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Enabling Circular Economy Practices: Repair and Recycling of PBAs

This CEN-CENELEC Workshop Agreement has been drafted and approved by a Workshop of representatives of interested parties, the constitution of which is indicated in the foreword of this Workshop Agreement.

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CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

Contents

Page

Foreword ... 3

Introduction ... 5

1 Scope ... 6

2 Normative references ... 6

3 Terms and definitions ... 6

4 Printed Board Assembly status definitions ... 12
4.1 Original state ... 12
4.2 New state ... 12
4.3 Repaired state ... 13
4.4 Modified Printed Board Assembly ... 14

5 Repair and Modification ... 15
5.1 General ... 15
5.2 Repair procedure selection ... 15
5.3 Repair equipment and materials ... 16
5.4 PBA and component handling considerations ... 16
5.5 Electronic component refurbishment ... 17
5.6 Repair proficiency ... 18
5.7 Data collection for repair ... 19
5.8 Authority determination ... 19

6 Recycling ... 22
6.1 General ... 22
6.2 Proficiency to recycle electronics ... 22
6.3 Data collection ... 23
6.4 Authority Determination ... 27

Annex A (normative) **Applying IPC-7711/21** ... 30

A.1 Guidelines for Personnel Proficiency ... 30

A.2 Guidance for skill level ... 31

A.3 Guidance for procedure selection and application ... 31

Annex B (informative) **Current state of the art regarding recycling** ... 33

Bibliography ... 35

Foreword

This CEN and CENELEC Workshop Agreement (CWA 18311:2025) has been developed in accordance with the CEN-CENELEC Guide 29 “CEN/CENELEC Workshop Agreements – A rapid way to standardization” and with the relevant provisions of CEN/CENELEC Internal Regulations — Part 2. It was approved by the Workshop CEN and CENELEC “Enabling Circular Economy Practices: Repair and Recycling of PBAs”, the secretariat of which is held by “DIN” consisting of representatives of interested parties on 2025-10-24, the constitution of which was supported by CEN and CENELEC following the public call for participation made on 2025-01-20. However, this CEN and CENELEC Workshop Agreement does not necessarily include all relevant stakeholders.

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The following organizations and individuals developed and approved this CEN and CENELEC Workshop Agreement:

— Altium Inc (Didrik Bech)

— ASUSTek Computer INC. (Alan Lai)

— Asteelflash Holding GmbH (Axel Wagner)

— ASTER Technologies (Christophe Lotz)

— AT & S Austria Technologie & Systemtechnik Aktiengesellschaft (Raphael Schumacher, Christof Wernbacher, Ewa Zaleskiewicz)

— BEAMA (Patricia Massey)

— BMK Professional Electronics GmbH (David Lee)

— cdmm (Michael Hofmann)

— CONFIDEE AS (Guro Krossen)

— Continental Automotive France SAS (Laurent Nardo)

— Continental Automotive Technologies GmbH (Daniel Kruff)

— EcoWise Ekodenge Ltd (Rembrandt Koppelaar)

— Erion Compliance Organization S.C.A R.L. (Simonetta Cota, Viola Corbellini, Luca Campadello)

— Estonian Electronics Industries Association (Arno Kolk)

— FuluhashiEnvironmental Institute Co., Ltd (Seiichiro Nakamura)

— Global Electronics Association (formerly IPC) (Diana Radovan, Francisco Fourcade)

— ifm efector gmbh (Fried Schütze)

— ILExpansions (Ana Semedo)

— imec (Geert Willems)

— Material Recycling and Sustainability (MARAS) B.V. (Antoinette van Schaik, Markus Reuter)

— Österreichische Gesellschaft für System- und Automatisierungstechnik (Bernd Kopacek)

— OFFIS e.V. (Alexandra Pehlken, Felix Schmedes)

— Politechnico di milano (POLIMI) (Paolo Rosa (chair), Daniele Perossa, Laila El Warraqi, Lorenzo Gandini)

— Retronix Europe (Marc Joussé)

— Scuola universitaria professionale della Svizzera italiana (SUPSI) (Siro Dell'Ambrogio)

— Zollner Elektronik AG (Thomas Mückl)

— Zhongguancun industry & information research institute of Two-dimensional code technology (ZIIOT) (Xiaobing Niu)

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Introduction

Repair, reuse, and recycling of products are key concepts of a sustainable economy. An increasing number of products contain electronics in the form of Printed Board Assemblies (PBA). These PBA are often valuable products in themselves, containing a wide variety of materials that are of critical economic and environmental importance. To facilitate the repair, reuse, and recycling of PBA, its components, and its materials, this document provides requirements, recommendations, and guidelines regarding:

— definition of the repair state of a PBA,

— repair and modification of PBA,

— design-for-Repair of products with embedded electronics,

— design-for-Repair of PBA,

— product and PBA mission tracking and event logging,

— full Material Declaration of location and amount of embedded materials,

— recycling of PBA,

— design-for-Recycling of products with embedded electronics,

— design-for-Recycling of PBA,

— responsibilities of manufacturers, repairers, recyclers, users.

The requirements and recommendations regarding Full Material Declaration and event logging prepare for its integration in a Digital Product Passport as required by the EU Ecodesign regulation for Sustainable Products (ESPR).

1 Scope

This CWA defines requirements and recommendations for recycling and repair aspects for printed board assemblies (PBAs) and could provide the basis for the repair and recycling related section in a future digital product passport for PBAs. The document excludes the definition of an IT infrastructure and is orientated on the current developments of CEN/CLC-JTC 24 – DPP.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61340-5-1, *Electrostatics — Part 5-1: Protection of electronic devices from electrostatic phenomena — General requirements*

ANSI/ESD S20.20, *Protection Of Electrical And Electronic Parts, Assemblies And Equipment (Excluding Electrically Initiated Explosive Devices)*

GEIA-STD-0006, *Requirements for Using Robotic Hot Solder Dip to Replace the Finish on Electronic Piece Parts*

IPC-1752B, *Materials Declaration Management Standard*

IPC-7711/21:2024, *Rework, Modification and Repair of Electronic Assemblies*

IPC-A-610:2024, *Acceptability for Electronic Assemblies*

IPC EIA/JEDEC J-STD-075, *Classification of Passive and Solid State Devices for Assembly Processes*

IPC/JEDEC J-STD-020, *Moisture/Reflow Sensitivity Classification for Non-hermetic Surface Mount Devices (SMDs)*

IPC/JEDEC J-STD-033, *Handling, Packing, Shipping and Use of Moisture, Reflow, and Process Sensitive Devices*

IPC/JEDEC J-STD-609, *Marking, Symbols, and Labels of Leaded and Lead-Free Terminal Finished Materials Used in Electronic Assembly*

IPC J-STD-003, *Solderability Tests for Printed Boards*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp/

— IEC Electropedia: available at https://www.electropedia.org/

3.1
product
any physical good that is placed on the market or put into service

[SOURCE: REGULATION (EU) 2024/1781, Article 2, Definition 1]

3.2
component
product (3.1) intended to be incorporated into another *product* (3.1)

[SOURCE: REGULATION (EU) 2024/1781, Article 2, Definition 2]

3.3
Printed Board Assembly
PBA
assembly that uses a printed (circuit) board for *component* (3.2) mounting and interconnecting purposes

Note 1 to entry: A PBA includes, besides all electronic components connected to it, also all mechanical components fixed to the PCB or one or more of its *components* (3.2) such as heat sinks, electromagnetic compatibility (EMC) shields, mechanical stiffeners, etc.

[SOURCE: IPC-T-50]

3.4
Printed Circuit Board
PCB
composite structure incorporating point-to-point interconnections for electronic circuits

Note 1 to entry: This document applies to all *PBA* (3.3) using a PCB complying to this definition irrespective of the base material used – rigid polymer, flexible polymer, ceramic, metal, or any combination of these.

Note 2 to entry: It may include embedded *components* (3.2).

[SOURCE: IPC-T-50]

3.5
electronic component
component (3.2) with an electronic function, typically mounted on a *PCB* (3.4) in a *PBA* (3.3)

3.6
package
total container which protects one or more *electronic components* (3.5) from mechanical, environmental and electrical damage throughout its operational life and which provides means of interconnection

[SOURCE: IPC-T-50]

3.7
Ball Grid Array
BGA
surface mount *package* (3.6) wherein the balls for terminations are formed in a grid on the bottom of a *package* (3.6)

[SOURCE: IPC-T-50]

3.8
leadframe
metallic portion of the device *package* (3.6) on which the integrated circuit die is mounted and connected from the die or dice bonding sites to the structure that becomes the outer leads of the *package* (3.6)

[SOURCE: IPC-T-50]

3.9
manufacturer
any natural or legal person that manufactures a *product* (3.1) or that has a *product* (3.1) designed or manufactured, and markets that *product* (3.1) under their name or trademark

Note 1 to entry: Natural or legal person with responsibility for the design, manufacture, packaging and labelling of a device before it is placed on the market under his own name, regardless of whether these operations are carried out by that person himself or on his behalf by a third party.

[SOURCE: REGULATION (EU) 2024/1781, Article 2, Definition 42, modified – Note 1 to entry has been added from ISO 7396-2:2007, 3.20]

3.10
authorized representative
any natural or legal person established in the Union that has received a written mandate from the *manufacturer* (3.9) to act on the manufacturer's behalf in relation to specified tasks with regard to the manufacturer's obligations under the ESPR regulation

Note 1 to entry: Relevant regulations are CE marking, RoHS, Reach, ESPR, etc.

[SOURCE: REGULATION (EU) 2024/1781, Article 2, Definition 43, modified – the word "this" has been changed with ESPR, Note 1 to entry has been added]

3.11
design authority
manufacturer (3.9) or its authorized representative designing a *product* (3.1) to be placed on the market

3.12
independent operator
natural or legal person that is independent of the *manufacturer* (3.9) and is directly or indirectly involved in the refurbishment, repair, maintenance or repurposing of a *product* (3.1), and includes waste management operators, refurbishers, repairers, *manufacturers* (3.9) or distributors of repair equipment, tools or spare parts, as well as publishers of technical information, operators offering inspection and testing services and operators offering training for installers, *manufacturers* (3.9) and repairers of equipment

[SOURCE: REGULATION (EU) 2024/1781, Article 2, Definition 47]

3.13
repairer
any natural or legal person who, related to that person's trade, business, craft or profession, provides a repair service, including *manufacturers* (3.9) and sellers that provide repair services and repair service providers whether independent or affiliated with such *manufacturers* (3.9) or sellers

[SOURCE: DIRECTIVE (EU) 2024/1799, Article 2, Definition 2]

3.14
professional repairer
natural or legal person that provides professional repair or maintenance services for a *product* (3.1), irrespective of whether that person acts within the manufacturer's distribution system or independently

[SOURCE: REGULATION (EU) 2024/1781, Article 2, Definition 48]

3.15
authorized repairer
natural or legal person that provides professional repair or maintenance services for a *product* (3.1), acting as *authorized representative* (3.10) for regulatory compliant refurbishment

3.16
recycler
any natural or legal person who carries out recycling in a permitted facility

[SOURCE: REGULATION (EU) 2024/1252, Article 2, Definition 58]

3.17
customer
natural or legal person that purchases, hires or receives a *product* (3.1) for their own use whether or not acting for purposes which are outside their trade, business, craft or profession

[SOURCE: REGULATION (EU) 2024/1781, Article 2, Definition 35]

3.18
user
natural or legal person that uses a *product* (3.1) whether or not for purposes which are outside their trade, business, craft or profession

3.19
repair
one or more actions carried out to return a defective *product* (3.1) or waste to a condition where it fulfils its intended purpose

[SOURCE: REGULATION (EU) 2024/1781, Article 2, Definition 20]

3.20
refurbishment
action carried out to prepare, clean, test, service and, where necessary, *repair* (3.19) a *product* (3.1) or a discarded *product* (3.1) in order to restore its performance or functionality within the intended use and range of performance originally conceived at the design stage at the time of the placing of the *product* (3.1) on the market

[SOURCE: REGULATION (EU) 2024/1781, Article 2, Definition 18]

3.21
modification
the revision of the form, fit and/or functional capability of a *product* (3.1) to satisfy new acceptance criteria

[SOURCE: IPC-T-50]

3.22
recycling
any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes

Note 1 to entry: It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.

[SOURCE: DIRECTIVE 2008/98/EC, Article 3, Definition 17]

3.23
CE marking
marking by which the *manufacturer* (3.9) indicates that the *product* (3.1) is in conformity with the applicable requirements set out in Community harmonisation legislation providing for its affixing

[SOURCE: REGULATION (EC) No 765/2008, Article 2, Definition 20]

3.24
technical specification
document that prescribes technical requirements to be fulfilled by a *product* (3.1), process or service

[SOURCE: REGULATION (EU) 2024/1781, Article 2, Definition 49]

3.25
defect
departure of a quality characteristic from its intended purpose, level or state that occurs with a severity sufficient to cause an associated *product* (3.1) or service not to satisfy intended purpose, usage, performance, quality or compliancy requirements

[SOURCE: IPC-T-50, modified]

3.26
electrostatic discharge
ESD
rapid flow of electricity between objects with different potential

[SOURCE: IPC-T-50]

3.27
reliability
probability that a *product* (3.1) functions as required under given conditions for a given duration without an occurrence which results in a primary or secondary function of the *product* (3.1) no longer being performed

3.28
base material
insulating material upon which a conductive pattern may be formed

[SOURCE: IPC-T-50]

3.29
hot air solder leveling
HASL
physical deposition process using a solder bath into which the printed board is immersed into a molten solder bath and withdrawn across a set of hot air knives used to remove excess solder

[SOURCE: IPC-T-50]

3.30
critical metals
metals that belong to the group of Critical Raw Materials (CRM) listed by the EU commission in its communication on critical raw materials in the framework of the Critical Raw Materials Act (REGULATION (EU) 2024/1252)

3.31
potting
process of molding or encapsulating with a resin or other organic compound

[SOURCE: IPC-T-50]

3.32
conformal coating
insulating protective covering that conforms to the configuration of the object coated providing a protective barrier against deleterious effects from environmental conditions

[SOURCE: IPC-T-50]

3.33
underfill
compound used to fill the space underneath an electronic device

[SOURCE: IPC-T-50]

3.34
staking adhesive
bonding or attaching of *components* (3.2), or component elements, to a surface or together by the application of small quantities of adhesive material

[SOURCE: IPC-T-50]

3.35
homogeneous material
material of uniform composition throughout or a material, consisting of a combination of materials, that cannot be disjointed or separated into different materials by mechanical actions such as unscrewing, cutting, crushing, grinding and abrasive processes

[SOURCE: DIRECTIVE 2011/65/EU, Article 3, Definition 20]

3.36
board type
PBA (3.3) type as defined by IPC-7711/21 for *repair* (3.19) procedure selection purposes

Note 1 to entry: The following types can be distinguished:

— Type R. Rigid Printed Boards and Assemblies;

— Type F. Flexible Printed Boards and Assemblies;

— Type W. Discrete Wiring Boards and Assemblies;

— Type C. Ceramic Boards and Assemblies.

[SOURCE: IPC-7711/7721]

3.37
logbook
record used to record states, events, or conditions applicable to complex machines or the personnel who operate them

[SOURCE: https://en.wikipedia.org/wiki/Logbook]

3.38
digital product passport
DPP
set of data specific to a *product* (3.1) that includes the information specified in the applicable delegated act adopted pursuant to Article 4 and that is accessible via electronic means through a data carrier

[SOURCE: REGULATION (EU) 2024/1781, Article 2, Definition 28]

3.39
exergy
amount of work or entropy-free energy a system can perform when it is brought into thermodynamic equilibrium with its environment, also referred to as “available energy” or “useful work potential”

[SOURCE: ScienceDirect https://www.sciencedirect.com/topics/earth-and-planetary-sciences/exergy]

3.40
manufactured part
part of a *product* (3.1) that is a basic part which is not an assembly of other parts and is created by the processing of *base materials* (3.28)

Note 1 to entry: The *base materials* (3.28) can be metal alloys, polymers, ceramics, semiconductors, chemicals, etc. The processes can be deposition, etching, milling, curing, etc.

Note 2 to entry: A characteristic of manufactured parts is that the separation of the *homogeneous materials* (3.35) in the manufactured part into separate material streams is often practically or economically not feasible. They are the parts at the lowest level in a system hierarchy that, typically, do not allow further disassembly.

4 Printed Board Assembly status definitions

4.1 Original state

A PBA is in the original state when it is in the state, used or not, as it was put on the market by the manufacturer without having been subjected to any type of repair or modification.

4.2 New state

A PBA is in the new state when it is in the original state without having been put into service.

4.3 Repaired state

4.3.1 General

A repair action brings a product with defects into a state which partially or completely restores the product's purpose, quality, characteristics, performance, and regulatory compliancy.

The following repaired states are defined:

a) Repaired Printed Board Assembly: the repaired product performs its intended purpose. The quality, performance, or other characteristics may differ from that of the original PBA. Repair may yield a product that is not compliant to applicable regulations.

b) Refurbished Printed Board Assembly: the repaired product performs its intended purpose. Quality, performance and other characteristics except the remaining lifetime, are restored as proven by testing approved by the product's manufacturer. Refurbishment may yield a product that is not compliant to applicable regulations.

c) Compliantly Refurbished Printed Board Assembly: the refurbished product is proven to be compliant to all regulations applicable to the original product. Its remaining lifetime may be lower than that of the new PBA.

4.3.2 Repaired Printed Board Assembly

The repairer shall follow guidance and recommended practices for ESD and other handling considerations of Printed Board Assemblies, as specified in IPC-A-610:2024, Appendix A.

A Printed Board Assembly shall be repaired as specified in IPC-7711/21 or repair instructions identified or provided by the manufacturer. The latter takes precedence over IPC-7711/21.

Repair as specified in IPC-7711/21 shall be performed by professional repairers with IPC-7711/21 certified operators, see Annex A, or equivalently qualified operators per quality-controlled training program and company specific certification auditable by third parties.

Independent operators shall be professional repairers to be able to deliver PBA with the status "repaired PBA" to third parties.

Since compliance may be lost by repair, a product with repaired PBA may require compliancy testing and approval by the manufacturer before it can be placed on the market.

4.3.3 Refurbished Printed Board Assembly

In order to be able to deliver PBA in the refurbished state, in addition to the Repaired Printed Board Assembly requirements, professional repairers shall have:

— Instructions to remove PBA from the product without creating additional damage to the PBA, other product components, and the product as a whole;

— access to the PBA's technical specifications, the detailed Bill-of-Material (BOM) and the design documentation of the PBA and its PCB, including electrical schematics, layout, PCB build-up, PCB ordering specification;

— PBA test information and set-up that is capable to assure the post-repair quality of the PBA per the manufacturer's technical specification;

— instructions to reinstall the PBA in the product in a way that the product's intended purpose, quality, and performance is restored.

A refurbished Printed Board Assembly requires the highest level of conformance as defined in IPC-7711/21.

Professional repairers acting as independent operators can only deliver refurbished PBA if the above-mentioned PBA documentation has been made public by the manufacturer or is offered by the manufacturer under contract to independent operators.

Since compliance may be lost by refurbishment, a product with refurbished PBA may require compliancy testing and approval by the manufacturer before it can be placed on the market.

4.3.4 Compliantly Refurbished Printed Board Assembly

A PBA is a component. Regulatory compliancy applies to the final product. Therefore, compliancy is achieved by a set of technical specifications applying to the PBAs in a product, to other components, and to the product as a whole.

A refurbished PBA state is a necessary but not a sufficient repair state to ensure compliance to all regulatory requirements of the product containing the refurbished PBA. Restoring intended purpose, quality, and performance repair actions may still jeopardize regulatory requirements related to e.g. EMC compliancy, electrical safety, RoHS compliancy, etc. The manufacturer should provide the technical documentation:

— to allow compliant PBA refurbishment;

— to ensure product compliancy after reinstallment of the compliantly refurbished PBA into the product, e.g. with respect to EMC and electrical safety compliancy.

Specific repair instructions as well as additional compliancy testing may be required to reinstate regulatory compliance of the refurbished product.

The manufacturer specifies if and under what conditions a (re)use of repaired or modified electronic components, e.g. reballed electronic components (Ball Grid Array), is acceptable for a compliantly refurbished PBA.

Compliantly refurbished Printed Board Assemblies can only be delivered by the manufacturer or an authorized repairer.

4.4 Modified Printed Board Assembly

4.4.1 General

A modified Printed Board Assembly is a refurbished PBA with hardware (component change) or software modifications to make changes to the PBA's functionality, performance, or any other characteristics.

4.4.2 Compliantly modified Printed Board Assembly

A compliantly modified PBA is a modified PBA that is fully compliant with applicable regulation to be put on the market.

Compliantly modified Printed Board Assemblies can only be delivered by the manufacturer or an authorized repairer that has received the authorization and means from the manufacturer to perform modifications on a manufacturer's PBA.

4.4.3 Used state

A PBA is in the used state when it has been put into service. This state shall be used in combination of the PBA states: original, repaired, refurbished, compliantly refurbished, modified, or compliantly modified.

5 Repair and Modification

5.1 General

Repair consists of a sequence of several repair actions following industry-established procedures. The repair and modification methodology for PBA prescribed by IPC-7711/21 shall be followed by the repairer.

Repair includes the following:

— Repair Procedure Selection;

— Repair Equipment and Materials;

— Component Handling Considerations;

— Component refurbishment.

5.2 Repair procedure selection

5.2.1 General

Repair procedures should be selected based on several factors and the advantages of each method.

Any repair activity may consist of the execution of several procedures in a specified order.

Each procedure contains specific indicators for:

— Levels of Conformance;

— Skill Levels;

— Board Types.

Guidance on procedure selection and application is found in Annex A.

Additionally, for further information and guidelines on selecting a process, see IPC-7711/21.

5.2.2 Levels of conformance

Electronic assembly repairs following procedures in IPC-7711/21 are attributed a specific level of conformance when successfully completed.

The level of conformance ratings is mainly based on serviceability factors but also on the skill of the repair personnel. Each repair procedure indicates a level of conformance obtained after the repair action is executed.

Levels of conformance established by IPC-7711/21 are as follows:

— Lowest Level: Significant variance with the physical character of the original and may vary with many of the electrical, functional, environmental and serviceability factors.

— Medium Level: Some variance with the physical character of the original and most likely varies with some of the functional, environmental and serviceability factors.

— Highest Level: Most closely duplicates the physical characteristics of the original and most probably complies with all the functional, environmental and serviceability factors.

For further guidance and functional considerations on the levels of conformance, IPC-7711/21 provides specific information on functional considerations as per each level of conformance in IPC-7711/21:2024, Table 1.

5.2.3 Board Types

Procedures are intended to be used on specific board types, given the nature of the substrates in each type of PBA.

Each procedure in IPC-7711/21 indicates the applicable board type for which the procedure is designed.

For definitions of specific board types and their applicable procedures see IPC-7711/21D:2024, 1.8.

5.3 Repair equipment and materials

Professional repairers shall have access to guidelines and instructions to ensure repaired or modified PBA are delivered in the envisaged state. Professional repairers acting as independent operators can only deliver refurbished PBA if the above-mentioned PBA documentation has been made public by the manufacturer or is offered by the manufacturer under contract to independent operators.

Each rework and repair procedure established by IPC-7711/21 prescribes its required tooling, equipment, and materials. These are essential to ensure that personnel performing the repair can follow the procedure successfully.

The repairer shall only use tooling, equipment, and materials prescribed in IPC-7711/21.

IPC-7711/21:2024, Section 1.12 Workstations, Tools, and Materials, provides general information on equipment, tools, and materials.

5.4 PBA and component handling considerations

5.4.1 General

A repair activity includes the handling of PBA and components that may be sensitive to moisture, soldering process conditions, chemicals, cleaning agents and electrostatic discharge. Mitigation actions shall be taken to ensure that the repair activity does not cause damage to components being replaced or subjected to repair, as well as to adjacent components.

5.4.2 Moisture, reflow and process sensitive devices handling

Components classified to sensitivity levels as established by IPC/JEDEC J-STD-020 or IPC EIA/JEDEC J-STD-075 shall follow the handling, packing, and shipping requirements for moisture, reflow, or process-sensitive devices as described in IPC/JEDEC J-STD-033.

IPC/JEDEC J-STD-033 provides a methodology for preventing damage caused by moisture absorption and exposure to solder reflow temperatures. The standard is used for mass reflow processes but also applies to single local heating actions, such as hot air rework.

The sensitivity ratings have been established by industry and are described by the following standards:

— IPC/JEDEC J-STD-020 – Establishes Moisture Sensitivity Level (MSL) criteria;

— IPC EIA/JEDEC J-STD-075 – Establishes Process Sensitivity Level (PSL) criteria.

Moisture-sensitive components removed from the PBA for reuse shall be evaluated for compatibility with dry-baking conditions of IPC/JEDEC J-STD-033. Components that can withstand the specified baking conditions shall be baked per one of the IPC/JEDEC J-STD-033 baking conditions. Components that cannot be safely baked shall be replaced. After removal, all reusable moisture-sensitive components shall be packaged and handled as described in IPC/JEDEC J-STD-033 requirements.

5.4.3 Electrostatic discharge prevention

When the repair actions involve printed board assemblies that contain components that are sensitive to electrostatic discharge (ESD), the repairer shall follow ESD guidelines as specified by IPC-A-610:2024, Appendix A, and implement a documented ESD control program following either:

— ANSI/ESD S20.20;

— IEC 61340-5-1;

as established in agreement with the manufacturer.

5.5 Electronic component refurbishment

5.5.1 General

Component refurbishment or reclamation utilizes specialized processes that require controls to ensure the physical integrity of the component and termination are maintained for component reuse.

In general, the macro process consists of the following steps:

a) Pre-baking of PBA for moisture removal;

b) Component removal via localized reflow with a controlled and appropriate time/temperature profile for thermal management (see IPC-7711/21);

c) Component termination refinishing;

d) The processes are package type specific, such as BGA reballing or alloy refresh;

e) Component cleaning to eliminate flux residues and ionic contamination;

f) Component inspection and process qualification to include the following:

   1) First Article Inspection (FAI) to assess remount reliability;

   2) Process controls, such as the use of automated optical inspection (AOI), solderability tests, X-ray inspection, electrical testing and alloy purity testing;

   3) Component handling, packaging and storage under controlled conditions, as specified in IPC/JEDEC J-STD-033.

5.5.2 Pre- and post-refurbishment drying and dry storage

Drying and components that are removed from the PBA to be reused shall be dry storage-baked as described in IPC/JEDEC J-STD-033 conditions and after removal, be packaged, handled and stored as described in IPC/JEDEC J-STD-033.

This step is especially critical to avoid moisture-induced damage as described in J-STD-020, J-STD-033 and J-STD-075 to those components for reuse. See 5.4.2 for moisture, reflow and process sensitive devices handling considerations.

5.5.3 Reballing of BGA electronic components

Ball grid array (BGA) components are non-hermetic packages that are prone to internal damage due to moisture absorption. When a BGA is removed for reuse, special considerations are necessary such as recommended maximum reflow cycles established by the component manufacturer, rework process

temperature profiles and dry-baking to avoid a popcorning effect. For specialized information on BGA rework processes, refer to process guidance on IPC-7095.

Ball grid array (BGA) components shall be reballed before reuse, as per procedures prescribed by IPC-7711/21. Refer to the following industry-adopted procedures in IPC-7711/21 for reballing:

— 5.7.4 BGA Reballing Procedure – Paper Carrier Method;

— 5.7.5 BGA Reballing Procedure – Polyimide Stencil Method;

— 5.7.6 BGA Reballing Procedure – Polyimide Solder Ball Stencil Carrier Method.

5.5.4 Leadframe based electronic components

Leadframe-based packages use a metal leadframe to create the solderable terminals and to which the electronic component structure (Integrated Circuits (IC) or non-Integrated Circuit (non-IC)) is connected. The use of plastic makes them sensitive to moisture and certain process conditions. See IPC/JEDEC J-STD-020 (non-hermetic SMD) and IPC EIA/JEDEC J-STD-075 (non-IC) for classifications of such components and identification of bake cycles required.

When this type of component is removed for reuse, the component terminations or leads shall be refinished in accordance with GEIA-STD-0006.

Solderability test for component termination or leads shall be conducted as defined in IPC J-STD-003.

5.5.5 Non-IC electronic components

Non-IC electronic components have thermal process limitations as prescribed and classified by IPC EIA/JEDEC J-STD-075. This joint standard defines evaluation procedures to classify these packages based on their process sensitivity level (PSL) rating, which is used to determine whether a component can withstand a solder assembly process while still meeting reliability and quality requirements.

When this type of component is removed for reuse, the component terminations or leads shall be refinished in accordance with GEIA-STD-0006.

Solderability test for component termination or leads shall be conducted as defined in EIA/IPC/JEDEC J-STD-003.

5.5.6 Electronic components marking

Marking and labelling of components for reuse shall be in accordance with IPC/JEDEC J-STD-609. This joint standard provides the requirements for marking of components regarding the terminal metallization used and labelling their shipping packaging. A unique identifier shall be used to enable traceability and unit-level tracking.

5.6 Repair proficiency

5.6.1 Importance of repair proficiency

The quality and reliability of a repaired product is highly dependent on the skill and competence of the individual performing the repair action. Training and certification are essential to ensure the repair action complies with the existing best industry practices and procedures.

5.6.2 Personnel proficiency

The individual performing the repair actions shall be proficient in the task to be performed. Proficiency requires personnel to be certified in IPC-7711/21 or equivalently qualified and approved by the manufacturer for authorized repairers. Objective evidence of such proficiency shall be maintained and available for review.

Supervised on-the-job training is acceptable until proficiency is demonstrated.

See Clause A.1 for further information on personal proficiency.

5.6.3 Training and certification

The electronics industry relies on the IPC-7711/21 Training and Certification program to ensure that rework and repair operations follow industry consensus procedures.

See Annex A for further guidelines in applying IPC-7711/21.

5.6.4 Skill level

The IPC-7711/21, establishes three skill levels that should be used as a guide in selecting a procedure for repair:

— Intermediate Level;

— Advanced Level;

— Expert Level.

Each repair procedure contains a skill level indicator based on industry experience. See Clause A.2 for further information on determining the skills level of the personnel.

5.7 Data collection for repair

5.7.1 Mission tracking

Depending on contractual and regulatory restrictions the manufacturer of the product with embedded PBA may implement means to monitor and track the use of the product and its status for reasons like customer support, maintenance, reuse, etc. If available, the manufacturer shall grant access to its authorized repairers and may grant access to independent professional repairer to use this information to evaluate the viability of executing a repair with respect to remaining lifetime, economic viability, quality and reliability risks, etc.

5.7.2 Product logbook

It is recommended to log all maintenance and repair events as well as all exceptional events that may have an impact on the reliability of a product, in a product logbook that should be used by the repairer for evaluating a repair.

NOTE Regulation EU 2024/1781 ESPR specifies requirements for the digital product passport. Specifically, the product parameters are described in Annex I.

5.8 Authority determination

5.8.1 Responsibilities regarding repairability of PBA and compliance of products with repaired/refurbished/modified PBA

Only regulatory compliant products can be placed on the market, e.g. CE certified products. According to EU 2024/1781 Regulation ESPR Article 44 the manufacturer of a product bears full responsibility of the compliancy of the products it places on the market. Therefore, only manufacturers or their authorized representatives can place a refurbished or modified product on the market. These refurbished or modified products shall be in the compliant product state.

Removal of PBA for reuse shall be performed by a professional repairer. For compliant reuse, the repairer shall be an authorized repairer.

The manufacturer shall make available the list and contact information of its authorized repairers.

The manufacturer is encouraged to define repair and modification actions which are allowed to be executed by independent operators without losing regulatory compliancy that is under the manufacturer's responsibility. Such acceptable actions can be the replacement of PBA or other components of a product by approved spare parts.

The manufacturer shall make the instructions for these actions publicly available as part of the product's user or maintenance manual. If required, the instructions shall define the use of specific tools for disassembly and reassembly. If applicable, (dis)assembly tools shall be delivered together with the product for parts that need regular replacement. The manufacturer shall provide correct and clear instructions to execute the repair actions safely and with a minimal probability of damaging the product or its components. The instructions may specify the required skill level of the repairer.

Compliant refurbishment or modification of product components, such as PBA, are typically out of scope of independent repairers. With proper repair instructions the manufacturer can make an exception to this general rule.

If the manufacturer has information that is helpful in reducing the risks of repair processes, it shall be made accessible to the repairer. This information may include, for example, indications of which toxic substances are released during thermal processes, e.g. desoldering a conformally coated component.

5.8.2 Documentation, certification and labelling

All repair actions shall be documented.

1) For the product, this documentation shall at least contain:

    a) date of repair;

    b) list of repairs;

    c) list of replaced parts and full identification of the spare parts used. The latter can be a repaired PBA. Specification of the tests performed to ensure quality of repair;

    d) if applicable, specification of tests performed to ensure final product compliancy.

2) For the repair of a PBA, this documentation shall at least contain:

    a) date of repair;

    b) list of repairs;

    c) for all repairs, identification of the repair procedures as described in IPC-7711/21 or per manufacturer's repair instructions;

    d) identification of PBA components (electronic or other) that are replaced (location, circuit reference (if available), type) and the detailed identification of the replacing component (component ID, supplier, Manufacturer Part Number);

    e) specification of the tests performed to ensure quality of repair;

    f) if applicable, specification of tests performed to ensure final product compliancy.

3) For compliantly refurbished or modified PBA the manufacturer or its authorized repairer shall provide:

    a) all the required certifications per CE certification;

b) a new CE marking (see Articles 44 to 47 of EU 2024/1781 (ESPR));

c) an indication of its compliantly refurbished state and date of refurbishment;

d) if there is insufficient room on the product, labels or their content shall be added on the package and in the product documentation.;

e) all other certifications that may be required to operate the refurbished or modified PBA in the envisaged application compliantly shall be provided.

5.8.3 Design-for-Repair

5.8.3.1 Product Design-for-Repair

The manufacturer should maximize the repairability of a product. Accessibility and possibility to disassemble and reassemble repaired product components is essential for repairability. The following Design-for-Repair actions at product level should be applied by the design authority related to the PBA embedded in the product:

— the PBA is accessible and can be removed without requiring extensive disassembly of the product;

— the PBA can be accessed and removed without compromising the ability to reassemble the product in its original, compliant condition;

— the PBA can be electrically and mechanically disconnected from the product without compromising the ability to reconnect it in its original, compliant state;

— the use of special disassembly and reassembly tools should be avoided;

— create PBA removal instructions for repair or reuse;

— create PBA (re)installment instructions.

Permanent connection methods shall be avoided for interfaces that must be disconnected during repair procedures. This includes connections that are soldered, welded, glued, riveted or connected by any other method that requires destructive deconnection. As an alternative, reconnectable technologies such as bolts, screws, electrical connectors, clamps or similar methods should be used. To allow ease of deconnection and reconnection the connections should be accessible and provide sufficient room for tool placement and use. Any potential negative impact of the selected method on the product's reliability should be minimized.

5.8.3.2 PBA Design-for-Repair

To enable professional repairers to perform PBA repairs in accordance with IPC-7711/21 or an equivalent standard, the design authority should implement appropriate design-for-repair measures during the design phase, while carefully evaluating the impact of these measures on the overall reliability of the PBA:

— no use of potting. Potted PBA are unrepairable;

— no use of conformal coating. If unavoidable, a coating that can be chemically or mechanically removed locally should be selected. Clear instructions shall be provided for its reapplication;

— no use of component underfill. If unavoidable, a repairable underfill should be selected. Clear instructions shall be provided for its reapplication. The use of repairable underfill may have a negative impact on the reliability of the PBA by increasing solder joint fatigue;

— no use of staking adhesives. The absence of staking adhesives can have a negative impact on the robustness and reliability under vibration of the PBA;

— make mechanical components such as EMC shields, heatsinks, and stiffeners easily removable; Provide instructions for their proper reassembly; For heatsinks, specify the thermal interfacing material and its proper application;

— connect daughter boards to mother boards using connectors to provide access to components underneath the daughter boards. The use of connectors may have a negative impact on the reliability of the PBA by introducing contact wear as a reliability hazard;

— put components with a limited lifetime or that are upgradable or expandable in capacity like memory ICs, in sockets;

— provide sufficient room around IC components with bottom-side contacts like Ball Grid Arrays:

  — 4 mm free of neighbouring IC components;

  — 2 mm free of neighbouring non-IC components such as resistors and capacitors.

— select PCB base materials that allow two IC replacements per IC. This implies six solder cycles on top of the number of soldering processes required to assemble the PBA. For Hot Air Solder Levelled (HASL) PBA, add two additional solder steps. For repair with lead-free solder this typically implies the use of mid- or high- performance lead-free solderable laminates as described by IPC-4101 and for board type R PBA by IPC-7711/21;

— create PBA compliant refurbishment instructions for the authorized repairer.

6 Recycling

6.1 General

The Full Material Declaration (FMD) provided by the manufacturer for its products should provide the recycler with the location and the amounts of valuable materials. It is the basic source of information for recycling optimisation. The content and responsibilities regarding the FMD are specified. Technical documentation and disassembly instructions should help the recycler to optimize waste streams and to allow the selective removal of components. Design-for-Recycling recommendations to facilitate recycling by the manufacturer are given.

6.2 Proficiency to recycle electronics

To maximize recycling efficiency the recycler of products containing electronics should obtain basic knowledge:

— of the use of materials in electronics;

— where the most valuable and critical metals are typically located in electronics, including PCB, PBA, electronic components, cabling, and mechanical parts.

This will allow the recycler to optimally sort PCB and electronic components towards the proper metal recycling processes.

6.3 Data collection

6.3.1 Full Material Declaration

6.3.1.1 General

The manufacturer shall provide a full material disclosure of the products it places on the market. The material disclosure shall specify the composition of materials including detailed chemical identification (CAS number, chemical formula) and the weight of the constituting elements, for all its components at the homogeneous material level.

Regulation EU 2024/1781 ESPR specifies requirements for the digital product passport. The FMD shall meet the requirements of the DPP, specifically the product parameters that should be provided described in Annex I (f).

In addition to complying with all applicable legal requirements for material declarations, a reference shall be provided to the full material declaration, which specifies the location and quantity of the substances to which the declarations apply.

The product full material disclosure allows the recycler to identify which materials are located where and in which concentrations in the product and its components such as its PBAs.

The manufacturer shall make the product FMD publicly and electronically accessible through its proprietary database or, preferably, through publicly accessible databases.

NOTE Electronics can have hundreds or thousands of components sourced from multiple tiers of suppliers. Tracing materials through each tier is time-consuming and often opaque. Suppliers may be reluctant to share detailed material data due to concerns like intellectual property. Gathering, validating, and maintaining FMD data requires significant time, expertise, and tools, especially for small and medium-sized enterprises. These challenges mean that FMD is not currently available for all parts. Yet, FMD is necessary for a circular economy. FMD enables faster and more accurate responses to regulatory changes, audits, and customer requests, and knowing the full material content is essential for recycling and reuse. Without precise knowledge of what substances are present in a product, recyclers cannot safely or efficiently separate and process materials. Accurate recycling assessment, including recovery rates, energy use, emissions, and exergy, requires detailed knowledge of chemical composition, material combinations, and how components are connected. High-quality secondary raw materials and effective design for recycling depend on this precision. A circular economy also relies on knowing what materials are present and available in the market. Without FMD, such distinctions are impossible to automate or scale, leading to downcycling, hazardous waste, or missed recovery opportunities. Additionally, full visibility into materials helps identify supply chain vulnerabilities and improve risk management as it supports sustainable product development and circularity.

6.3.1.2 PBA

For the PBA the product manufacturer shall provide a FMD as described in IPC-1752B class D or equivalent. The FMD shall include at homogeneous material level:

— FMD of all components;

— FMD of the PCB;

— FMD of the materials added in Printed Board assembly (solder, adhesives, no-clean fluxes, etc.) in their final state in the assembly, e.g., $SnAg_3Cu_{0.5}$ solder alloy, not solder paste.

6.3.1.3 Accuracy of Full Material Declaration

The composition of a homogeneous material shall be specified with an accuracy of 0,1 mass fraction in % point.

For substances that may vary in concentration due to manufacturing process variations or due to variations of natural origin, the concentration or weight range shall be specified by either:

— a minimum, maximum and typical value, e.g., phosphorous in electroless nickel: min. 5,7 %, typical 7,6 %, max. 10,2 %;

— a median value and a minimum to maximum concentration range for symmetrically distributed variations around the median, e.g., Ag in $SnAg_3Cu_{0.5}$ solder alloy: (3,0 ± 0,2) %.

Substances of the homogeneous material below 0,1 % mass fraction do not need to be declared except when required per regulations, e.g., 0,01wt% for Cd per Restriction on Hazardous Substances (RoHS) directive.

In a manufactured part, the composition of homogeneous materials that constitute less than 0,1 % mass fraction of the manufactured part do not need to be declared in detail except when required per regulations. For example, metal interconnect and dielectric layers of ICs do not need to be declared except if they contain regulated substances like lead in PZT ferroelectric layers per RoHS directive. If the IC's transistor and interconnect structure constitute less than 0,1 % mass fraction of the silicon die, the IC die can be declared as 100 % silicon.

When the total amount of homogeneous materials that individually constitute less than 0,1 % mass fraction of the manufactured part, constitute more than 0,1 % mass fraction of the manufactured part, they can be collected in a material category "Miscellaneous materials" for which:

— the total mass and the composition are specified;

— the weight of those constituents of the "Miscellaneous materials" collective that make up as a whole 0,1 % mass fraction or more of the part are specified.

The sum of the weight of all its constituents shall sum to the total weight of the homogeneous material.

The weight of all homogeneous materials making up a part will sum to the total weight of the part.

6.3.1.4 Substance identification

Substance identification shall be as follows, in order of decreasing preference:

a) Substances shall be identified by their CAS registry number;

b) Mixtures of substances making up a homogeneous material that does not have a CAS registry number assigned, shall be identified by the CAS registry number of their constituents and their weights or weight percentages;

c) Substances that have no CAS registry number shall be identified by their chemical formula identifying all chemical elements and their number, e.g., silicon nitride is identified as Si_3N_4 not SiN. Additionally, information regarding the material's nature relevant for recycling should be provided, e.g., solid phase state: amorphous, crystal type, or other.

d) Substances that cannot be identified using CAS registry numbers or chemical formulas, should be described as accurate as possible using internationally standardized material nomenclature such as ISO 1043 series for plastics, ISO 1629 and ISO 18064 for elastomers, EN 10027 series for steel, EN 573 series for aluminium alloys, etc.

6.3.1.5 Right of non-disclosure

Regulated substances need to be declared per applicable regulation.

Industry standards may mandate the declaration of additional substances.

For trade secret reasons and for substances not belonging to the above, the manufacturer has the right not to disclose publicly and in detail up to 10 % of the total mass fraction of a homogeneous material. The information should be available to authorized representatives and users on a need-to-know basis, and to governmental institutions if required per regulations.

To allow safe, quality repair and modification, and for efficient recycling, non-disclosed substances in homogeneous materials shall at a minimum be specified by:

a) their weight;

b) their functionality in the homogeneous material being declared and that belongs to following material categories:

    1) Polymers:

        i. Plasticizer

        ii. Flame retardant

        iii. Filler: thermomechanical properties

        iv. Filler: electromagnetic properties

        v. Filler: optical properties (pigment, UV resistance…)

        vi. Copolymer

        vii. Other: describe

    2) Metals and alloys:

        i. Alloying element: mechanical properties

        ii. Alloying element: electromagnetic properties

        iii. Alloying element: optical properties

        iv. Alloying element: corrosion and wear

        v. Filler: thermomechanical properties

        vi. Filler: electromagnetic properties

        vii. Filler: optical properties

        viii. Filler: corrosion and wear

        ix. Other: describe

    3) Ceramics:

        i. Filler: thermomechanical properties

        ii. Filler: electromagnetic properties

        iii. Filler: optical properties

iv. Filler: corrosion and wear

v. Other: describe

4) Glass:

i. Glass compound: mechanical properties

ii. Glass compound: electromagnetic properties

iii. Glass compound: optical properties

iv. Glass compound: corrosion and wear

v. Filler: thermomechanical properties

vi. Filler: electromagnetic properties

vii. Filler: optical properties

viii. Filler: corrosion and wear

ix. Other: describe

5) Semiconductors:

i. Doping

ii. Other: describe

6) Liquids and pastes:

i. Chemical compound: mechanical properties

ii. Chemical compound: electromagnetic properties

iii. Chemical compound: optical properties

iv. Chemical compound: degradation

v. Filler: thermomechanical properties

vi. Filler: electromagnetic properties

vii. Filler: optical properties

viii. Filler: degradation

ix. Other: describe

c) their nature:

1) Inorganic:

i. Metal, metal alloy

ii. Ceramic

iii. Glass

iv. Semiconductor

v. Inorganic chemical: acid, base, salt…

vi. Other: describe

2) Organic:

i. Polymer

ii. Biomaterial

iii. Organic chemical: acid, base, alcohol, …

iv. Metal-organic compound, e.g., anti-tarnishing and brightener compounds in metal finishes.

v. Other: describe.

6.4 Authority Determination

6.4.1 Full Material Declaration responsibilities

The manufacturer shall provide the FMD for the product it places on the market, including all of its components.

For creating the FMD of a PBA, the following steps should be taken:

a) The manufacturer or its design authority shall collect the FMDs of all the components in the Bill-of-Material of the PBA from the component suppliers.

b) The manufacturer or its design authority shall create the FMD of the PCB based on the PCB design and the FMD of the base materials (laminates), solder mask, and all other materials added. PCB suppliers should collect FMD information from their material suppliers to make it available to their customers. The design authority may delegate the creation of the PCB FMD to its PCB or electronics manufacturing service provider; however, it retains ultimate responsibility for its accuracy and completeness.

c) The manufacturer or its design authority shall create the FMD of the PBA based on the FMDs of the components, the FMD of the PCB, the PBA design which determines the type and mass of materials such as solder and adhesives added, and the FMD of the assembly materials used. An electronic assembly service supplier should collect FMD information from its material suppliers to make it available to its customers. The design authority may delegate the creation of the FMD to its electronic manufacturing service provider; however, it retains ultimate responsibility for its accuracy and completeness.

6.4.2 Responsibilities related to recycling of PBA

The manufacturer should maximize the recyclability of its products. Ease of disassembly of the product and sorting of its components according to their material content are essential to maximize recyclability of the product.

Since PBAs typically contain high-value and critical metals, manufacturers should design products to allow easy removal of the PBA. In recycling scenarios, PBA removal may involve destructive processes affecting both the product and the PBA, and reassembly is not possible. To support proper recycling, manufacturers should provide clear, publicly accessible instructions for PBA removal.

Whenever possible, the recycler should:

— establish specific metal recycling flows, e.g. for low value metals (Fe, Al, etc), high value metals (noble metals, Cu, Sn, etc.), specific metals (Ta, Co, etc);

— gain knowledge about the materials used in PBA, its PCB and its components for sorting purposes;

— identify the product to be recycled;

— obtain the disassembly instructions for product and PBA;

— obtain the FMD of the product and its components;

— remove PBA per removal instructions for recycling;

— remove mechanics such as heatsinks, shields, stiffeners from the PBA;

— desolder electronic components;

— using the FMD information or technology knowledge-based sorting techniques, sort PBA components and PCB with respect to their suitability to enter the recycling flow with the highest recyclability efficiency;

— avoid shredding of PBA prior to desoldering of components.

6.4.3 Disassembly instruction for recyclers

6.4.3.1 Product disassembly

The manufacturer of products with embedded PBAs shall provide a dedicated disassembly instruction to allow the recycler to remove PBA from the product for recycling that consists of at least the following structure:

— product identification;

— drawings of the product build-up indicating the location of PBAs;

— disassembly instructions;

  — step by step documentation of the disassembly;

  — recommended tools for disassembly;

— product Bill-of-Materials with FMD per component;

  — for PBA as specified in IPC-1752A, class D or equivalent, e.g. International Material Data System (IMDS) for automotive PBA.

6.4.3.2 PBA disassembly

If applicable the manufacturer may:

— supply instructions for the removal of certain components from the PBA;

— identify electronic components that cannot be removed by (mass) desoldering.

If the manufacturer has information that is helpful in reducing the risks of recycling processes, it should be made accessible to recyclers. This information may include, for example, indications of which toxic substances are released during thermal processes.

6.4.3.3 Information for selective removal of components

For selective removal of components, it is necessary to have information on the position of the components to be removed selectively.

A layout with position of the components and component identification is required and should be obtained from the manufacturer by the recycler.

6.4.4 Design-for-Recycling

6.4.4.1 Product Design-for-Recycling

The manufacturer should maximize the recyclability of a product. Possibility to disassemble the product is essential to recyclability maximization, see Annex B. The following Design-for-Recycling actions at product level should be applied by the design authority related to the PBA embedded in the product:

— PBA is accessible and removable as a whole from the product prior to shredding of the product. Electrical and mechanical connections between PBA and the product may be irreparably broken;

— create PBA removal instructions for recycling.

To allow ease of disconnection the connections should be accessible and provide sufficient room for disconnection tool placement and use.

6.4.4.2 PBA Design-for-Recycling

To allow a recycler to maximize recycling efficiency, the following PBA design-for-Recycling actions should be taken by the design authority:

— put power electronics which contains a high amount of low value metals like Fe and Al on a separate PBA;

— avoid the use of potting. Potting makes PBA disassembly impossible;

— avoid the use of thermo-hardened underfills or adhesives like epoxies that attach components to the PCB. Such components cannot be desoldered from the PCB;

— facilitate the disconnection of mechanical components such as EMC shields, heatsinks, and stiffeners. Disconnection may be destructive, e.g. using breakable connections. Such connections should not jeopardize the PBA’s robustness or reliability.

Annex A
(normative)

Applying IPC-7711/21

A.1 Guidelines for Personnel Proficiency

A.1.1 General

Authorized repair personnel are certified under the training and certification program of IPC-7711/21 to become proficient in the task to be performed. This training exposes the personnel to many repair procedures, following the electronics industry's step-by-step procedures to successfully complete the repair activity.

A.1.2 Training and Certification to IPC-7711/21

The Certified IPC Specialist (CIS) Certification is modular and may be tailored to the type of repair activity needed. Workmanship skills/inspection modules are categorized as follows:

a) Wiring:

   1) Wire Splicing Module

b) Through Hole Technology:

   1) Through-Hole Components Module

c) Surface Mount Technology:

   1) Chip and MELF Components Module

   2) Gull Wing Components Module

   3) J-Lead Components Module

d) Board Level Repair:

   1) PWB Circuit Repair Module

   2) Laminate Repair Module

e) Coatings:

   1) Conformal Coating Module

IPC-7711/21 Certificates display the following information:

— Name of certified individual;

— Date of completion of mandatory module;

— IPC-7711/21 Certified IPC Trainer (CIT) name and company/employer;

— Certification expiration date;

— Workmanship skills/inspection modules completed date.

All instructors involved in repair activities shall be certified to IPC-7711/21 as Certified IPC Trainers. This certification is not modular since the instructors have to be able to train repair personnel on any module of the Certified IPC Specialist program.

Certifications are issued to individuals, are non-transferable, and remain active for 24 months as prescribed by IPC policies and procedures.

A.2 Guidance for skill level

The IPC-7711/21 establishes three skill levels that are used as a guide when selecting a procedure for repair. These levels are defined by IPC-7711/21 as:

— Intermediate Level: Technician with skills in basic soldering and component rework but inexperienced in general repair/rework procedures;

— Advanced Level: Technician with soldering and component rework skills and exposure to most repair/rework procedures but lacking extensive experience;

— Expert Level: Technician with advanced soldering and component rework skills and extensive experience in most repair/rework procedures.

These levels serve as a guide. They are intended to provide a difficulty rating of each procedure and assist in the selection of a method based on the operator's skill.

A.3 Guidance for procedure selection and application

The intended PBA product functionality determines the primary considerations when selecting the procedures to be used in a repair activity.

It is established by combining the indicators that each procedure contains in IPC-7711/21. The order in which the procedures are applied and the procedures selected have a critical impact on the repaired PBA.

The order in which the activity is performed is crucial to the repair action, typically the repair action consists of:

a) PBA preparation: For example, baking of the PBA to remove moisture and avoid entrapped moisture-related defects;

b) coating removal: Many PBA are protected with conformal coating or other coatings that are used to prevent ingression of moisture in their service environment;

c) component removal: Selecting the adequate method for removing the component on the PBA;

d) land preparation: Before a new component can be installed, the lands on the PBA must be prepared for installation;

e) component installation: Selecting the method in which the new component will be installed on the PBA;

f) cleaning of rework area and PBA: The cleaning procedure must be followed to ensure any FOD is removed from the surface of the PBA;

g) coating replacement: re-application of protective coatings to adhere to the product's intended end-use environment requirements.

Consider the available tooling and equipment, the skill level of the personnel performing these actions, and the type of printed board of the PBA to be repaired.

As previously mentioned, the repair activity may consist of executing several procedures in a specified order.

EXAMPLE Serving as a guide on the replacement of a QFP IC (Quad-Flat Pack Integrated Circuit) in a PBA may include the following procedures:

1) Baking of the PBA Procedure (i.e. IPC-7711/21:2024, 1.14.1 Conditioning – Baking and Preheating);

2) Conformal Coating Removal Procedure (i.e. IPC-7711/21:2024, 1.14.2 Conformal Coating Removal);

3) SMT Component Removal Procedure (i.e. IPC-7711/21:2024, 3.7.7 Gull Wing Removal (four-sided) – Hot Gas (Air) Reflow Method;

4) SMT Land Preparation Procedure (i.e. IPC-7711/21, :2024 4.1.2 Surface Mount Land Preparation);

5) Component Installation Procedure (i.e. IPC-7711/21:2024, 5.5.1 Gull Wing Installation – Multi-Lead Method – Top of Lead);

6) Cleaning Procedure (i.e. IPC-7711/21:2024, 1.14.3 Cleaning);

7) Coating Replacement Procedure (i.e. IPC-7711/21:2024, 1.14.3.2 Coating Replacement – Conformal Coating/Encapsulation).

Annex B
(informative)

Current state of the art regarding recycling

Recycling processes convert linear value chains into circular economy systems. The degree of circularity and hence Circularity Data for End of Life (EoL) achieved strongly depends on the effectiveness and efficiency of recycling and, therefore, these need to be quantified. The recycling system of complex PBA containing products consists of a combination of physical separation (shredding/sorting) combined with the unmixing of complex designed mixtures of functional materials in metallurgical and other end processing technologies. Recent developments and insights in recycling system set-up have proven that additional, selective disassembly can contribute significantly to improve the recycling rate of elements and materials of interest (such as critical raw materials) as well as of connected materials and elements in a specific module or part by reducing the multi-material complexity of parts and/or products, which complicates and limits recycling due to physics and process thermodynamic reasons (nature laws) (see Ballester et al, 2017). When disassembled parts are being directed to the most suitable final treatment processing infrastructures, this can result in optimised recovery, reduction of losses and emissions, and higher quality levels of recovered materials. The latter is essential in view of realising true Circular Economy (CE).

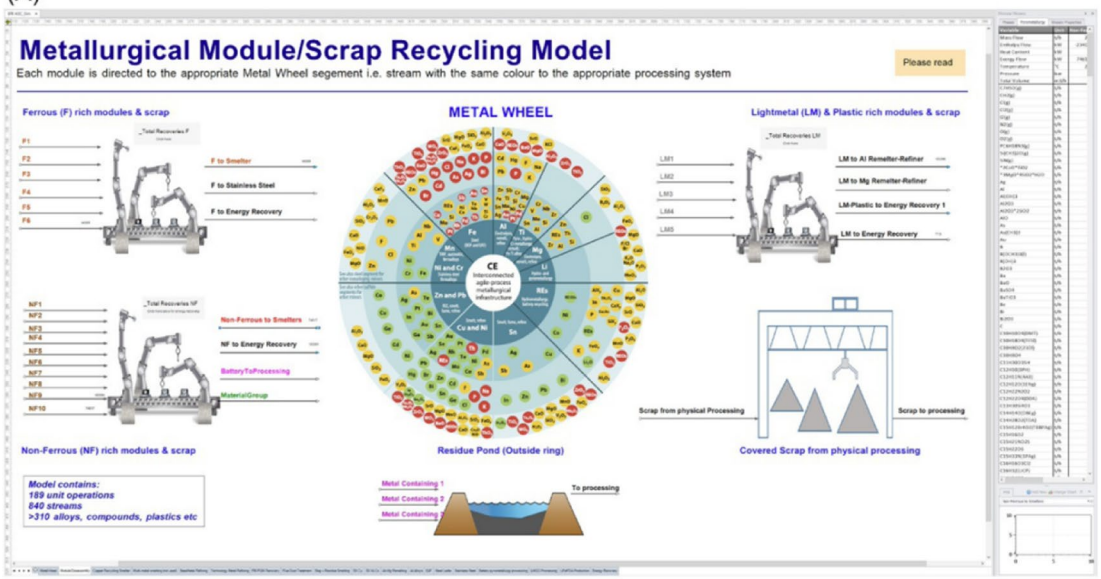
Like production processes, recycling processes consume resources to recover valuable materials from the end-of-life products treated. Their resource efficiencies and contribution to CE are determined by the types and quantities of resources consumed, the quantities of wastes and treatable residues generated, the efficiency with which the desired elements, compounds or materials are recovered within that process, and the quality at which they are recovered.

Sophisticated computer-based modelling tools exist that enable the evaluation of all these parameters that effect the CE of a product and allows to provide CE relevant recyclability data (see Reuter et al., 2019, Reuter and Van Schaik, 2023; Van Schaik and Reuter, 2024). These process simulation models provide a digital twin of disassembly, liberation and sorting processing linked to Best Available Techniques (BAT) in metallurgical recycling processing infrastructures as depicted by the Metal Wheel in Figure B.1. It also includes other applicable final treatment processes such as energy recovery processing as present in industry for the processing and recovery of all materials and compounds included in the PBA (or any other part/component under consideration). A rigorous simulation-based approach based on the physics and chemistry of the system is available and provides the basis for a dynamic (flexible over time) and reliable harmonization method to calculate recycling rates and the Recycling Efficiency (RE) of the CE system, in which the influence of EoL processing and product type/design are considered. This approach allows for the calculation of mass, energy, and exergy balances for the processing of all materials and elements, compounds, alloys, etc., present in products, with exergy being a key aspect that defines the efficiency of CE and providing a key EoL Circularity KPI. It permits the calculation of material-specific recycling rates, depending on, e.g., product, product category, and design. This rigorous economic and physics-based understanding of technology and systems for recycling make it possible to make informed decisions over the CE system and understand and capture the factors crucial for CE and provide the data on recycling and circularity based on linking Beginning-of-Life (BoL) with EoL on the basis of well-organised and structured data availability on PBA full composition (see 6.3.1). Rigorous simulation will also provide a thermodynamic basis for the environmental impact analysis. This includes the design and recycling route-dependent recoveries, losses, and the environmental footprint of any created residue. The generated information can be linked to commercially available and open-source Life-Cycle Analysis software tools. Through this link, it is possible to evaluate the environmental impact of different designs and scenarios based on actual environmental impact, linked to the mass and material flows and the

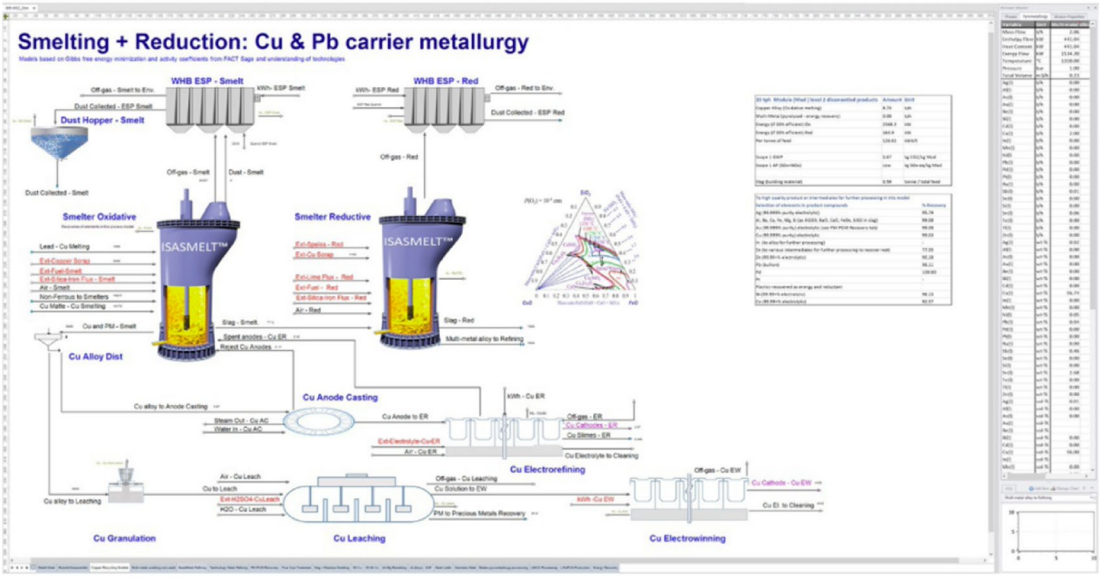
detailed compositions of each stream. This is not possible based on general databases as often applied in LCA and databases.

At the same time, with these tools, Design for Recycling (DfR) hotspots can be identified, appropriate design adjustments can be prioritized, and their impact on resource efficiency can be quantified on a recycling industry physics and thermodynamic reality basis.

(A)



(B)



NOTE The tabs show all the involved technologies to realize the CE recycling

Figure B.1 — A complete simulation model for the recycling of complex consumer products and PBAs providing circularity data on recycling (applied to e.g. mobile phones, WEEE goods, laptops, LED lamps, and car electronics) made in process simulation software

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