Table A2.1.
% to waste water, sol. > 1 mg/l	2%	Estimate based on TGD Table A2.1.

Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). This demonstrates that the process is relatively efficient.

Solid and liquid wastes that arise pass to waste water, recovery, chemical waste or landfill from larger sites. Larger scale formulators may have waste disposal and treatment procedures in place (in refining a site-specific assessment this possibility should be explored). In the worst case, release could be to waste water.

Release via waste solids (adsorbing to process sludges or solids from settled waste water) is expected to be zero due to the solubility of acetone.

Overall daily release to air is calculated as follows:

Daily usage * % release rate to air

(50 t / 300 days) * 2.5% = 4.2 kg/d to air

Overall daily release to waste water is calculated as follows:

Daily usage * % release rate to waste water

(50 t / 300 days) * 2% = 3.3 kg/d to waste water

Applying the SimpleTreat model for distribution from waste water treatment, a high level of removal by volatilisation and biodegradation in the waste water treatment plant would be predicted. It is beyond the scope of this ESD to explore such issues further.

Manufacture of components (refer to Section 3.9.3)

Most use of acetone in the electronics industry (>90 per cent) is in the photolithography process, used for removing photoresist materials prior to etching. The components are either immersed in a tank or sprayed with a solvent preparation, washing off the photoresist material. Residual solvent on the components will evaporate to the atmosphere.

Used solvent containing residues of photoresist will be disposed of as waste solvent, usually by incineration (usually off-site). No waste water is generated in the process.

The only release to air is that associated with solvent cleaning. Volatile components will evaporate and although workplace exposure limits exist, local exhaust ventilation may result in a significant loss to the local air compartment. This loss has not been quantified by users or suppliers.

Cleaning of components (refer to Section 3.9.4.3)

Release scenario for cleaning processes: non-aqueous preparations applies. Usage of 15 tonnes/year shows that we should refer to the scenario for large-scale sites, and consideration of the chemical properties of acetone allows us to identify the relevant release rates.

Description	Large scale	Comments
Total use	> 1000 kg/pa	
Days in use	300	Most processes are continuous and not based on campaigns.
Releases information		For non-aqueous preparations: Proportion lost to air, water and soil is variable and dependent upon chemical properties. Refer to TGD Table A4.1, cleaning products UC48 (solvents).

From TGD Table A4.1, cleaning products UC48 (solvents):

Vapour pressure Pa	Water solubility mg/l	% emission to air	% emission to waste water	% emission to soil
> 10 000	> 1000 mg/l	17.5%	60%	0.5%

Overall daily release to air is calculated as follows:

Daily usage * % release rate to air

(15 t / 300 days) * 17.5% = 8.8 kg/d to air

Overall daily release to waste water is calculated as follows:

Daily usage * % release rate to waste water

(15 t / 300 days) * 60% = 30 kg/d to waste water

Applying the SimpleTreat model for distribution from waste water treatment, a high level of removal by volatilisation and biodegradation in the waste water treatment plant would be predicted. It is beyond the scope of this ESD to explore such issues further.

Assembly

Due to evaporation of the solvents from components prior to further processing and assembly, there is not considered to be any residue of cleaning solvents in the electronic equipment.

Service-life

There is no residual acetone remaining after the component manufacturing stage. There is therefore no release during the service-life of equipment.

Disposal and recovery – end of life

There is no residual acetone remaining after the component manufacturing stage. There is therefore no release during equipment disposal / recovery processes.

4.3 Worked example: Inorganic salt used as an etchant

An inorganic salt (ammonium persulfate is used as an example) is known to be used as an etchant in the manufacture of PCBs and semiconductors. Risk assessment for the environment is required for a relatively small site.

Approach:

- Refer to section on spin coating (Section 3.6) and particularly the section on use of etchants in this industry (Section 3.6.2.1).
- Identify relevant life cycle stages (from the Summary given in Section 3.6.1).
- Refer to the Sections describing release scenarios for the process itself (Section 3.6.3) and from associated processes such as formulation, handling and cleaning (Section 3.6.4).
- Consider physicochemical properties.
- Consider whether large or small site scenario is more relevant.
- Calculate releases.

<u>Overview of life cycle</u>

Chemical type: inorganic salt

Processes: chemical handling, etching

Ammonium persulfate is used in wet etching processes and, unusually for an etchant, is supplied in solid form and formulated *in situ*. There is therefore no need to consider releases from formulation separately in this case. The site of interest uses 100 kg/year.

Overview of chemical properties

The substance is a strong oxidising agent and is classified as hazardous, with the labelling requirements specified in Annex I as O, Xn, R8, 22, 36/37/38, 42/43. An extremely low vapour pressure and very high water solubility are to be expected.

4.3.1 Process details

Handling by user (refer to Section 3.6.4.2)

The substance is used in a number of industrial applications and the material supplied to the electronics industry sector is believed to be of the same quality as that supplied to other sectors. The pack sizes of down to one kilogram may be smaller than the containers supplied to other sectors and supply may take place through a series of traders and re-packaging activities.

Release scenario for handling by the user: inorganic solids applies. Usage of 100 kg/year shows that we should refer to the scenario for small-scale sites, and consideration of the chemical properties of ammonium persulfate allows us to identify the relevant release rates.

Description	Small scale	Comments
Total use	100 kg/y	Volume relates to quantity of formulated solid produced.
Days in use	250	Most processes are continuous and not based on campaigns.
% to air	0%	Dust will be trapped in filter systems[1].
% to waste water	2%	Estimate based on TGD Table A2.1.

Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). This demonstrates that the process is relatively efficient.

Solid and liquid wastes which arise pass to waste water or landfill from small scale operations (no specialist disposal methods).

The amount of waste solid is estimated (on the basis of metals/materials adsorbing to process sludges or solids from settled waste water) to be in the order of 2 per cent at small scale sites.

Overall daily release to air is zero as shown in the table.

Overall daily release to waste water is calculated as follows:

Daily usage * % release rate to waste water

(100 kg / 250 days) * 2% = 0.008 kg/d to waste water

Formulation

Ammonium persulfate is supplied as a crystalline technical grade solid in containers between 1 and 25 kg. It is formulated *in situ*.

Manufacture of printed circuit boards (refer to Section 3.6.3)

Most use of ammonium persulfate in the electronics industry (>90 per cent) is in etching processes to clean and remove copper and other metals from the surface of PCBs. There is a minor use for etching silicon wafers in semiconductor manufacture. Other etching systems may be used, but ammonium persulfate appears to offer a good level of control over acid / peroxide mixtures.

Ammonium persulfate is dissolved in water to make a 10 – 25 per cent w/w solution and components are immersed for a period of time to remove copper or, less commonly, other metals such as tin. The oxidising (etching) power of the solution is diminished as the substance is consumed and further ammonium persulfate must be added to the etching solution to maintain activity. The substance does not penetrate the organic photoresist layer.

The processes may be conducted at elevated temperatures (50 – 70°C) to speed the process and increase the solubility of the copper sulfate produced.

Removal of ammonium persulfate occurs in two ways: consumption through reaction with the metal being etched (forming the metal sulfate) and carry-over to washing and rinsing tanks. Sulfuric acid may be used in the first rinse, but further rinses may include fresh water.

Copper sulfate formed in the reaction is precipitated out, often by periodic cooling of the tanks, for removal as solid waste. The solid waste can either be disposed as chemical waste (for recovery) or recycled into the electroless plating stage of PCB manufacture.

During waste disposal and treatment processes, any unreacted ammonium persulfate will quickly react and degrade through neutralisation and reduction as when in contact with other substances. End products will include water-soluble sulfates and ammonium salts (including ammonium sulfate).

Release scenario for etching, aqueous preparations applies. Usage of 100 kg/year shows that we should refer to the scenario for small-scale sites, and consideration of the chemical properties of acetone allows us to identify the relevant release rates.

Description	Small scale	Comments
Total use	< 1000 kg/y	Volume relates to quantity of formulated solid added to aqueous systems.
Days in use	250	Most processes are continuous and not based on campaigns.
% to air	0%	Releases to water only are anticipated.

Description	Small scale	Comments
% to waste water	50%	Estimate based on TGD Table A3.7, assuming Main Category of 3 (default indicating non-dispersive use).

Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). This demonstrates that the process is relatively efficient.

Waste from the process is liquid (water-soluble aqueous waste), which passes to waste water. The waste water may be subject to cursory control, such as pH. No specialist disposal methods are to be expected at small-scale sites.

No waste solids are estimated (on the basis of water-soluble material not adsorbing to process sludges or solids from settled waste water).

Overall daily release to air is zero as shown in the table.

Overall daily release to waste water is calculated as follows:

Daily usage * % release rate to waste water

(100 kg / 250 days) * 50% = 0.2 kg/d to waste water

Assembly

Due to washing of components prior to further processing and assembly, there is not considered to be any residual etching materials in the electronic equipment.

Service life

There is no residual persulfate remaining after the PCB manufacturing stage. There is therefore no release during the service-life of equipment.

Disposal and recovery – end of life

There is no residual persulfate remaining after the PCB manufacturing stage. There is therefore no release during the service-life of equipment.

4.4 Worked example: Diazo photoresist used in PCB manufacture

A diazo organic compound is known to be used as a photoresist in the manufacture of PCBs and semiconductors. Risk assessment for the environment is required

Approach:

- Refer to section on photolithography (Section 3.9) and particularly the section on use of photoresists in this industry (Section 3.9.2.3).
- For assessment of usage in the manufacture of semiconductors, refer to the existing ESD (OECD, 2004b).
- Identify relevant life cycle stages (from the Summary given in Section 3.9.1).
- Refer to the Sections describing release scenarios for the process itself (Section 3.9.3) and from associated processes such as formulation, handling and cleaning (Section 3.9.4).
- Consider physicochemical properties.
- Consider whether large or small site scenario is more relevant.
- Calculate releases.

Overview of life cycle

Chemical type: organic solid

Processes: formulation, chemical handling, photolithography/spin coating

The photoresist has a low vapour pressure <1 Pa and limited solubility in water at <1 mg/l. No information is available regarding the tonnage of this substance used for this application at the main site. The total tonnage used at the main site is estimated at approximately 10 t per year.

4.4.1 Process details

Chemical formulation (refer to section 3.9.4.1)

The photoresist is incorporated into (or onto) a suitable polymeric material (such as resins) or glass / quartz plates using a solvent, dried into a film. In this example it is assumed that the photoresist is present at 10 per cent in the formulation (at main site, 100 t formulation produced per year)

The technology for production of the plastic films is considered to be comparable with photographic film production and similar products will include silver halide preparations or other light-sensitive components.

Material supplied in liquid form (to be applied by the user) is dissolved in suitable solvents that have correct evaporation properties to allow even drying after application. This is a simple blending operation at ambient temperatures.

Release scenario for chemical formulation; non-aqueous preparations applies. Usage of 100 t/year shows that we should refer to the scenario for large-scale sites, and consideration of the chemical properties of the photoresist allows us to identify the relevant release rates.

Description	Large scale	Comments
Total use	100 t/y	Volume relates to quantity of formulation produced.
Days in use	50	Production campaigns may be used for formulating.
% to air, vp < 100 Pa	0%	Estimate based on TGD Table A2.1.

Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). This demonstrates that the process is relatively efficient.

Solid and liquid wastes are to be expected (solid residues from formulation removed when cleaning equipment, and water or solvent washings from the process). From large-scale sites the wastes may pass to waste water, recovery, chemical waste or landfill. Larger scale formulators may have waste disposal and treatment procedures in place.

Release via waste solid (based on photoresist adsorbing to process sludges or solids from settled waste water) is estimated to be in the order of 2 per cent.

Overall daily release to air is zero as shown in the table.

Overall daily release to waste water is also zero, as the anticipated release via waste water is anticipated to be adsorbed to process sludges or to solids in settling tanks, and pass instead as waste solids, which may pass to recovery, chemical waste or landfill.

Chemical handling by user (refer to section 3.9.4.2)

The material, supplied in the form of films (plastic sheet), is packed in light-proof wrapping in a variety of sizes to suit customer requirements. The films may be further cut down in size to suit specialist applications by small scale users.

Release scenario for handling by the user: organic solids applies. Usage of 100 t/year shows that we should refer to the scenario for large-scale sites, and consideration of the chemical properties of the photoresist allows us to identify the relevant release rates.

Description	Large scale	Comments
Total use	> 10 t/y	Volume relates to quantity of formulated solid produced.
Days in use	300	Most processes are continuous and not based on campaigns.
% to air, vp < 100 Pa and all inorganic solids	0%	Dust will be trapped in filter systems[1].

Note

[1] A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control.

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). This demonstrates that the process is relatively efficient.

The type of waste will be solid and liquid at both large and small scale installations (solid waste and washings from process). These wastes (including solid residues from formulation removed when cleaning equipment) would pass to waste water, recovery, chemical waste or landfill from larger sites (specialist disposal methods). Larger scale users may have waste disposal and treatment procedures in place.

The amount of waste solid is estimated (on the basis of photoresist adsorbing to process sludges or solids from settled waste water) to be in the order of 2 per cent.

Overall daily release to air is zero as shown in the table.

Overall daily release to waste water is also zero as the anticipated release via waste water is anticipated to be adsorbed to process sludges or to solids in settling tanks, and pass instead as waste solids, which may pass to recovery, chemical waste or landfill.

Processing

Alternatively, the photoresist may sometimes be supplied in solution. In this case it will be applied to the appropriate substrate by spraying or spin coating. This use is more common in semiconductor manufacture where the scale of use is very small for unit production (although the number of units will be large).

Manufacture of components (refer to section 3.9.3)

The films, of varying quality and size, are placed on the silicon wafer or PCB board. Light of a specific wavelength is projected on to the film through a template (mask) in the pattern of the circuits to be made.

The diazo reacts where exposed to light and changes the properties of the polymer film or coated photoresist. Depending on whether it is a ‘positive’ or ‘negative’ resist, the reaction will either make the surface coating more or less soluble in specific media (such as alkaline solutions or polar solvents).

After exposure, the component may be washed in aqueous or solvent systems to remove the coating where the surface needs to be etched, or may be placed directly in the etching tank where the soluble photoresist film is removed, allowing the copper, tin or other metal layer to be etched with it.

The component will emerge from etching and rinsing with photoresist still covering the parts that were not intended to be etched – depending on whether a positive or negative resists is used, these areas may contain light-reacted or non-reacted diazo.

The remaining coating may be washed off with suitable solvent systems, such as acetone (especially in the silicon wafer etching processes).

Loss of the diazo PAC occurs in two ways: as solid waste in the application of the film and discarding of non-required material, and secondly, washing off non-light exposed solid surface coating (film or dried photoresist following application as solution) from the components being produced. Areas exposed to the light source will have lost their identity, and even though specific wavelengths are used for exposure, normal daylight will lead to a moderately quick photo-reaction that will cause the PAC to lose its identity. As a reasonable worst-case estimate, 50 per cent of the material will be consumed during use (exposed to the light source) and the remainder will be un-exposed either as off-cut waste or edges during application or as areas not exposed to the light through the use of the photo-mask.

The degradation products from the light-exposure portions perhaps need considering, as these will include amines that are themselves potentially hazardous. Similar degradation products will form more slowly on non-exposed waste during exposure to daylight over a period of a few hours. Where reacted photoresist is removed in etching, the reacted products (such as amines) will be removed in the waste water in the same way as the etchants.

Components may be washed with solvent to remove the remaining photoresist. This is almost universal in semiconductor manufacture, but less essential in PCB fabrication. Washing involves the use of solvents such as acetone, or ethanol.

Release scenario for photolithography: organic solids applies. Usage of 10 t photoresist/year shows that we should refer to the scenario for large-scale sites, which allows us to identify the relevant release rates.

Description	**Large scale**	**Comments**
Total use	10 t/y	Volume relates to quantity of photoresist used.
Days in use	300	Most processes are continuous and not based on campaigns.
% to air	0%	Photoresist materials typically non-volatile.
% to waste water	50%	Based on aqueous washing or during etching process.

Total loss (wastage) from the process is estimated to be typically 50 per cent, based on 50 per cent photo-reaction. While this process efficiency is low, it is in the nature of the process.

Liquid wastes (liquid washings; aqueous or solvents) are to be expected. Aqueous wastes would pass to waste water. Solvent-based wastes (including some wastes from processes using organic solids and non-aqueous preparations) would be collected for chemical waste disposal. Larger scale users may have on-site waste water treatment (in refining a site-specific assessment this possibility should be explored).

No release to waste solid (process sludges or solids from settled waste water) is estimated.

Overall daily release to air is zero as shown in the table.

Overall daily release to waste water is calculated as follows:

Daily usage * % release rate to waste water

(10 t / 300 days) * 50% = 16.7 kg/d to waste water

On-site waste water treatment may be occurring and this should be explored.

Assembly

Where components have not been washed (such as PCBs) some photoresist will remain on the component. This is not considered to result in significant release.

Service-life

Whether positive or negative photoresist, the residue will have had a chance to react to light by the time the components reach the consumer. However, the remaining film will include the degradation (reaction) products. There should be no release during service-life

Disposal– end of life waste

Non-washed components may have residues of film remaining that contain the reaction products of the diazo (such as amines). These may be released during disposal or recovery of components (for example during heating of PCBs to over 250°C to recover solder).

Release scenario for recovery; organic solids applies.

It has been noted that plastics (non-metallic, organic solids) are generally disposed with other plastics from domestic or industrial applications. These are covered by other emission scenario documents, but it is worth noting that some of this plastic waste is recovered for use as low-grade materials such as building materials, garden products (planters), street furniture or even as chippings for sports surfaces or horse exercise yards. It is estimated that 8 per cent of UK plastic waste is from electrical and electronic goods (Waste Online, 2006).

Although the plastics themselves are not considered hazardous, degradation may lead to the release of chemicals within them, including flame retardants or other substances that may be of potentially high concern.

With regard to release of plastics additives (such as flame retardants) from plastic components of electronics products during recovery processes, risk assessors should refer to the Emission Scenario Document for plastics additives (OECD, 2004a).

4.5 Worked example: Electroplating chemical

An electroplating chemical (zinc chloride is used as an example) used in the manufacture of PCB, hybrid circuit boards, and other components, requires environmental risk assessment. For the sake of example, let us assume that electroless plating is not believed to be relevant for zinc chloride.

- Refer to section on electroplating (Section 3.5) and particularly the sections on use of plating chemicals and inorganic salts in this industry (Section 3.5.2.1-3.5.2.2).
- Identify relevant life cycle stages (from the Summary given in Section 3.5.1).
- Refer to the Sections describing release scenarios for the process itself (Section 3.5.3) and from associated processes such as formulation, handling and cleaning (Section 3.5.4).
- Consider physicochemical properties.
- Consider whether large or small site scenario is more relevant.
- Calculate releases.

Chemical Type: Inorganic metal salt, electroplating chemical

Processes: chemical handling, electroplating, recovery from waste

Zinc chloride is an inorganic solid with negligible vapour pressure and very high water solubility. A tonnage of 75 tonnes/year is consumed in this application. A concentration of 25 per cent w/w in the plating solution is assumed to be typical (a risk assessor could expect to find this information for the purposes of risk assessment)

4.5.1 Process details

Formulation

Zinc chloride is supplied as a technical grade solid in containers up to 25 kg with no formulation stage.

Handling by user (refer to Section 3.5.4.2.1)

The substance is used in the electroplating of metal connector housings and other specialist components. The solid is dissolved in water and the formulated aqueous product is dispensed into an open plating bath. Using an automated system, the metal substrate is dipped in the bath for the required time, and then transferred to a rinsing bath. There is some spillage due to drag-out between the baths, which may be collected for professional disposal. In the worst case, this waste is washed to drain.

Two scenarios apply: ***Release scenario for handling by the user: inorganic solids*** and ***Release scenario for handling by the user: aqueous preparations***.

For handling of zinc chloride as inorganic solid:

Usage of 75 tonnes/year shows that we should refer to the scenario for large-scale sites, which allows us to identify the relevant release rates.

Description	Large scale	Comments
Total use	75 t/y	Volume relates to quantity of formulated solid produced.
Days in use	300	Most processes are continuous and not based on campaigns.
% to air	0%	Dust will be trapped in filter systems[1].
% to waste water	2%	Estimate based on TGD Table A2.1.

Note

1. A number of commercial filters are available, and the onus is on the user to ensure that the correct filter composition, size and flow rate is used to ensure control.

Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). This demonstrates that the process is relatively efficient.

Solid and liquid wastes which arise pass to waste water, recovery, chemical waste or landfill from larger sites (specialist disposal methods). Larger scale formulators may have waste disposal and treatment procedures in place.

The amount of waste solid is estimated (on the basis of metals adsorbing to process sludges or solids from settled waste water) to be in the order of 2 per cent.

Overall daily release to air is zero as shown in the table.

Overall daily release to waste water is calculated as follows:

Daily usage * % release rate to waste water

(75 t / 300 days) * 2% = 5 kg/d to waste water

<u>For handling of zinc chloride as aqueous solution:</u>

Usage of 75 tonnes/year shows that we should refer to the scenario for large-scale sites, and consideration of the chemical properties of zinc chloride allows us to identify the relevant release rates.

Description	Large scale	Comments
Total use	75 t/y	Volume relates to quantity of formulated solid produced.
Days in use	300	Most processes are continuous and not based on campaigns.
% to air, vp < 100 Pa	0%	Estimate based on TGD Table A2.1.
% to waste water	2%	Estimate based on TGD Table A2.1.

Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). This demonstrates that the process is relatively efficient.

Solid and liquid wastes which arise pass to waste water, recovery, or as chemical waste for specialist treatment. Level of discharge to waste water relates to local discharge consent for specific dangerous components, such as metal salts. Other aqueous waste may only be subject to cursory control, such as pH. Larger scale formulators may have waste disposal and treatment procedures in place.

Regarding releases via waste solids (on the basis of water-soluble material adsorbing to process sludges or solids from settled waste water), certain metal salts may adsorb. To assume the worst case it will be assumed that the zinc chloride remains in settled waste water for release into the municipal waste water system.

Overall daily release to air is zero as shown in the table.

Overall daily release to waste water is calculated as follows:

Daily usage * % release rate to waste water

(75 t / 300 days) * 2% = 5 kg/d to waste water

<u>Electroplating process (refer to Section 3.5.3)</u>

The processes may be conducted at elevated temperatures (50 – 70°C) to speed the process and increase the solubility of the copper sulfate produced.

Baths are replenished periodically by removing a portion of spent solution and topping up with fresh. Spent solution is stored and mixed with other site effluents for professional disposal or discharge into waste water.

Release scenario for electroplating: aqueous preparations (inorganic compounds) applies. Usage of 50 tonnes/year shows that we should refer to the scenario for large-scale sites, which allows us to identify the relevant release rates.

Description	**Large scale**	**Comments**
Total use	75 t/y	Volume relates to quantity of formulated solid added to aqueous systems.
Days in use	300	Most processes are continuous and not based on campaigns.
% to air	0%	
% to waste water	50%	Estimate based on TGD Table A3.7, assuming Main Category of 3 (default indicating non-dispersive use).
	0.002 - 0.1 % w/w of metals	From BREF (EC, 2006; see below).

Other information: Total loss (wastage) from the process is estimated to be typically 2 per cent (with reference to TGD Table A2.1). Liquid wastes are to be expected from this process (water-soluble aqueous waste), which will pass to waste water from both small and large scale sites. The level of discharge to waste water relates to local discharge consent for specific dangerous components, such as metal salts. Other aqueous waste may only be subject to cursory control, such as pH. Larger scale formulators may have waste disposal and treatment procedures in place but no specialist disposal is to be expected at small sites.

No release of waste solid is estimated (on the basis of water-soluble material not adsorbing to process sludges or solids from settled waste water). Certain metal salts may adsorb.

Overall daily release to air is zero, as shown in the table.

Overall daily release to waste water is calculated as follows:

Daily usage * % release rate to waste water

(75 t / 300 days) * 50% = 125 kg/d to waste water stream

Some waste disposal/treatment or recovery is probable and in accordance with the BREF figures the final release is recalculated as follows:

75 t zinc chloride contains ca. 36 t zinc.

Overall daily release to municipal waste water system is calculated as follows:

Daily usage * % release rate to waste water

(36 t / 300 days) * 0.002 - 0.1 % = 0.24 – 12 kg/d to municipal waste water

Assembly

Due to washing of components prior to further processing and assembly, there is not considered to be any plating chemical residue on the electronic equipment other than the metal deposited.

Service life

There is no residual material remaining after the manufacturing stage. There is therefore no release during the service-life of equipment.

Disposal and recovery – end of life (refer to Section 3.13.1.1)

The zinc deposited during the manufacture of the component will remain and may be recovered at end of life.

Release scenario for recovery: metals applies.

Total loss (wastage) from the process is estimated to be typically zero. Waste will comprise exclusively of solid metal that will either be sent for recovery or disposed of as solid waste. The degree of recovery will reflect the value of metal waste. Waste metals will be disposed of through specialist handlers for recovery. No release to waste solid (process sludges or solids from settled waste water) is estimated.

Description	**Any scale**	**Comments**
Total use	any	
Days in use	300	Continuous use.
% to air	0%	
% to waste water	0%	

Overall daily release to air and to waste water is zero, as shown in the table.

ANNEXES

Annex I: substances, preparations and components to be removed from separately collected WEEE

- Capacitors containing polychlorinated biphenyls (PCBs).
- Mercury-containing components such as switches or backlighting lamps.
- Batteries.
- Printed circuit boards of mobile phones and other devices if the surface area of the circuit board is greater than 10 square centimetres.
- Toner cartridges.
- Plastic containing brominated flame retardants (BFRs).
- Asbestos waste and components that contain asbestos.
- Cathode ray tubes (CRTs).
- Chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs) and hydrocarbons (HCs).
- Gas discharge lamps
- Liquid crystal displays (LCDs) of a surface area greater than 100 square centimetres (together with their casing where appropriate), and all those back-lighted with gas discharge lamps.
- External electrical cables.
- Components containing refractory ceramic fibres.
- Components containing radioactive substances above exemption thresholds.
- Electrolyte capacitors containing substances of concern (height > 25 mm, diameter > 25 mm or proportionally similar volume).

Annex II: List of relevant industry associations

URL addresses appearing here are correct as of September 2008

Intellect – Representing the UK technology industry. Formed in May 2002 following the merger between the Computing Services and Software Association (CSSA) and the Federation of the Electronics Industry (FEI). Website: http://www.intellectuk.org/

British Electrostatic Control Association (BECA). Website: http://www.beca.co.uk

Electronics Manufacturing Productivity Facility (EMPF). Website: http://www.empf.org

International Microelectronics and Packaging Society (IMAPS). UK website: http://www.dialspace.dial.pipex.com/town/road/xjl41

IPC Designers Council UK Chapter - Resource for PCB designers. Website: http://dcchapters.ipc.org/uk/

The Institute of Production Engineering Research (IVF). Website: http://www.ivf.se/

JEDEC Solid State Technology Association (formerly the Joint Electron Device Engineering Council) - The semiconductor engineering standardisation body of the Electronic Industries Alliance (EIA). Website: http://www.jedec.org

Loughborough University Interconnection Group. Website: http://www.lboro.ac.uk/icg

Ireland's National Microelectronics Research Centre (NMRC). Website: http://www.nmrc.ucc.ie

NPL: Electronics Interconnection. Website: http://www.npl.co.uk/server.php?show=nav.593

Packaging and Interconnection Electronic Newsletter - An IEEE newsletter. Website: http://msrc.wvu.edu/CPMT/

PRIME Faraday Partnership. Website: http://www.primefaraday.org.uk

US Surface Mount Trade Association (SMTA). Website: http://www.smta.org

Society of Manufacturing Engineers. Website: http://www.sme.org

Soldertec Global. Website: http://www.lead-free.org

The Welding Institute (TWI). Website: http://www.twi.co.uk/j32k/index.xtp

UK Laser and Electro-Optics Association (UKLEO). Website: http://www.ukleo.org/

European Information and Communication Technologies Association (EICTA) - The representative body for the electronics sector and ICT products. Website: http://www.eicta.org/

Annex III: Substances relevant to the electronics industry

The list below details substances that have been identified from public-domain sources as rerlevant to the electronics industry.

There are several purposes for the inclusion of this list:

It describes the nature and scope of the use of chemicals in electronics, and as such supports the emission scenarios and acts as a check on their completeness.

Some of the substances may have data sets in the public domain, which could be useful to risk assessors. No attempt has been made to list all possible sources of data, or to track down the exact use of every substance.

There is an accompanying Appendix that is not for public use since it summarises data in the Confidential IUCLID (International Uniform ChemicaL Information Database) file.

Key for sources referred to in Table 5.1 (full references are given in the main text)

IUCLID 2000: IUCLID (International Uniform ChemicaL Information Database) 2000 edition data set available from European Chemicals Bureau (ECB), 2000. available online via ESIS at http://ecb.jrc.ec.europa.eu/esis/index.php?PGM=dat

Scoping report (Appendix 3.1 unless stated): Environment Agency (unpublished), 1999. *Documentation of chemical usage for risk assessment studies - Scoping project*. R&D Technical Report. Peter Fisk Associates.

P and G: Pohanish and Greene, 1998. *Electronic and Computer Industry Guide to Chemical Safety and Environmental Compliance.* WileyBlackwell

Nokia report: NOKIA , 2005. *Integrated Product Policy Pilot Project, Stage 1 Final Report: Life Cycle Environmental Issues of Mobile Phones.* April, 2005

FR project database: unpublished database of flame-retardants associated with the Environment Agency, 2003. *Prioritisation of Flame Retardants for Environmental Risk Assessment*. P. R. Fisk, A. E. Girling and R. J. Wildey.

EECA White Book: European Electronic Component Manufacturers Association, European Passive Components Industry Association (EECA EPCIA), June 2002. *The Passive Component Industry in Europe White Book* [online]. Available from: http://www.eeca.org/pdf/WhiteBook.pdf.

RAR for 1,3 butadiene: European Chemicals Bureau (ECB), 2002. EU *Risk Assessment Report 1,3-butadiene CAS-No.: 106-99-0 EINECS-No.: 203-450-8* [online]. Available from: http://ecb.jrc.it/existing-chemicals/

Table A3.1 Summary of substances relevant to the electronics industry[3]

Chemical Name	CAS RN	IUCLID 2000	Function *where known*	Application(s) *where known*	Source 1	Source 2
1,1,1,3,3,3-hexamethyldisilazane	999-97-3	Y	Photoresist adhesion promoters.		Scoping report	P and G
1,1,1-trichloroethane	71-55-6	Y	Solvents. Solvent dry film photoresists. Dry film photoresist developer; negative photoresist developer. Solvents for removing screening inks.	Semiconductor manufacture; printed circuit board manufacture.	Scoping report	P and G
1,1,2-trichlorotrifluoroethane, Freon 113	76-13-1	Y	Fluorocarbon solvent.		Scoping report	P and G
1,2,4-trichlorobenzene	120-82-1	N			P and G	
1,2-dichloroethylene	540-59-0, 159-59-2, 156-60-5	N			P and G	
1-methoxypropan-2-ol	107-98-2	Y			P and G	
1-methyl-2-pyrrolidone	872-50-4	Y			P and G	
2-(2-Butoxyethanol) ethanol, diethylene glycol monoethyl ether	112-34-5	Y			P and G	
2-Butoxyethanol	111-76-2	N			P and G	
2-Butoxyethanol acetate	112-07-2	Y			P and G	
2-ethoxyethanol	2110-80-5	N			P and G	
2-ethoxyethanol acetate	111-15-9	Y			P and G	
2-Hexanone	591-78-6	N			P and G	
2-Isopropoxyethanol	109-59-1	N			P and G	
2-methoxy-1-methylethyl acetate	108-65-6	N			P and G	
2-Methoxyethanol	109-86-4	Y			P and G	

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[3] For more detail on sources referred to here, please see the Key on the previous page

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
2-Methoxyethyl acetate	110-49-6	N			P and G	
2-Pentanone	107-87-9	N			P and G	
Acetic acid	64-19-7	Y	Blended with nitric acid as an etch.	Semiconductor manufacture.	Scoping report, table 3.3	P and G
Acetone	67-64-1	Y	Solvents.	Semiconductor manufacture; printed circuit board manufacture.	Scoping report	P and G
Acetonitrile	75-05-8	Y			P and G	
Acetylene	74-86-2	Y			P and G	
AlAs			Semiconductor substrate.	Semiconductor manufacture.	Scoping report	
Alumina (Al_2O_3)			Ceramic substrates; insulating layer in capacitors.	Capacitors, resistors.	Scoping report; EECA White Book	
Aluminium	7429-90-5	Y			P and G	
Aluminium Acetate	142-03-0	N			P and G	
Aluminium chloride	7446-70-0	Y			P and G	
Aluminium fluoride	7784-18-1	Y			P and G	
Aluminium oxide	1344-28-1	Y			P and G	
Ammonia andhydrous	7664-41-7	Y			P and G	
Ammonia, aqueous solution, hydroxide	1336-21-6	Y		Semiconductor manufacture.	Scoping report, table 3.3	P and G
Ammonium chloride	12125-02-9	Y			P and G	
Ammonium citrate dibasic	3012-65-5, 7632-50-0	N			P and G	
Ammonium dichromate	7789-09-5	Y			P and G	
Ammonium fluoride	12125-01-8	N	Buffered oxide etch usually 6:1 ammonium fluoride: hydrofluoric acid.		Scoping report	P and G

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
Ammonium hydrogendifluoride / bifluoride	1341-49-7	Y			P and G	
Ammonium Nitrate	6484-52-2	Y			P and G	
Ammonium phosphate	7783-38-0	N			P and G	
Ammonium sulfamate	7773-06-0	N			P and G	
Ammonium sulfate	7783-20-2	Y			P and G	
Aniline	62-53-3, 142-04-1	Y,N			P and G	
Antimony	7440-36-0	N			P and G	
Antimony trichloride	10025-91-9	N	Inorganic liquid dopants.		Scoping report	
Aqua Regia	8007-56-5	N			P and G	
Argon	7440-37-1	N			P and G	
Arsenic	7440-38-2	N		Semiconductor manufacture.	Scoping report, table 3.3	P and G
Arsine	7784-42-1	N	Light-emitting diode gases (deposit epitaxial layers of gallium arsenide, gallium phosphide, and gallium arsenide phosphide); dopants.		Scoping report	P and G
Asbestos	1332-21-4	N			P and G	
Barium chloride	10361-37-2	Y			P and G	
Barium hydroxide	12230-71-6	N			P and G	
Barium nitrate	10022-31-8	Y			P and G	
Benzyl Alcohol	100-51-6	Y			P and G	
Beryllium	7440-41-7	N			P and G	
Beryllium Oxide	1304-56-9	N			P and G	
Boric acid	10043-35-3	Y	Electrolytic tin-lead plating: inhibition of tetrafluoroborate decomposition; buffer in nickel	Printed circuit board manufacture.	Scoping report	P and G

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
			electroplating.			
Boron Nitride	10043-11-5	N			P and G	
Boron Oxide	1303-86-2	Y			P and G	
Boron tribromide	10294-33-4	N	Inorganic liquid dopants.		Scoping report	P and G
Boron trichloride	10294-34-5	N		Semiconductor manufacture.	Scoping report, table 3.3	P and G
Boron trifluoride	7637-07-2	N		Semiconductor manufacture.	Scoping report, table 3.3	P and G
Butane	106-97-8	Y			P and G	
Calcium carbonate	471-34-1, 1317-65-3	N			P and G	
Calcium chloride	10043-52-4	Y			P and G	
Calcium Hypochlorite	7778-54-3	Y			P and G	
Calcium oxide	1305-78-8	Y			P and G	
Calcium sulfate	7778-28-9	N			P and G	
Carbon black	1333-86-4	Y			P and G	
Carbon Dioxide	124-38-9	Y			P and G	
Carbon Disulfide	75-15-0	Y			P and G	
Carbon monoxide	630-08-0	Y			P and G	
Carbon Tetrachloride	56-23-5	Y			P and G	
Carbon tetrafluoride	75-73-0	N			P and G	
Carboxylic acid			Liquid positive photoresists: product.		Scoping report	
Catechol	120-80-9	Y			P and G	
CdTe			Semiconductor substrate.	Semiconductor manufacture.	Scoping report	
Chlorine	7782-50-5	N		Semiconductor	Scoping report, table	P and G

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
				manufacture.	3.3	
Chlorine dioxide	10049-04-4	Y			P and G	
Chlorobenzene	108-90-7	Y			P and G	
chlorodifluoromethane, Freon 22	75-45-6	Y			P and G	
Chloroform	67-66-3	Y			P and G	
Chromic anhydride	1333-82-0, 11115-74-5	Y,N			P and G	
Chromic sulfate	10101-53-8	N			P and G	
Citric acid, anhydrous	77-92-9	Y			P and G	
Cobalt			Ferromagnetic core in inductors.	Inductors.	Nokia report	
Cobalt nitrate	10141-05-6. 10026-22-9	N			P and G	
Cobalt sulfamate	16107-41-3	N			P and G	
Copper	7440-50-8	Y	Wire used in inductors.	Inductors.	Nokia report	P and G
Copper arsenite	10290-12-7	N			P and G	
Copper chloride	1344-67-8, 7447-39-4	N			P and G	
Copper cyanide	544-92-3, 14763-77-0	N			P and G	
Copper nitrate	3251-23-8	N			P and G	
Copper Oxide	1317-29-1, 1317-38-0	N			P and G	
Copper pyrophosphate		N	Electrolytic copper plating chemical; pyrophosphate process.	Printed circuit board manufacture	Scoping report	
Copper sulfate	7758-98-7	N	Electrolytic copper plating chemical; acid sulfate	Printed circuit board manufacture.	Scoping report	P and G

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
			process.			
Cresol	1319-77-3	Y			P and G	
Cyanogen	460-19-5	N			P and G	
Cyanogen chloride	506-77-4	N			P and G	
Cyclohexane	110-82-7	Y			P and G	
Cyclohexanone	108-94-1	Y			P and G	
Diacetone Alcohol	123-42-4	N			P and G	
Diammonium peroxodisulfate, ammonium persulfate	7727-54-0	Y			P and G	
Diantimony trioxide	1309-64-4	Y	Inorganic liquid dopants.		Scoping report	P and G
Diarsenic trioxide	1327-53-3	Y	Inorganic liquid dopants.		Scoping report	P and G
Diborane	19287-45-7	N	Dopant.	Semiconductor manufacture.	Scoping report, table 3.3	Scoping report
Dichlorosilane			Silicon deposition.	Semiconductor manufacture.	Scoping report	Scoping report table 3.3
Dietheyl telluride	627-54-3	N			P and G	
Diethylene glycol	111-46-6	Y			P and G	
Diethylene glycol dimethyl ether	111-96-6	Y			P and G	
Diethylene glycol montoethyl ehter acetate	112-15-2	N			P and G	
Diiron trioxide	1309-37-1	Y			P and G	
Dimethyl acetamide	127-19-5	Y			P and G	
Dimethyl sulfoxide	67-68-5	Y			P and G	
Dioxane	123-91-1	Y			P and G	
Dipentene	138-86-3	N			P and G	
Diphosphorus pentaoxide	1314-56-3	Y	Inorganic liquid dopants.		Scoping report	P and G

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
Dipropylene glycol methyl ether	34590-94-8	Y			P and G	
Dodecachlorodimethan-o-dibenzocyclooctane	13560-89-9	N	Flame retardant.		FR project database	
Edetic acid, ethylenediamine tetraacetic acid	60-00-4	Y	Component of electrolyte and plating baths.	Printed circuit board manufacture.	P and G	
Epichlorohydrin	106-89-8	Y			P and G	
Epoxidised polybutadiene			Epoxy resin for sealants and electronics.		RAR for 1,3-butadiene	
Ethane-1,2-diol	107-21-1	Y			P and G	
Ethanol			In fluorocarbon solvents, for cleaning wafers, degreasing PCBs, defluxing after component attachment.		Scoping report	
Ethanolamine	141-43-5	Y			P and G	
Ethyl acetate	141-78-6	Y			P and G	
Ethyl acrylate	140-88-5	Y			P and G	
Ethyl Alcohol	64-17-5	Y			P and G	
Ethyl ether	60-29-7	Y			P and G	
Ethyl lactate	97-64-3	N			P and G	
Ethylbenzene	100-41-4	Y			P and G	
Ethylenediamine	107-15-3	Y			P and G	
Ethyul silicate	78-10-4	N			P and G	
Ferrous chloride	7758-94-3	Y			P and G	
Ferrous sulfate	7720-78-7	Y			P and G	
Fluorine	7782-41-4	N			P and G	
Fluoroboric acid	16872-11-0	Y	Electrolytic tin-lead (solder) plating chemical.	Printed circuit board manufacture.	Scoping report	

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
Formaldehyde	50-00-0	Y	Component of electroless copper solutions.	Printed circuit board manufacture.	Scoping report	P and G
Formic Acid	64-18-6	Y			P and G	
Freon 11	75-69-4	Y			P and G	
Freon 112-A	76-11-9	N			P and G	
Freon 114	76-14-2	Y			P and G	
Freon 12	75-71-8	Y			P and G	
Freon 13	75-72-9	N			P and G	
Freon 21	75-43-4, 39289-28-6	N			P and G	
Furfuryl alcohol	98-00-0	Y			P and G	
Gadolinium gallium garnet	12024-36-1	N	Semiconductor substrate.	Semiconductor manufacture.	Scoping report	
Gallium	7440-55-3	N			P and G	
Gallium arsenide, Gas	1303-00-0	N	Semiconductor substrate.	Semiconductor manufacture.	Scoping report	P and G
Gallium phosphide			Semiconductor substrate.	Semiconductor manufacture.	Scoping report	
Gasoline	8006-61-9	Y			P and G	
Germanium	7440-56-4	N	Semiconductor substrate.	Semiconductor manufacture.	Scoping report	P and G
Germanium tetrahydride	7782-65-2	N			P and G	
Glutamic acid hyrdrochloride	138-15-8	N			P and G	
Glutaric acid	110-94-1	N			P and G	
Glycerin	56-81-5	Y			P and G	
Glycidyl methacrylate	106-91-2	N			P and G	
Helium	7440-59-7	N			P and G	

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
Hexabromobiphenyl (mainly 2,2',4,4',5,5'-hexabromo-)	59536-65-1	N	Flame retardant.		FR project database	
Hexachlorobutadiene	87-68-3	N			P and G	
hexachloroethane	67-72-1	N			P and G	
Hexafluoroethane				Semiconductor manufacture.	Scoping report, table 3.3	
Hexylene glycol	107-41-5	Y			P and G	
Hydrazine	302-01-2	Y			P and G	
Hydrofluoric acid*	7664-39-3	Y	Used with nitric acid) to etch conductive paths on the surface of the wafer.	Semiconductor manufacture.	Scoping report, table 3.3	Scoping report
Hydrogen	1333-74-0	Y			P and G	
Hydrogen chloride	7647-01-0	Y			P and G	
Hydrogen peroxide	7722-84-1	Y	Wafer cleaner and resist stripper; in tin-lead strippers.	Semiconductor manufacture.	Scoping report	P and G
Hydrogen selenide	7783-07-5	N			P and G	
Hydrogen sulfide	7783-06-4	Y			P and G	
Hydroquinine	123-31-9	Y			P and G	
Hyrdazine sulfate	10034-93-2	N			P and G	
Hyrdocyanic acid	74-90-8	Y			P and G	
Hyrdrobromic acid	10035-10-6	Y			P and G	
Indium	7440-74-6	N			P and G	
InP			Semiconductor substrate.	Semiconductor manufacture.	Scoping report	
Iodine	7553-56-2	N			P and G	
Iron	7439-89-6	Y	Ferromagnetic core in inductors.	Inductors.	Nokia report	

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
Iron trichloride, ferric chloride	7705-08-0	Y			P and G	
Isobutylene	115-11-7	Y			P and G	
Isoprene	78-79-5	Y			P and G	
Isopropyl alcohol*			Solvent.	Semiconductor manufacture; printed circuit board manufacture.	Scoping report	
Kerosene	8008-20-6	Y			P and G	
Krypton	7439-90-9	N			P and G	
Lead	7439-92-1	Y		Semiconductor manufacture.	Scoping report, table 3.3	P and G
Lead acetate	301-04-2	N			P and G	
Lead Nitrate	10099-74-8	N			P and G	
Lead tetrafluoroborate	13814-96-5	N	Electrolytic tin-lead (solder) plating chemical; corrosion products in electrolytic tin-lead plating.	Printed circuit board manufacture.	Scoping report	
Liqueified petroleum gas	68476-85-7	Y			P and G	
Lithium Hydroxide	1310-65-2	N			P and G	
Magnesium Acetate	142-72-3	N			P and G	
Magnesium	7439-95-1	N			P and G	
Magnesium chloride	7786-30-3	Y			P and G	
Magnesium dioxide	14452-57-4	N			P and G	
Magnesium oxide	1309-48-4	Y			P and G	
Manganous sulfate	7785-87-7	Y			P and G	
m-Cresol	108-39-4	Y			P and G	
Melamine	108-78-1	Y	Flame retardant.		FR project database	P and G

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
Melamine borate	53587-44-3	N	Flame retardant.		FR project database	
Melamine cyanurate	37640-57-6	N	Flame retardant.		FR project database	
Melamine pyrophosphate	70776-17-9	N	Flame retardant.		FR project database	
Mercuric acetate	1600-27-7	N			P and G	
Mercury	7439-97-6	N	Fluorescent tubes for mobile phone screen lights.	Displays	Nokia report	
Methane	74-82-8	Y			P and G	
Methanol	67-56-1	Y	Solvents, for example for removing screening inks.	Semiconductor manufacture.	Scoping report	P and G
Methyl chloride	74-87-3	Y			P and G	
Methyl isoamyl ketone	110-12-3	Y			P and G	
Methyl isobutyl ketone	108-10-1	Y			P and G	
Methyl isopropyl ketone	563-80-4	N			P and G	
Methyl phenyl ether	100-66-3	N			P and G	
Methylene bisphenyl isocyanate	101-68-8	N			P and G	
Methylene chloride	75-09-2	Y	PCB strippers.		Scoping report	P and G
Mineral Oil	8012-95-1	N			P and G	
Morpholine	110-91-8	Y			P and G	
N,N-dimethylformamide	68-12-2	Y			P and G	
Naphtha	8030-30-6	Y			P and G	
Naphtha (petroleum), hydrotreated light	64742-49-0	Y			P and G	
Napthalene	91-20-3	Y			P and G	
n-butyl acetate	123-86-4	Y	Solvents.	Semiconductor manufacture; printed circuit board manufacture.	Scoping report	P and G
n-butyl alcohol	71-36-3	Y			P and G	

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
n-butyl glycidyl ether	2426-08-6	N			P and G	
Nickel	7440-02-0	Y	Nickel electroplating; ferromagnetic core of Inductors.	Inductors.	Scoping report; Nokia report	P and G
Nickel bromide	13462-88-9	N	Nickel electroplating.		Scoping report	
Nickel sulfamate	13770-89-3	N	Nickel electroplating.		Scoping report	P and G
Nickel sulfate	7786-81-4	Y	Nickel electroplating.		Scoping report	
Nitric acid	7697-37-2	Y	Cleaning (semi-conductors and PCBs); etching (see below).		Scoping report	P and G
Nitric oxide	10102-43-9	Y			P and G	
Nitrogen	7727-37-9	N			P and G	
Nitrogen dioxide	10102-44-0	N			P and G	
Nitrogen triflouride	7783-54-2	N			P and G	
Nitromethane	75-52-5	Y			P and G	
Nitrous oxide	10024-97-2	Y			P and G	
Nonphenolic formulations, based on sulfonic acid or chromic acid	7738-94-5	N	Photoresist strippers.		Scoping report	P and G
o-Chlorotoluene	95-49-8	N			P and G	
o-Cresol	95-48-7	Y			P and G	
Octane	111-65-9	Y			P and G	
Octanol	111-87-5	Y			P and G	
o-dichlorobenzene	95-50-1	Y			P and G	
Ortho diazoketone			Liquid positive photoresists: substrate.		Scoping report	
Oxalic acid	144-63-7	N			P and G	
Oxygen in a plasma state			Photoresist strippers.		Scoping report	

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
Ozone	10082-15-6	N			P and G	
Palladium chloride	7647-10-1	N	Component of electroless copper catalysts.	Printed circuit board manufacture.	Scoping report	P and G
p-Cresol	106-44-5	Y			P and G	
p-dichlorobenzene	106-46-7	Y			P and G	
Pentabromodiphenyl ether	32534-81-9	N	Flame retardant.		FR project database	
Pentabromophenol	608-71-9	N	Flame retardant.		FR project database	
Perchloric acid	7601-90-3	N			P and G	
Periodic acid	10450-60-9, 13444-71-8	N			P and G	
Phenol*	108-95-2	Y		Semiconductor manufacture.	Scoping report, table 3.3	P and G
Phenolic-based formulations			Photoresist strippers.		Scoping report	
Phenylethylamine	64-04-0	N			P and G	
Phosphine	7803-51-2	N			P and G	
Phosphoric acid*	7664-38-2	Y		Semiconductor manufacture.	Scoping report, table 3.3	P and G
Phosphorus	7723-14-0	Y		Semiconductor manufacture.	Scoping report, table 3.3	P and G
Phosphorus oxychloride*	10025-87-3	Y		Semiconductor manufacture.	Scoping report, table 3.3	P and G
Phosphorus Pentafluoride	7647-19-0	N			P and G	
Phosphorus tribromide	7789-60-8	N	Inorganic liquid dopants.		Scoping report	P and G
Phosphoryl trichloride	10025-87-3	Y	Inorganic liquid dopants.		Scoping report	
Pinene	80-56-8	Y			P and G	
Platinised titanium	7440-32-6	Y	Rhodium electroplating: anode.		Scoping report	P and G

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
Platinum	7440-06-4	N			P and G	
Poly(pentabromobenzylacrylate)	59447-57-3	N	Flame retardant.		FR project database	
Polycarbonate			Insulating layer in capacitors.	Capacitors.	Nokia report	
Polyester			Insulating layer in capacitors.	Capacitors.	Nokia report	
Polyester film			Dry film photoresists.		Scoping report	
Polyethelene glycol	25322-68-3	N			P and G	
Polyethylene			Dry film photoresists.		Scoping report	
Polyimide			Passivation layers.		Scoping report	
Potassium bromide	7758-02-3	Y			P and G	
Potassium carbonate	584-08-7	Y			P and G	
Potassium chloride	7447-40-7	Y			P and G	
Potassium chromate	7789-00-6	N			P and G	
Potassium cyanate	590-38-3	N			P and G	
Potassium cyanide	151-50-8	Y			P and G	
Potassium dichromate	7778-50-9	N			P and G	
Potassium gold cyanide			Electrolytic gold plating chemical.	Printed circuit board manufacture.	Scoping report	
Potassium hydroxide	1310-58-3	Y	Positive photoresist developers.		Scoping report	P and G
Potassium iodide	7758-05-6	N			P and G	
Potassium nitrate	7757-79-1	Y			P and G	
Potassium permanganate	7722-64-7	Y			P and G	
Potassium phosphate	7778-53-2	Y			P and G	
Potassium pyrophosphate	7320-34-5	Y	Electrolytic copper plating chemical: pyrophosphate process.	Printed circuit board manufacture.	Scoping report	

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
Potassium sulfate	7778-80-5	Y			P and G	
Propan-2-ol	67-63-0	Y	In fluorocarbon solvents, for cleaning wafers, degreasing PCBs, defluxing after component attachment.		Scoping report	P and G
Propane	74-98-6	Y			P and G	
Propene glycol	57-55-6	Y			P and G	
Propionic acid	79-09-4	Y			P and G	
Pyridine	110-86-1	N			P and G	
Pyrogallic aicd	87-66-1	N			P and G	
Selenium	7782-49-2	N			P and G	
Silane	7803-62-5		Silicon deposition.		Scoping report	P and G
Silica, amorphous	7631-86-9, 112945-52-5	N			P and G	
Silicon	7440-21-3	Y		Semiconductor manufacture.	Scoping report, table 3.3	P and G
Silicon nitride formed by the reaction of silane and ammonia gases			Passivation layers.		Scoping report	
Silicon tetrachloride	10026-4-7	N	Silicon deposition.		Scoping report	P and G
Silicon tetrafluoride	7783-61-1	N			P and G	
Silicone	63394-02-5, 63148-62-9	N			P and G	
Silicon-on-sapphire			Semiconductor substrate.	Semiconductor manufacture.	Scoping report	
Silver	7440-22-4	Y		Semiconductor manufacture.	Scoping report, table 3.3	P and G
Silver acetate	563-63-3	N			P and G	

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
Silver nitrate	7761-88-8	Y			P and G	
Sodium acetate	127-09-3	Y			P and G	
Sodium bicarbonate	144-55-8	Y			P and G	
Sodium bisulfate	7681-38-1	Y			P and G	
Sodium bisulfite	7631-90-5	Y			P and G	
Sodium carbonate	497-19-8	Y	Aqueous dry film photoresists.		Scoping report	P and G
Sodium chloride	7647-14-5	Y			P and G	
Sodium citrate	144-33-2	N			P and G	
Sodium cyanide	143-33-9	Y			P and G	
Sodium fluoride	7681-49-4	N			P and G	
Sodium hydroxide	1310-73-2	Y	Component of electroless copper solutions. Positive photoresist developers. PCB strippers.	Printed circuit board manufacture.	Scoping report	P and G
Sodium hypochlorite	7681-52-9	Y			P and G	
Sodium hypophosophite	7681-53-0	Y			P and G	
Sodium metasilicate	6834-92-0	Y			P and G	
Sodium nitrate	7631-99-4	Y			P and G	
Sodium nitrite	7632-00-0	Y			P and G	
Sodium sulfate	7757-82-6	Y			P and G	
Sodium sulfite	7757-83-7	Y			P and G	
Sodium tetraborate	1330-43-4, 12179-04-3, 1303-96-4	Y,N,N			P and G	
Sodium thiosulfate	7772-98-7, 10102-17-7	Y,N			P and G	

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
Stoddard solvent	8052-41-3	N			P and G	
Styrene, monomer	100-42-5	Y			P and G	
Succinic acid	110-15-6	N			P and G	
Sulfamic acid	5329-14-6	Y			P and G	
Sulfur hexafluoride	2551-62-4	Y			P and G	
Sulfuric acid	7664-93-9	Y	Electrolytic copper plating: acid sulfate process; tin electroplating; rhodium electroplating; cleaning semiconductor substrate surfaces.	Printed circuit board manufacture; semiconductor manufacture.	Scoping report	P and G
Tantalum oxide			Insulating layer in capacitors.	Capacitors.	EECA White Book	
Teflon			Insulating layer in capacitors.	Capacitors.	Nokia report	
Tellurium	13494-80-9	N			P and G	
Tetrabromobisphenol A	79-94-7	Y	Flame retardant.		FR project database	
Tetrachlorobutadene	921-09-5	N			P and G	
Tetrachloroethylene	127-18-4	Y			P and G	
Tetrachlorophthalic anhydride	117-08-8	N	Flame retardant.		FR project database	
Tetradecabromodiphenoxybenzene	58965-66-5	N	Flame retardant.		FR project database	
Tetrafluoromethane				Semiconductor manufacture.	Scoping report Table 3.3	
Tetrahydrofuran	109-99-9	Y			P and G	
Tetrakis(2-chloroethyl)ethylene diphosphate	33125-86-9	N	Flame retardant.		FR project database	
Tetramethylammonium hydroxide	75-59-2	N			P and G	
Thiocarbamide	62-56-6	Y			P and G	
Thionyl chloride	7719-09-7	Y			P and G	

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
Tin	7440-31-5	Y	Electrolytic tin-lead plating: tin-lead anodes.	Semiconductor manufacture.	Scoping report Table 3.3	P and G
Tin (II) chloride	7772-99-8	N	Component of electroless copper catalysts.	Printed circuit board manufacture.	Scoping report	P and G
Tin (IV) chloride	7646-78-8	Y			P and G	
Tin bis(tetrafluoroborate)	13814-97-6	N	Electrolytic tin-lead (solder) plating chemical; corrosion products in electrolytic tin-lead plating.	Printed circuit board manufacture.	Scoping report	
Tin(II) sulfate	7488-55-3	N	Tin electroplating.		Scoping report	P and G
Toluene	108-88-3	Y			P and G	
Toluene-2,4-Diisocyanate	584-84-9	Y			P and G	
Trichloroacetic acid	76-03-9	Y			P and G	
Trichloroethylene*	79-01-6	Y	Solvent. Negative photoresist developers.	Semiconductor manufacture; printed circuit board manufacture.	Scoping report	P and G
Trichlorosilane	10025-78-2	Y	Silicon deposition.		Scoping report	P and G
Triethanolamine	102-71-6	Y			P and G	
Triethylene glycol	112-27-6	Y			P and G	
Trimethyl aluminium	75-24-1	N			P and G	
trimethyl borate	121-43-7	N			P and G	
Trimethyl phosphite	121-45-9	Y			P and G	
Triphenyl phosphate	115-86-6	Y	Flame retardant.		FR project database	
Trisodium phosphate	7601-54-9, 10101-89-0	Y, N	Aqueous dry film photoresists.		Scoping report	
Tungsten	7440-33-7	Y			P and G	
Tunsten hexafluoride	7783-82-6	N			P and G	

Chemical Name	**CAS RN**	**IUCLID 2000**	**Function *where known***	**Application(s) *where known***	**Source 1**	**Source 2**
Vinyl cyclohexene dioxide	106-87-6	N			P and G	
Xenon	7440-63-3	N			P and G	
Xylene	1330-20-7, 95-47-6, 103-38-3	Y, Y,N	Negative photoresist developers.		Scoping report	P and G
Zinc oxide	1314-13-2	Y			P and G	
Zinc selenide			Semiconductor substrate.	Semiconductor manufacture.	Scoping report	
Zinc sulfide	1314-98-3	Y	Semiconductor substrate.	Semiconductor manufacture.	Scoping report	

Annex IV: Relevant A- and B-tables

The following A- and B-tables are reproduced from the Technical Guidance Document (EC, 2003a).

IC = 4: ELECTRICAL/ELECTRONIC INDUSTRY

PRODUCTION Table A1.1

Compartment	Conditions		Emission factors			
	T (tonnes/year)	Vap. (Pa)	All MCs	MC=1b	MC=1c	MC=3 (1)
Air		<1		0	0	0.00001
		1-10		0	0.00001	0.0001
		10-100		0.00001	0.0001	0.001
		100-1,000		0.0001	0.001	0.01 (2)
		1,000-10,000		0.001	0.005	0.05
		>10,000		0.005	0.01	0.05
Waste water	<1000		0.02			
	≥1,000		0.003			
Soil			0.0001			

Notes:
(1) Default
(2) Misprint in TGD A-table (‘0.0’); value obtained from EUSES v2.0

FORMULATION Table A2.1

Compartment	Conditions		Emission factors			
	T (tonnes/year)	Vap. (Pa)	All MCs	MC=1b	MC=1c	MC=3 (1)
Air		<10		0.0005	0.001	0.0025
		10-100		0.001	0.0025	0.005
		100-1,000		0.0025	0.005	0.01
		>1,000		0.005	0.01	0.025
Waste water	<1000		0.02			
	≥1,000		0.003			
Soil			0.0001			

Notes:
(1) Default

INDUSTRIAL USE Table A3.4

Compartment	Conditions	Emission factors	
	Vap. (Pa)	MC=2	MC=3 (1)
Air	<100	0.0005	0.0005
	≥100	0.0005	0.001
Wastewater		0.0001	0.005
Soil		0.0001	0.01

Notes:
(1) Default

PRIVATE USE Not applicable

WASTE TREATMENT Not applicable

IC = 4: ELECTRICAL/ELECTRONIC INDUSTRY

PRODUCTION Table B1.7 for non-HPVC

T (tonnes/year)	f main source	No. of days
<100	1	0.1 x f x T
100-1,000	0.9	0.1 x f x T
1,000-2,500	0.8	0.1 x f x T
≥2,500	0.75	300

PRODUCTION Table B1.6 for HPVC (default ≥7,000)

T (tonnes/year)	f main source	No. of days
<10,000	1	300
10,000-50,000	0.75	300
50,000-250,000	0.6	300
≥250,000	0.5	300

FORMULATION

Table B2.4 for non-HPVC

T (tonnes/year)	f main source	No. of days
<10	1	2 x f x T
10-50	0.9	f x T
50-500	0.8	0.4 x f x T
500-2,000	0.75	0.2 x f x T
≥2,000	0.65	300

Table B2.3 for HPVC

T (tonnes/year)	f main source	No. of days
<3,500	1	300
3,500-10,000	0.8	300
10,000-25,000	0.7	300
25,000-50,000	0.6	300
≥50,000	0.4	300

INDUSTRIAL USE Table B3.2

T (tonnes/year)	f main source	No. of days
<10	0.8	2 x f x T
10-50	0.65	f x T
50-500	0.5	0.4 x f x T
500-2,000	0.4	0.25 x f x T
2,000-5,000	0.3	0.2 x f x T
5,000-25,000	0.25	300
25,000-75,000	0.2	300
≥75,000	0.15	300

PRIVATE USE Not applicable

WASTE TREATMENT Not applicable

NOTES ON THIS DOCUMENT: DATA GAPS, LIMITATIONS AND IMPROVEMENTS

The Electronics industry is by its nature an industry of rapid development and changing technology. Nonetheless, the research undertaken in the course of this project has led to the development of release scenarios, supported by contextual information regarding typical site extent and practices.

As with any guidance document, the difficulty is deciding where the reader will start. The 'process map' shows starting points to be chemical suppliers (such as synthesisers or formulators), metal component suppliers (such as those that supply wires or casings) and component suppliers. Many of the processes are typical for the chemical/component types themselves (such as metals, plastics, paint or adhesives), and are not specific to the electronics industry and therefore should be covered by other relevant ESDs. The problem is defining where this ESD starts and others finish.

Consequently, users of this ESD may need to start in different places and in time, formatting could be improved to help users.

Source of information

Research underlying the development of this ESD was conducted during 2005.

Due to the scale of operations in the UK, with few large component manufacturers, there was only limited experience with large users. In some cases, details of waste levels and potential exposure had to be extrapolated from smaller users by reading across from other ESDs or assuming the few endpoint information available were typical in the scale-up of production. There is limited production of semiconductors in Europe with only a few exceptions, and most UK activity is in research and small scale, specialist work.

Consequently, the only site visits possible in the UK were to small scale suppliers. The document could therefore be improved in scope and applicability in future if wider research/review in industry could be undertaken.

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Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy (Water Framework Directive)

Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS) (as amended)

Directive 2002/96/EC on waste electrical and electronic equipment (WEEE) (as amended)

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GLOSSARY

	Definition	Refer to section:
Regulatory and technical		
BAT	Best Available Techniques.	
BERR	UK Department for Business Enterprise and Regulatory Reform (formerly the DTI).	
BREF	BAT Reference document.	
Defra	UK Department of the Environment, Food and Rural Affairs.	
DTI	Former UK Department of Trade and Industry.	
ECB	European Chemicals Bureau	
EEE	Electrical and electronic equipment.	
EPA	US Environmental Protection Agency	
EQS	Environmental Quality Standards	
IPPC	Integrated pollution prevention and control.	
HPV	High production volume	
HSE	Health and Safety Executive	
IC	Industry Category	
LAAPC	Local authority air pollution control.	
MERAG	Metal Risk Assessment Guidance document	
NACE	Internationally harmonised code system for classifying economical activities for use in REACH (Nomenclature générale des Activités économiques dans les Communautés Européennes).	
NONS	Notification of New Substances	
OECD	Organisation for Economic Co-operation and Development	
PHS	Priority Hazardous Substances	
PPC	Pollution prevention and control.	
REACH	Registration, Evaluation, Authorisation and restriction of CHemicals	

	Definition	Refer to section:
RoHS	Restriction of hazardous substances.	
SPIN database	Publicly searchable online database of chemical volume and use information from the Nordic countries' product registers. (http://195.215.251.229/fmi/xsl/spin/SPIN/maininfo.xsl?-db=SPINstof&-lay=SpinNavn&-max=1&-findall).	
TGD	Technical guidance document for risk assessment.	
WEEE	Waste electrical and electronic equipment.	
WEL	Worker exposure limit.	
WFD	Water framework directive.	
Article	An object which during production is given a special shape, surface or design which determines its function to a greater degree than does its chemical composition.	
Preparation	Mixture or a solution composed of two or more substances. The term can include alloys.	
Substance	Chemical element and its compounds in the natural state or obtained by any manufacturing process, including any additive necessary to preserve its stability and any impurity deriving from the process used, but excluding any solvent which may be separated without affecting the stability of the substance or changing its composition.	
Industry		
ATF	Authorised Treatment Facility	
CAD	Computer-aided design.	
CAS	Chemical Abstracts Service	
CFCs	Chlorofluorocarbons	
CRT	Cathode ray tubes.	
CVD, MOCVD	Chemical vapour deposition; metal organic chemical vapour deposition.	
DBC	Direct bond copper.	
EDTA	Ethylenediaminetetraacetic acid.	
EECA	European Electronic Component Manufacturers Association	
EICTA	European Information and Communication Technologies Association	
ESIA	European Semiconductor Industry Association	
HASL	Hot air solder levelling.	
HCs	Hydrocarbons	
HCFCs	Hydrochlorofluorocarbons	
ICCA	International Council of Chemical Associations	

	Definition	**Refer to section:**
ICMM	International Council of Mining and Metals	
IPS	In-plane switching.	
ISMI	International SEMATECH Manufacturing Initiative	
LCD	Liquid crystal display.	
LED	Light-emitting diode.	
PBBs	Polybrominated biphenyls	
PBDEs	Polybrominated diphenyl ethers	
PCB aka PWB	Printed circuit board (printed wiring board).	
PVD	Physical vapour deposition.	
TFT	Thin film transistor.	
Cathode fluorescent tubes	A cathode is any electrode that emits electrons. When used in electrical and electronic devices (most fluorescent lamps, vacuum tubes and so on), the cathode is explicitly heated, creating a hot cathode. By taking advantage of thermionic emission, electrons can overcome the work function of the cathode without an electric field to pull the electrons out. But if sufficient voltage is present, electrons can still be stripped even out of a cathode operating at ambient temperature. Because it is not deliberately heated, such a cathode is referred to as a cold cathode, although several mechanisms may eventually cause the cathode to become quite hot once it is operating. Most cold cathode devices are filled with a gas which can be ionized. A few cold cathode devices contain a vacuum.	2.7.7
Coated laminates	A sheet of material made by bonding two or more layers of material. The laminate is subsequently coated with a metal that can be etched to reveal a printed circuit.	3.7.2.3, 3.10.2.2, 3.14.1.1,
Computer aided design	A system where engineers create a design and see the proposed product in front of them on a graphics screen or in the form of a computer printout or plot. In electronics, the result would be a printed circuit layout.	3.9.1
Electron beam	A narrow stream of electrons moving in the same direction, all having about the same velocity.	2.7.7, 3.9.1
Epitaxial growth	In the context of doping and deposition processes, the deposition of a layer of mineral onto another mineral, such that the crystalline structural orientation of both mineral layers is the same.	
High vacuum evaporation (metallisation)	In vapour deposition techniques by evaporation, the conversion into vapour phase is achieved by applying heat to the source material. This is done in a high-vacuum environment, so that the vaporised atoms or molecules will be transported to the substrate with minimal collision interference from other gas atoms or molecules.	3.7
Integrated circuits	A complex set of electronic components and their interconnections that are etched or imprinted onto a tiny slice of semi conducting material.	3.6.1
Liquid crystals	Any of various liquids in which the atoms or molecules are regularly arrayed in one dimension or two dimensions, the order giving rise to optical properties, such as anisotropic scattering,	3.11.1

	Definition	Refer to section:
	associated with the crystals.	
Micro-electronic components	Discrete electronic components assembled in an extremely small and compact form, it is often taken as a synonym for integrated circuit technology.	2.7, 3.2 – 3.9
Optical display system	A system for displaying components outputs in a visual format, for example a liquid crystal display (LCD).	3.11.2
Photomask	A film or glass negative that has many high-resolution images, used in the production of semiconductor devices and integrated circuits.	3.9.1
Photoresists	A film used in photolithography that temporarily holds the pattern of a circuit path or microscopic element of a chip. When exposed to light, it hardens and is resistant to the acid bath that washes away the unexposed areas. There are two types: positive and negative. The positive resists is exposed with UV light wherever the underlying material is to be removed. This changes the chemical structure of the resist so that it becomes more soluble in the developer. The exposed resist is then washed away leaving a copy of the pattern which is to remain on the wafer. Negative resists behave in just the opposite manner – that is, exposure to the UV light causes the negative resist to become polymerised, and more difficult to dissolve. Negative resists were popular in the early history of integrated circuit processing, but positive resist gradually became more widely used since they offer better process controllability for small geometry features.	3.9.1, 3.9.2.3, 3.9.3.1, 3.9.4.3.2, 3.12, 4.1.4
Plasma screens	A display in which sets of parallel conductors at right angles to each other are deposited on glass plates, with the very small space between the plates filled with a gas; each intersection of two conductors defines a single cell that can be energised to produce a gas discharge forming one element of a dot-matrix display.	2.7, 2.7.3
Silicon wafers	The base unit of chip making. It is a slice taken from a salami-like silicon crystal ingot up to 12" (300mm) in diameter. The larger the wafer, the more chips produced in a single production pass, which comprises a series of photomasking, etching and implantation steps. Wafers are approximately 1/30th of an inch thick; however, the actual layers of transistors that make up the active circuitry are only a few microns deep.	2.7.4, 3.2.2.1, 3.2.4.1.1, 3.3.2.1 - 3.3.2.3, 3.3.4.2.1, 3.4.4.3.1, 3.5.4.3.1, 3.6.4.3.1, 3.7.2.1, 3.7.2.2, 3.7.2.4, 3.7.4.2.1, 3.8.3.3.1, 3.9.2.1, 3.9.2.3, 3.9.4.3.1. 4.1.3.1, 4.1.5.1
Spacers	Components used to separate the front and rear panels in liquid crystal displays (LCDs).	2.7.7

	Definition	**Refer to section:**
Spin coating	A procedure used to apply uniform thin films to flat substrates. An excess amount of a solution is placed on the substrate, which is then rotated at high speed in order to spread the fluid by centrifugal force.	2.7.1, 2.8, 3.1.1, 3.1.3.2, 3.4.2.2, 3.5.2.2, 3.6.2.2, 3.9.1, 3.9.2.2, 3.9.3, 3.9.3.1, 4.1.2, 4.1.4
Transistors (including thin film transistor)	A small electronic device containing a semiconductor and having at least three electrical contacts, used in a circuit as an amplifier, detector, or switch.	2.7.6, 2.7.7
Other Abbreviations (not listed above)		
BOD	Biochemical oxygen demand	
CD	Compact disc	
DIY	‘Do-it-yourself’	
DVD	Digital versatile disc	
ESD	Emission scenario document	
SME	Small and medium-sized enterprises	
WWTP	Wastewater treatment plant	