OPEN ACCESS
Scholars Bulletin
Abbreviated Key Title: Sch Bull
ISSN 2412-9771 (Print) |ISSN 2412-897X (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com

Subject Category: Engineering

Printed Circuit Boards and the Possibility of an Environmentally Friendly Substrate

Oludewa Popo[1], Joel Arumun [2*]

[1]Alumni, Sheffield Hallam, University, United Kingdom
[2]Alumni, University of Huddersfield, United Kingdom

DOI: https://doi.org/10.36348/sb.2025.v11i06.002 | **Received:** 07.04.2025 | **Accepted:** 15.07.2025 | **Published:** 19.07.2025

***Corresponding author:** Joel Arumun
Alumni, University of Huddersfield, United Kingdom

Abstract

Increase in the demand for consumer electrical and electronics equipment which is driven in part by the rate of technological advancements invariably gives rise to more products requiring the use of circuit boards. This paper analyses the manufacturing process of printed circuit board (PCB), disposal of waste PCBs at the end-of-life and how it affects the environments. Legislation on production and waste disposal was also be examined with specific interest in how these laws affect production and sustainable alternative ways to manufacture PCBs. Research into new types of environmentally friendly printed circuit boards, with particular interest in the recycle and re-use of the boards and components respectively and the life cycle assessments (LCA) which analyses the entire life phase of PCBs. In conclusion, the paper confirms the possibility of developing an environmentally friendly circuit board as an alternative to PCB.

Keywords: Circuit Boards, Substrate, Pollution, Environment, Legislation, Sustainability.

1.0 INTRODUCTION

Printed circuits boards, originally called printed wiring boards are used for a vast number of applications in electrical and electronics engineering and can be referred to as the backbone of most electronic products and devices, providing mechanical support and electrical interconnectivity for electronic components [1].

[1,2] both agree that the use of available convention PCB's either as a flexible or rigid substrate depends on its application. Rigid printed circuit boards utilised in electronics products are constructed in three design types: single sided, double sided being the most commonly manufactured and multiple sided boards. Flexible PCBs are not are widely used as the rigid type but the growing need for more versatile electronic products has garnered interest in researching more into this area.

1.1 Manufacturing Process of PCBs

The industrial manufacturing and assembly process of PCBs is a very expensive and tedious process. The dual functionality of PCB's further affects the manufacturing process as the complexity and demanding steps required during production can sometimes be up to 50 steps [2]. According to [3,4], these processes which are chemical-intensive are akin to the same type of processes that are utilised in the electroplating and metal finishing industries.

The materials required for the manufacture of PCB substrates include laminate, epoxy resin-coated copper, and pre-impregnated materials [3]. Furthermore, [1] further illustrates that depending on the composition of the laminate, the materials can be sub-divided into ceramics, fibre glass, paper, composites and polymeric materials which serves as a specialty product in the fabrication process flow as shown in Figure 1.

1.2 Limitations

Some of the limitations associated with the current manufacturing process as highlighted by [3] and [6] are the hazardous waste water generated during etching and rinsing process which use organic and inorganic chemicals that contaminate water streams. The use of high temperature and labour-intensive force to manually disassemble electronic components and semiconductors from the PCB's during the process of recycling renders 90% of the components unfit for reuse.

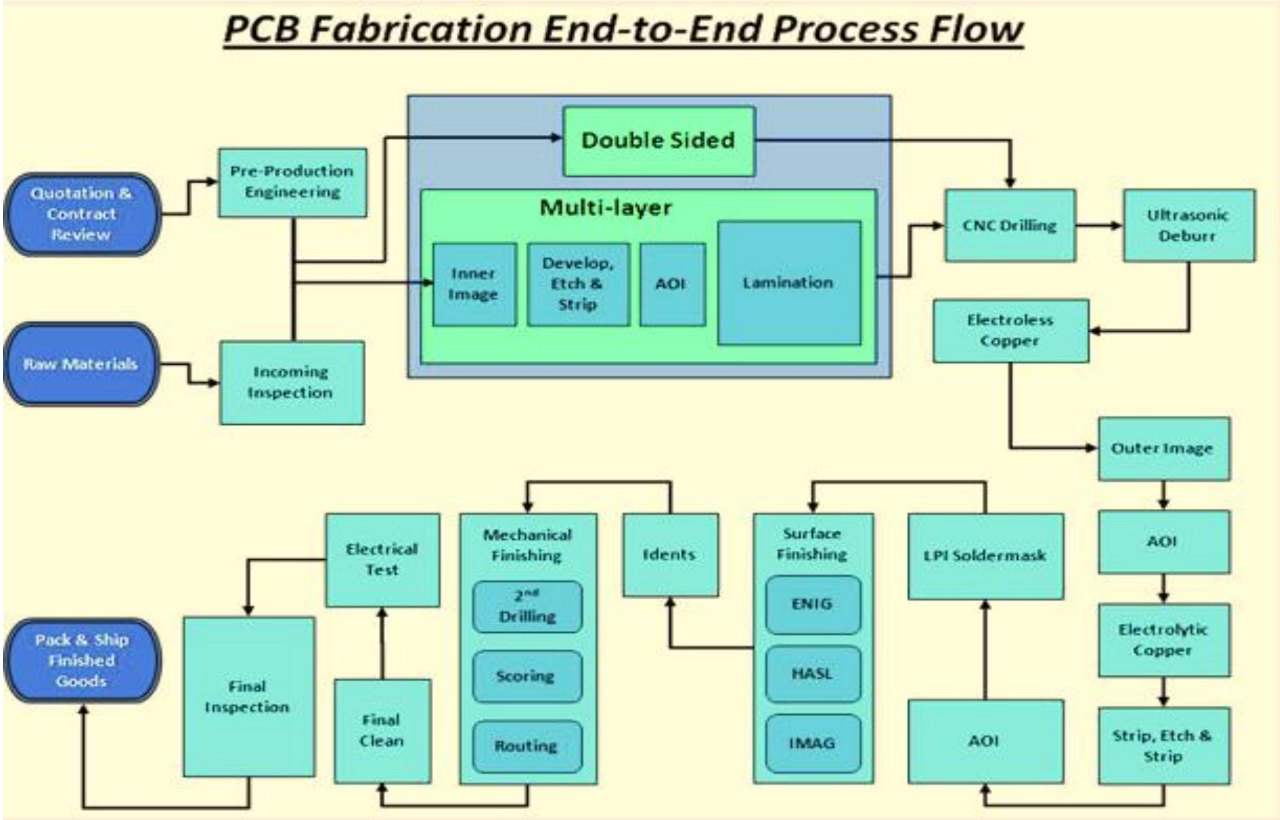

Figure 1: End-to-End process flow of PCB fabrication [5].

Similarly, [4] highlights the detrimental health concerns attributed to the variety of waste which comes in different forms like solids, liquids, gases and consists of composites, metals, tooling, catalysts and fixture waste that are eluted during the production process. [7] suggests that to mitigate the problems associated with the contamination of water stream, the developed halogen-free laminates, fluxes and solder paste will eradicate only a very small percentage of the problems with volume of PCB production still on the rise [8].

2.0 SUSTAINABILITY OF PRINTED CIRCUIT BOARDS

2.1 Waste PCBS

According to [9], the growing challenge of e-waste management are based mainly on the rapid growth of Waste Electrical and Electronics Equipment (WEEE) and their complexity, compared to other forms of waste streams, e-waste are the most complex because of the diverse variety of the products. [10] states that the annual household e-waste in China alone is about 200million which will grow annually by an estimated 12.3million tons. Figure 2 shows the process by which waste is managed in China from manufacturer to disposal.

2.2 Environmental Effects of PCBs

[3, 11] both agree that the chemicals used during manufacturing process of PCBs has a major effect on the environment. Processes such as the preparation of the surface of the board, application of catalyst, etching, and rinsing make use of organic solvents which when disposed of, end up in the waste streams. These streams contain a high metal concentration and solution of the chemicals used during the etching process. The hazardous environmental and harmful health problems caused by the contamination of the soil are of great concern and have brought about laws and directives in an attempt to contain the problem.

2.3 Recycling Methods

The increasingly difficult means of disposing of e-waste and in particular PCBs is a worldwide problem with major toxicological effects; the current recycling techniques used for waste PCBs include both chemicals and physical methods [12]. According to [13] smelters have been used to recover noble metals like platinum, gold, silver, palladium, base metals and copper from the scrap of waste PCBs. These metals which are found in larger quantities in high-end electronics have economic value of thousands of US dollars per metric ton. The smelting process is carried out in hot furnaces and leaves a by-product of slag and metallic-oxide filter dust that have a negative impact on the environment.

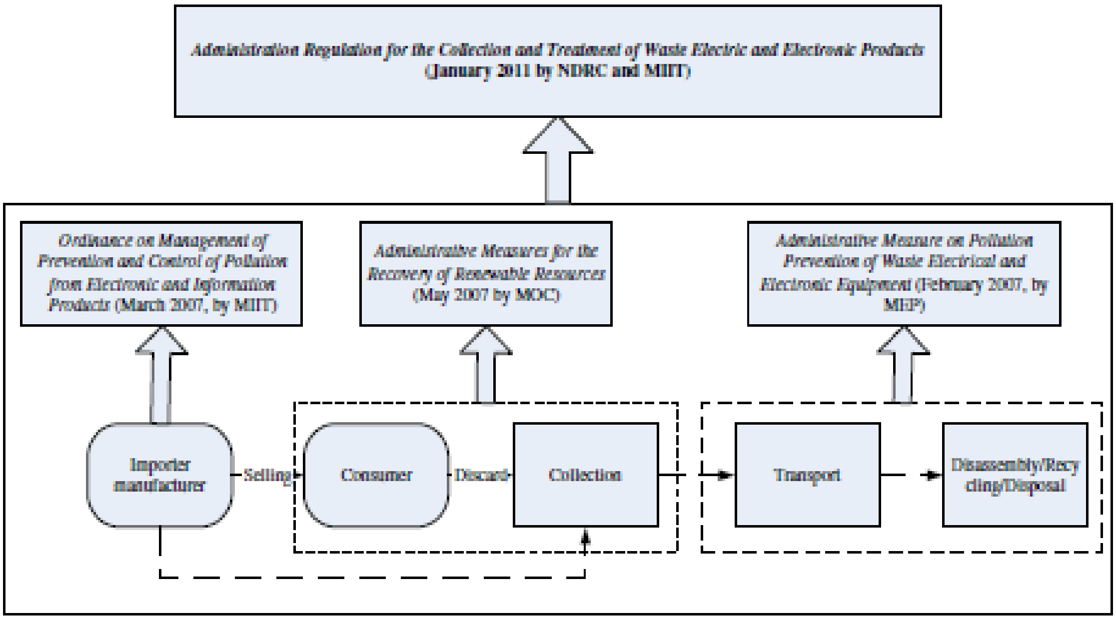

Figure 2: System of e-waste management in China [10].

Some of the chemical recycling methods are the pyrolysis, gasification and use of supercritical fluids and other physical methods include magnetic separation and gravity separation all of which involves an efficient technique for the physical fractional separation of the non-metallic and metallic parts of the waste PCBs.

In order to improve the sustainability of conventional PCBs it is of utmost importance to safely recycle the boards and re-use the electronic components, this process should not be limited only to components but also to resources utilized during the production process. The use of water should be minimised by optimising the rinsing and etching process. The waste water should be treated and re-used.

3.0 LEGISLATION

The growing concern over the increasing environmental issues associated with the production and disposal of electrical and electronics equipment's have led to the passing of legislation to control the manufacture and waste disposal of WEEE by government around the world. There are different tiers of legislation raging from global to national and they differ within countries; these laws completely cover the entire life cycle of electronics production process from the selection of raw materials to the disposal and recycling of electronic waste. These legislations have positively impacted the improvement design for environment in electronic products in terms of the reduction of greenhouse emissions, toxicity and management of natural resources [14].

3.1 WEEE Directive

The European Union passed legislation to ensure that manufacturers are accountable for their products at end of life in its take back scheme under the WEEE directive (EU, 2002/96/EC) which came into force in August 2005 [2]. Within this directive manufacturers have to finance the waste management of their products, this includes collecting from the end user by raising their awareness through retailers on free the take back scheme, financing the collection from these retailers to collection points and the final treatment and disposal of the waste.

3.2 Restriction on Hazardous Substance (Rohs)

According to [2], the RoHS directive which was enacted by the European union in 2003 (EU RoHS, 2003) aimed to restrict the use of hazardous substances in electrical and electronic equipment that were sold in the European markets by the 1st of July 2006. Although this law reduces some of the harmful chemicals being used on PCBs not all of the substances have been restricted and still poses as environmental hazards [17].

3.3 Laws in USA

According to [13], 25 of the 50 states in USA have enacted e-waste laws and state wide recycling laws for over 65% of the population, the laws do not sufficiently provide dedicated funds and sufficient infrastructure to ensure that the public is fully aware and actively participate and enforce compliance. One of the first states legislation was by the state of California is the "*Electronic Waste Recycling Act* "(SB20) of 2003 [18] and [19].

3.4 Laws in China

Since 2003 the following laws have been set up in China "*the cleaner production promotion law ordinance*", "*Administrative regulation for the collection and treatment of WEEE*" and *"Management of prevention and control of pollution from Electronic and information products"*. All of the above-mentioned legislations were set up to control and manage the effect of manufacturing and waste disposal of electronics product of which a large percentage of them contain PCBs. These laws also encourage producers to either engage licensed companies or independently collect e-waste from end users, recording different categories in a database system which will be submitted to the appropriate government agency [10].

3.5 Laws affecting the Dumping of Electronics to Developing Countries

The practice of shipping toxic e-waste to developing countries has raised a public outcry, which has brought the notice of governments around the world and the United Nations to these illegal practices [11]. The ISO/TR 14062 (2002) and ISO 14001 (2004) standards were set by the international standard organisation assisted by the United Nations and the Basel convention on the control of trans boundary movement of hazardous wastes and their disposal, which states amongst other specific requirements that environmental aspects should be integrated into the design of products. In addition, [13] implies that the current legislation and policies can only mitigate some of the issues associated with illegal dumping and recycling of waste EEE but do not resolve its impact on the environment.

4. ALTERNATIVE PRINTED CIRCUIT BOARD

4.1 Alternative Substrates

According to [15], problems associated with the recycling and re-use of PCBs can be addressed by an alternative method for manufacturing electronic devices through which components found in electronic devices and precious metal content can be detached from the substrate at end of life. Terming this method as "*substrateless*" he further claimed that the route has the added advantage of fitting existing assembly equipment. This process eliminates the need for soldered interconnection and involves the direct attachment of electronic components to thermoplastics and inserts moulding. A number of developmental challenges such as suitable materials, and adhesives capable of withstanding the high temperatures required for injection moulding limit this innovative process.

[16] proposed the use bio based thermosetting matrix and natural fibres as substrates for PCBs, these substitutes consist of environmentally friendly benign additives, jute, sisal and flax fibres. Manufacturing involves the use of solvated matrix resin made from linseed oils and soybeans which cost relatively more that epoxy resin. Although there has been initial success in optimizing the formulation. [16] also agrees that a more compressive material and property characterisation need to be done to meet the required standards for certification.

[20,21] projected a new process developed in 2007 by Verdant Electronics Company termed the OCCAM process. This new development allows for the permanent or temporary placement of components on an adhesive film that is removable. The process is based on the encapsulation of the components which are immobilized temporarily for proper structure which forms a monolithic arrangement of burned in and tested components. Some processes such as mechanical abrasion, laser ablation and water-jet removal can be used to punch holes in the permanent base or separate the temporary one from the circuit.

The assembly can now be metalized using a copper additive process that creates circuit patterns that interconnects of the components leads. This process is still conceptual and is depicted in Figure **3**.

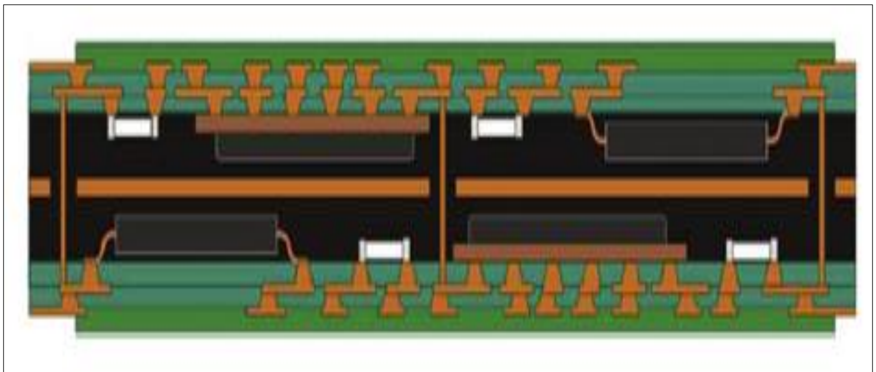

Figure 3: OCCAM interconnection process concept [21]

According to a review by [22], a joint study was carried out by Wurth Elektronik GmbH and Technische Universitat on the production techniques for printed circuit boards that can have their components separated from the substrate for the recycling at the end of life. This technique called "*Micro Via Technology*" is based on the use of TWINflex® an innovative material as a flexible circuit on a metal or smooth plastic substrate [23]. The electrical and mechanical function of a circuit board is separated by the TWINflex® and this makes the board easy to disassembly and components can be re-used. Figure **4** shows the difference between this process and conventional PCBs, which illustrates the possibility of cost reduction at the end of life because of the ease of separation of circuit from base material when the concept is materialised.

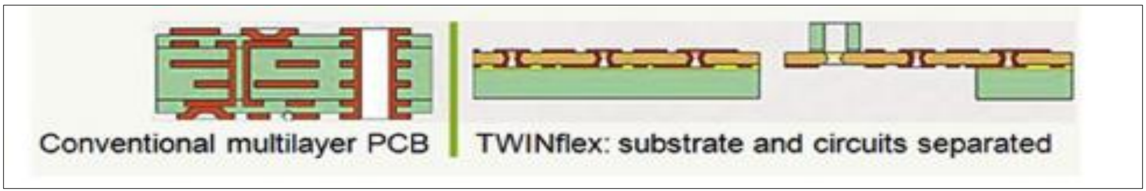

Figure 4: **Conventional printed circuits board and the TWINflex concept [23]**

4.2 Sustainable Circuit Boards

The National Physical Laboratory in Middlesex in collaboration with two manufacturing companies has made great leaps in the research for a more sustainable PCB named the reuse approach which is aimed at improving the ability to recycle PCBs safely and re use the components [24].

The novel process is based on the use of thermoplastic substrates and an innovative adhesive which can be used to bond both the dielectric substrate and the electronic components to the board. According to [24] one major feature of this process is the method of disassembly at end of life, the techniques is a simple process of soaking the board and components water at a near boiling temperature as shown in Figure 5. The substrate is based on unzippable feature of the materials also developed by [24], enables the components to be removed with minimum force for re-use and the recycling of the substrate.

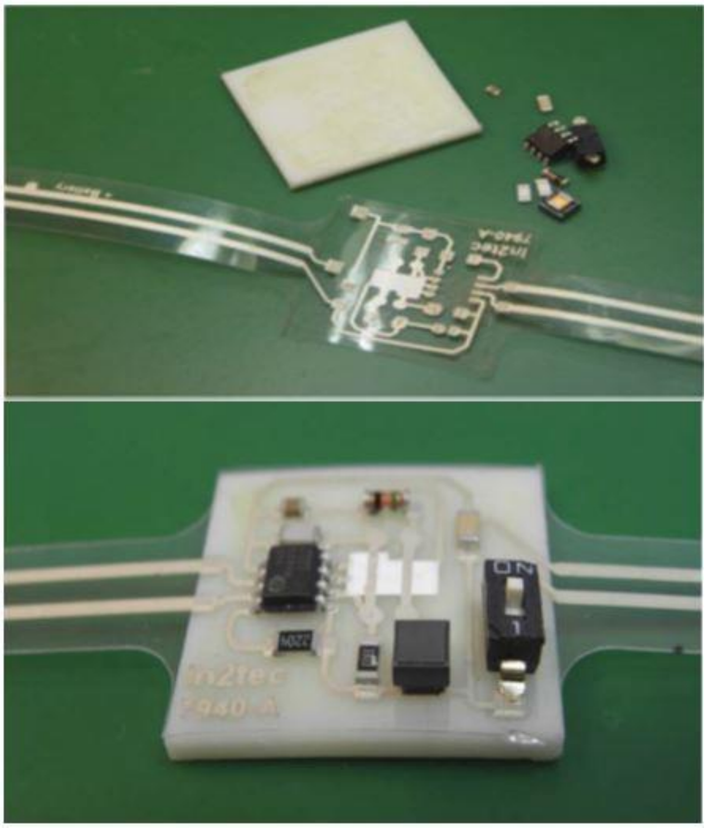

Figure 5: The Reuse Approach [23]

4.3 Life Cycle Assessment

The environmental impact associated with materials, processes, services and products as a result of the exponential increase in the demand and consumption of electrical and electronic components which a large percentage contains PCBs cannot be overemphasized. These burdens can be measured using a Life cycle assessment (LCA). Currently, a number of tools are available for environmental impact assessment according to [25], these include ecological footprint, life cycle assessment (LCA) and consequential life cycle analysis (CLCA). Of the three, the LCA is the most common. It is a valuable tool for computing the environmental impacts related to the production phases, use and end-of-life of PCBs [26]. The driving force of LCA can then be thought to be the advanced levels of processing, energy consumed and the by-products of materials utilised during production, usage and end-life waste management of PCBs which can be termed as from cradle to grave.

According to [27], in the past, the main focus during design processes were on making quality cost effective products and effectively translating it to the market. However, in the present time, this focus has shifted to making sustainable products that have little or no adverse environmental impacts resulting in the development of green eco-friendly products. The economic input output and the process-sum approaches are the two main approaches for evaluating the life cycle needs of resources and energy [28]. As stated by [27] and [29] a thorough LCA process is complex, time, and resource ineffective process therefore the need for the use of Simplified LCA tools (S-LCA). The decision on which simplified model to utilise is usually based on the indicator required for the impact analysis.

As a result of varying methods for life cycle analysis, the development of an international standard was pertinent. The four steps for assessment outlined in [30] are definition of goal and scope, inventory analysis, impact assessment and the interpretation of the results. Amongst researchers, the Life cycle of conventional PCB is a debated subject but can be summarized as shown in Figure 6.

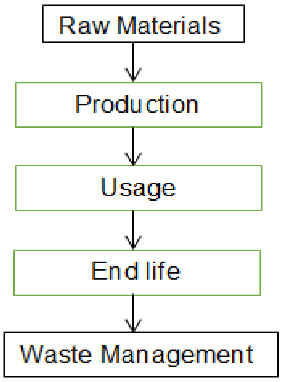

Figure 6: Schematic representation of Life Cycle Assessment Methodology

[31] conducted a comparative LCA study to validate the advantageous environmental impact of paper-based PCB over the conventional PCB. They found out that paper-based PCBs were two magnitudes below the conventional PCB across all impact categories as indicated in Figure 7.

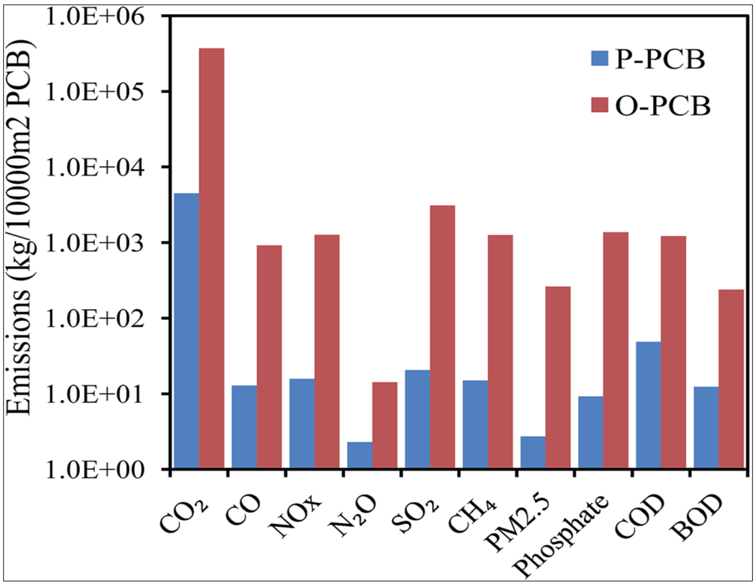

Figure 7: Comparative LCI analysis for Paper-based PCB and Conventional PCB [30]

The LCA is a valuable analytic tool utilised for informed decision making towards an end-of-life approach in designs and development of products for environment.

5.0 CONCLUSION

In conclusion, the paper examined printed circuit boards from inception to the finished product and when it becomes waste to the challenge with its disposal. Improper disposal of PCBs posses a serious danger to the environment and to human beings. Therefore, ways of PCB disposal were examined and the environmental impact assessed. Legislations covering the production, usage and disposal of the PCBs was not left out. Finally, alternative ways of making circuit boards apart from the printed circuit boards were studied.

This paper confirmed the possibility of developing a cheap, environmentally friendly circuit board as a substitute or alternative to printed circuit boards. Circuit boards will be easy to recycle and the removal of electronic components for reuse will be safe and effective.

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