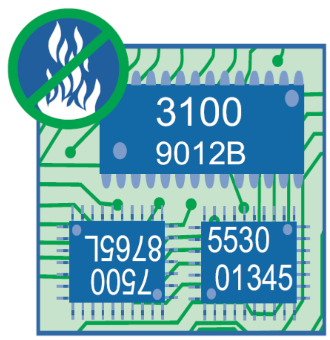
United States Environmental Protection Agency

FLAME RETARDANTS IN PRINTED CIRCUIT BOARDS

Chapter 1



FINAL REPORT

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1 Introduction

The electronics industry engaged in a multi-stakeholder partnership with the U.S. Environmental Protection Agency (EPA)'s Design for the Environment (DfE) Program to identify and evaluate commercially available flame retardants and their environmental, human health and safety, and environmental fate aspects in Flame Resistant 4 (FR-4) printed circuit boards (PCBs). The majority of PCBs are classified as FR-4, indicating that they meet certain performance criteria, as well as the V0 requirements of the UL (Underwriters Laboratories) 94 flammability testing standard.[2] For more than 90 percent of FR-4 PCBs, the UL 94 V0 requirement is met by the use of epoxy resins in which the reactive flame retardant tetrabromobisphenol A (TBBPA) forms part of the polymeric backbone of the resin.

As of 2008, alternative flame-retardant materials were used in only 3 to 5 percent of FR-4 boards, but additional alternative flame-retardant materials are under development. Little information existed at the time the partnership was convened concerning the potential environmental and human health impacts of the materials that are being developed as alternatives to the brominated epoxy resins. Environmental and human health impacts can occur throughout the life cycle of a material, from development and manufacture, through product use, and finally at the end of life of the material or product. In addition to understanding the potential environmental and human health hazards associated with the reasonably anticipated use and disposal of flame-retardant chemicals, stakeholders have expressed a particular interest in understanding the combustion products that could be formed during certain end-of-life scenarios.

A risk assessment conducted in 2006 by the European Union did not find significant human health risk associated with reacted TBBPA in PCBs.[3] However, the potential environmental and health impacts of exported electronic waste (e-waste) are not fully understood. A large percentage of e-waste is sent to landfills or recycled through smelting to recover metals. An unknown portion of the waste is recycled under unregulated conditions in certain developing countries, and the health implications of such practices are of concern.

This report aims to increase understanding of the potential environmental and human health impacts of PCBs throughout their life cycle. Information generated from this partnership will contribute to more informed decisions concerning the selection and use of flame-retardant materials and technologies and the disposal and recycling of e-waste.

1.1 Purpose of the Flame Retardant Alternatives Assessment

The partnership committee identified the overall purpose of this assessment as follows:

[2] FR-4 refers to the base material of the printed circuit board; namely, a composite of an epoxy resin reinforced with a woven fiberglass mat. UL 94 is an Underwriters Laboratories standard for flammability of plastic materials. Within UL 94, V0 classification entails one of the highest requirements.
[3] The EU results, while noteworthy, will not form the basis of this assessment, but rather should be viewed in conjunction with the independent conclusions drawn in this assessment.

- To identify and evaluate current and alternative flame retardants and their environmental, human health and safety, and environmental fate aspects in FR-4 PCBs.

- To allow industry and other stakeholders to consider environmental and human health impacts along with cost and performance of circuit boards as they evaluate alternative materials and technologies.

1.2 Scope of the Flame Retardant Alternatives Assessment

The partnership will incorporate life-cycle thinking into the project as it explores the potential hazards associated with flame retardants and potential exposures throughout the life cycle of flame retardants used in FR-4 PCBs. While the report focuses on flame retardants used in FR-4 PCBs, these flame retardants may also be applicable in a wide range of PCBs constructed of woven fiberglass reinforced with thermoset resin.

As appropriate, the scope will include aspects of the life cycle where public and occupational exposures could occur. For example, consideration of exposures from open burning or incineration at the end of life will be included, as will exposures from manufacturing and use.

The following investigations were considered within the scope of the project:

- An environmental, health, and safety (EHS) assessment of commercially available flame-retardant chemicals and fillers for FR-4 laminate materials;

- An assessment of environmental and human health endpoints (environmental endpoints include ecotoxicity, fate, and transport);

- A review of potential life-cycle concerns; and

- Combustion testing to compare the potential by-products of concern from commercially available FR-4 laminates and PCB materials during thermal end-of-life processes, including open burning and incineration.

The project's scope will be limited to flame-retardant chemicals used in bare (i.e., unpopulated) FR-4 PCBs. Other elements of PCBs (such as solder and casings) and chemicals in components often attached to PCBs to make an electronic assembly (such as cables, capacitors, connectors, and integrated circuits) will not be assessed.

The report is intended to provide information that will allow industry and other stakeholders to evaluate alternatives for flame retardants in PCBs. The report is organized as follows:

- *Chapter 1 (Introduction):* This chapter provides background to the Flame Retardants in Printed Circuit Boards partnership project including the purpose and scope of the partnership and of this report.

- *Chapter 2 (FR-4 Laminates):* This chapter describes the characteristics, market for, and manufacturing process of FR-4 laminates and investigates possible next generation developments.

- *Chapter 3 (Chemical Flame Retardants for FR-4 Laminates):* This chapter describes chemical flame retardants generally, as well as those specific flame retardants used in FR-4 laminates. The next generation of flame-retardant chemicals is also discussed.

- *Chapter 4 (Hazard Evaluation of Flame Retardants for Printed Circuit Boards):* This chapter explains the chemical assessment methodology used in this report and summarizes the assessment of hazards associated with individual chemicals.

- *Chapter 5 (Potential Exposure to Flame Retardants and Other Life-cycle Considerations):* This chapter discusses reasonably anticipated exposure concerns and identifies potential exposure pathways and routes associated with flame-retardant chemicals during each stage of their life cycle.

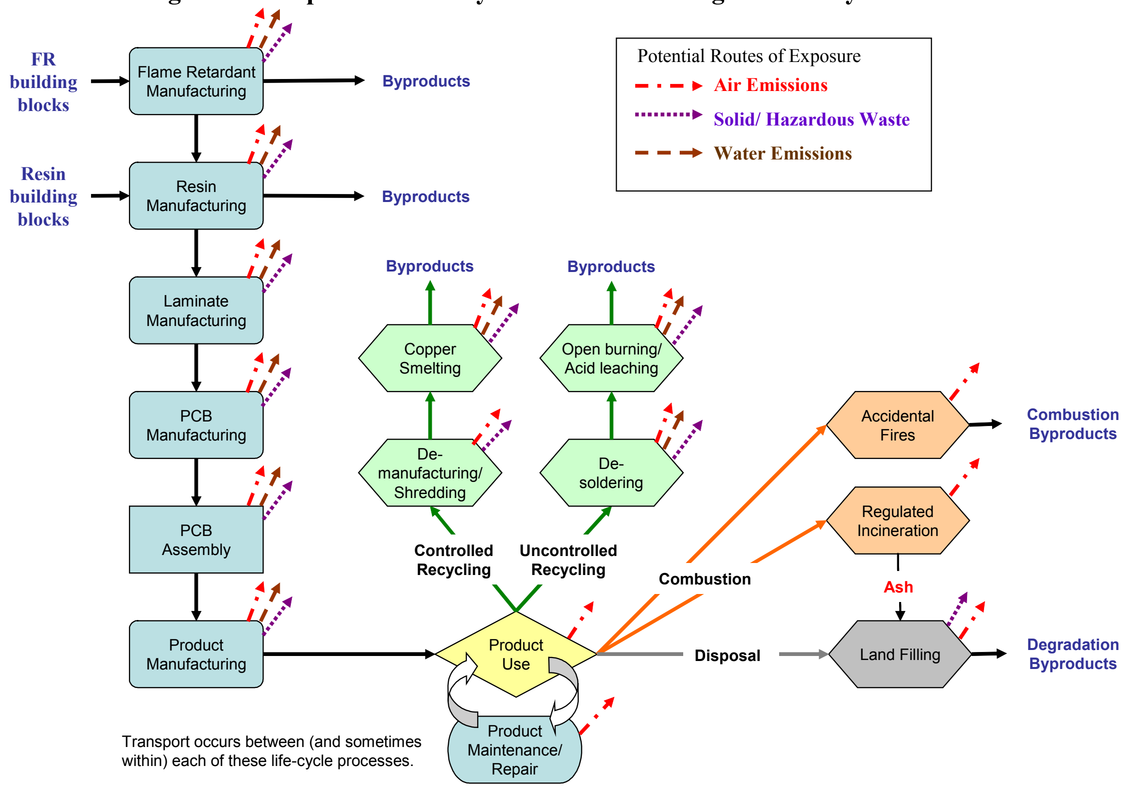
- *Chapter 6 (Combustion and Pyrolysis Testing of FR-4 Laminates):* This chapter describes the rationale and methods for combustion and pyrolysis testing of PCB materials.

- *Chapter 7 (Considerations for Selecting Flame Retardants):* This chapter addresses considerations for selecting alternative flame retardants based on environmental, technical, and economic feasibility.

1.2.1 Life-Cycle Stages Considered

Figure 1-1 shows the life-cycle stages of a PCB and the associated potential exposure pathways that will be examined in this report. In brief, the flame-retardant chemical is manufactured and then incorporated, either reactively or additively, into the epoxy resin. The epoxy resin is then applied to a woven fiberglass mat and hardened. Layers of copper foil are attached to both sides of the reinforced resin sheet to form a laminate. Next, a PCB is manufactured by combining several laminate layers that have had conductive pathways (i.e., circuits) etched into the copper foil. The layers are then laminated together, and holes are drilled to connect circuits between layers and hold certain electronic components (e.g., connectors or resistors). Once assembled, PCBs are incorporated into various products by original equipment manufacturers. When the product is no longer in use, there are several end-of-life pathways that the product may take: landfilling, regulated incineration, unregulated incineration (or open burning), and recycling. All of these life-cycle stages will be discussed in further detail in the subsequent chapters of this report.

Figure 1-1. Exposure Pathways Considered During the Life Cycle of a PCB



1.2.2 Aspects Beyond the Scope of This Assessment

Although the assessment will explore hazard data associated with potential exposure scenarios, the partnership does not intend to conduct a full risk assessment, which would require a full exposure assessment along with the hazard assessment. Likewise, the project will not be a complete life-cycle analysis, which inventories inputs and outputs from processes throughout the life cycle and evaluates the environmental impacts associated with those inputs and outputs.

Process chemicals (i.e., etching or washing solutions used in manufacturing PCBs) are not included in the scope of this assessment. Although PCBs come in many varieties, the scope of this assessment is limited to FR-4 boards which meet the V0 requirements of the UL 94 standard. Boards of this type are used in consumer products such as computers and cell phones and make up a large portion of the PCBs used in consumer products. The assessment may be useful beyond FR-4 boards to the extent that the same flame retardants are used in other laminates constructed of woven fiberglass reinforced with other thermoset resins such as phenolics.

Finally, this assessment is not a technical evaluation of key electrical and mechanical properties of halogenated and halogen-free materials. These properties have been explored in parallel assessments conducted by iNEMI (International Electronics Manufacturing Initiative) that are described in greater detail in Section 2.3 and Section 7.6.4 of this report. Together, these resources will provide information on both the performance and environmental properties of the various materials being evaluated.