Multilateral Investment Guarantees Agency

Environmental Guidelines for

Electronics Manufacturing

Industry Description and Practices

The electronics industry includes: the manufacture of: *passive components* (resistors, capacitors, inductors); *semiconductor components* (discretes, integrated circuits); *printed circuit boards* (single and multilayer boards); and *printed wiring assemblies*. This document addresses the environmental issues associated with the latter three manufacturing processes. The manufacturing of passive components is not included since it is similar to the manufacturing of semiconductors, (although passive component manufacturing uses less of the toxic chemicals used in doping semiconductor components and more of organic solvents, epoxies, plating metals, coatings, and lead).

Semiconductors: Semiconductors are produced by treating semiconductor substances with dopants such as boron or phosphorous atoms to give them electrical properties. Important semiconductor substances are silicon and gallium arsenide. Manufacturing stages include: crystal growth; acid etch and epitaxy formation; doping and oxidation; diffusion and ion implantation; metallization; chemical vapor deposition; die separation; die attachment; post-solder cleaning; wire bonding, encapsulation packaging; and final testing, marking and packaging. Several of these process steps are repeated several times so that the actual length of the production chain may well exceed one hundred single processing steps. Between the repetitions a cleaning step which contributes to the amount of effluent produced by the process is often necessary. Production involves carcinogenic and mutagenic substances and therefore production should be carried out in closed systems.

Printed circuit board (PCB*)* manufacturing: There are three types of boards: single sided boards (circuits on one side only); double sided boards (circuits on both sides); and multilayer boards (three or more circuit layers). Board manufacturing is accomplished by producing patterns of conductive material on a non-conductive substrate by subtractive or additive processes (the conductor is usually copper; the base can be pressed epoxy, teflon, or glass). The subtractive process is the preferred route and the steps include: cleaning and surface preparation of the base; electroless copper plating; pattern printing and masking; electroplating; and etching.

Printed wiring assemblies: Printed wiring assemblies consist of components attached to one or both sides of the printed circuit board. Attachment may be by ‘through hole’ technology where the ‘legs’ of the components are inserted through holes in the board and are soldered (solder is usually a tin-lead alloy) in place from underneath, or by ‘surface mount’ technology (SMT) where components are attached to the surface by solder or conductive adhesive. PCBs of all types may require that drilled holes be copper-plated to ensure interconnections between the different copper layers. SMT allows much denser packing of components, especially when components are mounted on both sides. It also offers higher speed performance and is gaining importance over ‘through-hole’ technology.

Waste Characteristics

Air Emissions

Potential air emissions from *semiconductor* manufacturing include: toxic, reactive and hazardous gases; organic solvents; and particulates from the process. The changing of gas cylinders may also result in fugitive emissions of gases. Chemicals in use may include: hydrogen, silane, arsine, phosphine, diborane, hydrogen chloride, hydrogen fluoride, dichlorosilane, phosphorous oxychloride, and boron tribromide.

Potential air emissions from the manufacture of *printed circuit boards* include: acids such as sulfuric, hydrochloric, phosphoric, nitric and acetic; chlorine; ammonia; and organic solvent vapors (isopropanol, acetone, trichloroethylene; N-butyl acetate; xylene; petroleum distillates; and ozone depleting substances (ODSs).

In the manufacture of *printed wiring assemblies*, air emissions may include organic solvent vapors, fumes from the soldering process, including aldehydes, flux vapors, organic acids, etc.

Throughout the electronics manufacturing sector chlorofluorocarbons (CFCs) have been a preferred organic solvent for a variety of applications. CFCs are ozone depleting substances (ODSs). Their production and import in developing countries will also soon be baned. HCFCs (hydrochlorofluorocarbons) have been developed as a substitute for CFCs but they too are ODSs and will be phased out. Methyl chloroform, another organic solvent, has also been used by the electronics industry. It too is an ODS and is being eliminated globally on the same schedule as CFCs. Chlorobromomethane and n-propyl bromide are also unacceptable because of high ozone depleting potential.

Effluents

Effluents from the manufacture of *semiconductors* may have a low pH from hydrofluoric, hydrochloric and sulfuric acids (the major contributor to low pH), and may contain organic solvents, phosphorous oxychloride (which decomposes in water to form phosphoric and hydrochloric acids), acetate, metals, and fluorides.

Effluents from the manufacture of *printed circuit boards* may contain: organic solvents, vinyl polymers, stannic oxide, metals such as copper, nickel, iron, chromium, tin, lead, palladium and gold, cyanides (some metals may be complexed with chelating agents), sulfates, fluorides and fluoborates, ammonia, and acids.

Effluents from *printed wiring assemblies* may contain: acids, alkalis, fluxes, metals, and organic solvents, and, where electroplating is included, metals, fluorides, cyanides, and sulfates.

Solid and Hazardous Wastes

Solid and hazardous wastes from *semiconductor* manufacture may include: heavy metals, solder dross (solder pot skimmings), arsenic, spent epoxy and waste organic solvents (which represents the largest waste). In *printed circuit board* operations, solid wastes may include scrap board materials, plating and hydroxide sludges, and inks, while in the manufacture of *printed wiring assemblies* solid wastes may include solder dross, scrap boards, components, organic solvents and metals. Boards may also be treated with brominated flame retardents which may pose some environmental risk when boards are disposed in landfills. All conventional electronics present additional hazards in landfills by the presence of lead in cathode-ray tube envelopes and solder, as well as lead and other metal salts, particularly if they have not been cleaned in a post-soldering operation.

For all three manufacturing processes there may also be sludges containing heavy metals where waste water treatment plants are operated. Other wastes requiring management and disposal are organic solvent residues.

Pollution Prevention and Control

Semiconductor industry

Measures such as plasma etching of silicon nitride, a dry process, in Metal Oxide Semiconductor (MOS) technology replaces the hot corrosive phosphoric acid (H_3PO_4) wet process, and provides reductions in generated waste, and better safety for workers, while reducing the number of processing steps. Due to the reaction of the plasma with the substrate, several substances are formed which are regarded as carcinogenic or mutagenic and which may pose a danger to maintenance personnel. Risks are minimized by sweeping equipment with nitrogen before opening. A gas mask with breathing equipment should be worn by personnel during repair and maintenance.

Printed Circuit Board Manufacturing

There are a number of process alternatives for consideration in the manufacture of printed circuit boards. These include:

- Board manufacture: SMT rather than plated through hole technology; injection moulded substrate; additive plating.
- Cleaning and surface preparation: use of non-chelating cleaners; extend bath life; improve rinse efficiency; counter current cleaning; recycle/reuse cleaners and rinses.
- Pattern printing and masking: aqueous processable resist; screen printing to replace photolithography; dry photoresist; recycle/reuse photoresist strippers; segregate streams; recover metals.
- Electroplating and electroless plating: replace by mechanical board production; non-cyanide baths; extend bath life; recycle/reuse cleaners and rinses; improve rinse efficiency; countercurrent rinsing; segregate streams; recover metals.
- Etching: use differential plating; non-chelated etchants and non-chrome etchant; pattern versus panel plating; additive versus subtractive process; recycle/reuse etchants.
- Metal recovery by regenerative electrowinning results in a near zero effluent discharge for segregated metal bearing streams. Heavy metals are recovered to metal sheets which eliminates 95% of sludge disposal. Metal bearing sludges that are not treated for recovery of metals should be disposed in secure landfills.

Printed Wiring Assemblies

In the printed wiring assembly process, non-ozone depleting alternatives are readily available for cleaning printed wiring assemblies including, for example, other organic solvents, hydrocarbon/surfactant blends, alcohols, and organic solvent blends), and aqueous and semi-aqueous processes. More importantly, the industry has shown that even sophisticated printed wiring assemblies intended for military uses (where specifications are very exacting) can be made without cleaning by using low residue fluxes that leave very little in the way of contamination on the boards. The no-clean concept eliminates organic solvent use and the need to dispose of organic solvent waste, eliminates a process step and equipment, and has been shown to give adequate product quality according to the application.

General

Organic solvent losses can reduced by conservation and recycling, through closed loop delivery systems, hoods, fans, and stills. Installation of activated carbon systems can achieve up to 90% capture and recycle of organic solvents used in the system. All solvents and hazardous chemicals (including wastes) require appropriate safe storage to prevent spills and accidental discharges. All tanks, pipework and other containers should be situated over spill containment trays whose dimensions are large enough to contain the total volume of liquid over it. Containment facilities must resist all chemical attack from the products. In lieu of containment facilities, the floor and walls, to a suitable height, may be treated (e.g., by an epoxy product, where chemically suitable) to prevent the possibility of leakage of accidental spills into the ground (untreated cement or concrete or grouted tile floors are permeable), with suitable door sills. It is unacceptable to have a drain in the floor of any shop where chemicals of any description are used or stored, except where such a drain leads to an adequate water-treatment plant capable of rendering used or stored chemicals in its catchment area.

Waste organic solvents should be sent to a solvent recycling operation for reconstitution and reuse. Where recycling facilities are not available waste solvent may need to be incinerated or destroyed, according to their chemical composition.

Target Pollution Loads

Implementation of cleaner production processes and pollution prevention measures can provide both economic and environmental benefits. The following production-related targets can be achieved by measures such as those detailed in the previous section.

Ozone depleting substances are not to used in production operations unless no proven alternative exists. Discharges of organic solvents should be minimized and alternative technologies should be considered where available. Solder dross should not to be disposed to landfills (waste can be sent to suppliers or approved waste recyclers for recovery of the lead/tin content of the dross). Scrap boards and assemblies having soldered components should have their components and solder connections removed before disposal in landfills or recycled for other uses.

Treatment Technologies

Wet scrubbers, point-of-use control systems and VOC control units are used to control toxic and hazardous emissions of the chemicals used in semiconductor manufacturing. It is often appropriate to scrub acid and alkaline waste gases in separate scrubbers because different scrubber liquids can be used resulting in higher removal efficiencies.

Air emission concentrations of chemicals such as arsine, diborane, phosphine, silane and the several other chemicals used in the process are to be controlled to worker health levels for plant operations.

Because of the many chemicals used in the electronics industry, wastewater segregation simplifies waste treatment and allows recovery and reuse of materials: organic wastes are collected separately from wastewater systems (note: solvent used in the semiconductor industry cannot be readily recycled because much of it is generated from complex mixtures such as photoresist); acids and alkalis are sent to wastewater treatment facilities on-site for neutralization, after segregation of heavy metal bearing streams for separate treatment; fluoride bearing streams in a semiconductor plant are segregated and treated on-site or sent off-site for treatment/disposal. Treatment steps for effluents from the electronics industry may include precipitation, coagulation, sedimentation, sludge dewatering, ion exchange, filtering, membrane purification and separation, and neutralization, depending on the particular stream. Sanitary wastes are treated separately (primary and secondary treatment followed by disinfection) or disposed to a municipal treatment system.

Emission Guidelines

Emission levels for the design and operation of each project must be established through the Environmental Assessment (EA) process, based on country legislation and the *Pollution Prevention and Abatement Handbook* as applied to local conditions. The emission levels selected must be justified in the EA and acceptable to MIGA.

The following guidelines present emission levels normally acceptable to the World Bank Group in making decisions regarding provision of World Bank Group assistance, including MIGA guarantees; any deviations from these levels must be described in the project documentation.

The guidelines are expressed as concentrations to facilitate monitoring. Dilution of air emissions or effluents to achieve these guidelines is unacceptable.

All of the maximum levels should be achieved for at least 95% of the time that the plant or unit is operating, to be calculated as a proportion of annual operating hours.

Air Emissions

For electronics manufacturing the following air emissions levels should be achieved:

Air Emissions from Electronics Manufacturing

Parameter	*Maximum Value milligrams per normal cubic meter* (mg/Nm^3)
VOC	20
Phosphine	1
Arsine	1
HF	5
HCl	10

Liquid Effluents

The following effluent levels should be achieved:

Effluents from Electronics Manufacturing

Parameter	*Maximum value milligrams per liter* (mg/L)
pH	6 – 9
BOD$_5$	50
Total suspended solids	
Maximum	50
Monthly average	20
Oil and grease	10
Phosphorous	5.0
Fluoride	20
Ammonia	10
Cyanide	
total	1.0
free	0.1
Total chlorocarbons and hydrochlorocarbons	0.5
Metals, total	10
Arsenic	0.1
Chromium, hexavalent	0.1
Cadmium	0.1
Copper	0.5
Lead	0.1
Mercury	0.01
Nickel	0.5
Tin	2.0

Note: Effluent requirements are for direct discharge to surface waters.

Ambient Noise

Noise abatement measures should achieve either the following levels or a maximum increase in background levels of 3 dB(A). Measurements are to be taken at noise receptors located outside the project property boundary.

Ambient Noise

	Maximum Allowable L_{eq} (hourly), in dB(A)	
Receptor	Daytime 07:00 - 22:00	Nightime 22:00 - 07:00
Residential; institutional; educational	55	45
Industrial; commercial	70	70

The emission requirements given here can be consistently achieved by well-designed, well-operated and well-maintained pollution control systems.

Monitoring and Reporting

Monitoring of sources of toxic emissions (such as the toxic gases used in the semiconductor industry, should be continuous and part of the process. Effluents should have continuous monitoring of pH and other parameters should be tested once per month.

Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken. Records of monitoring results should be kept in an acceptable format. These should be reported to the responsible authorities and relevant parties, as required. If requested, they should be provided to MIGA.

Key Issues

The following box summarizes the key production and control practices that will lead to compliance with emission requirements:

- Cylinders of toxic gases should be well secured and be fitted with leak detection devices as appropriate. Well designed emergency preparedness programs are required. Note: fugitive emissions occurring with gas cylinder change do not normally require capture for treatment, however appropriate safety precautions are expected to be in place.
- No ozone depleting chemicals should be used in the process (exceptions only where no proven alternatives are available)
- Equipment, such as refrigeration equipment, containing ozone depleting chemicals should not be purchased unless no other option is available
- Toxic and hazardous sludges and waste materials must be treated and disposed or sent to approved waste disposal and/or recycling operations
- Where liquid chemicals are employed, the plant, including loading/unloading areas should be designed to minimize evaporation (other than water) and to eliminate all risk of chemicals entering any water course, sewage system or ground in the event of an accidental leak or spill.

Further Information

The following are suggested as sources of additional information (these sources are provided for guidance and are not intended to be comprehensive):

World Bank, Environment Department. 1997. "Industrial Pollution Prevention and Abatement: Electronics Manufacturing." Draft document.