Guide to Safer Alternatives in Electronics Manufacturing

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1 Background

There are approximately 15-18 million workers involved in the production of electronic products globally, with manufacturing occurring in a highly fragmented and geographically diverse supply chain (Whittaker et al., 2023). Hundreds of different chemicals have been identified for use in manufacturing of electronic components, and it has been estimated that a single electronic product can contain over 1,000 chemicals (Whittaker et al., 2023; OECD, 2010; Sepulveda et al., 2010). Some of these chemicals are considered hazardous, potentially impacting worker health and safety, especially where insufficient exposure controls are in place. Insufficient controls during chemical use, storage, and waste disposal can also result in adverse environmental impacts due to releases to air, water, and soil.

One of the most effective measures for reducing human health and environmental risks associated with chemical use in manufacturing is substituting hazardous chemicals with safer alternatives. Using lower hazard chemicals in production not only protects worker health and safety, but also reduces regulatory compliance costs, and improves competitive advantage. For some electronics companies and suppliers, reducing use of hazardous chemicals may be hindered by a lack of knowledge or other resources necessary to identify hazardous chemicals within operations and find available safer replacement chemistries.

Recognizing the need for practical knowledge and resource sharing on safer alternatives, IPC International, Inc. partnered with the Clean Electronics Production Network (CEPN) to develop this guide for interested stakeholders throughout the electronics manufacturing supply chain. IPC also consulted with subject matter experts (SMEs) in safer alternatives from the electronics industry and we are grateful for their insights and peer review of this guide.

2 About this Guide

The purpose of this guide is to provide practical information for businesses in the electronics sector seeking to use safer alternatives in their products and processes. While consideration of product or process re-design to eliminate the need for use of a hazardous chemical altogether is a critical component of identifying safer alternatives (see Side box/side bar: Established Definitions of Safer Alternatives), the focus of this guide is providing information and resources to identify safer chemical alternatives. The guide is intended for use by a wide range of individuals charged with making chemical selection decisions (see Table 1).

Table 1. Safer Alternatives Guide - Intended Audience

Facility Managers - Individuals responsible for overseeing operations at manufacturing facilities who may benefit from understanding how to implement safer alternatives in their processes.
Environmental Health and Safety (EHS) Professionals - Individuals responsible for ensuring workplace safety and environmental compliance seeking to implement safer alternatives within their organization.
Product Designers and Engineers - Those involved in the design and engineering of electronic products seeking to incorporate consideration of chemical hazards and safer alternatives in R&D and product development processes.
Procurement Teams - Professionals involved in sourcing and purchasing materials and chemicals and seeking to create environmentally preferable purchasing policies and/or incorporate criteria for chemical selection in procurement decisions.
Regulatory Compliance Teams - Those responsible for ensuring products meet safety standards and regulations who seek to implement use of safer alternatives to avoid or reduce compliance burden.
Sustainability Officers and CSR Managers - Professionals focused on a company's Corporate Social Responsibility initiatives, particularly in relation to environmental impact and worker safety as well as managers working on sustainability strategies of a company, particularly those aimed at reducing the environmental impact of their products and processes.
Training and Development Coordinators - Individuals seeking to create internal training on implementing safer alternatives for their organizations.

Replacing hazardous chemicals in products and processes with safer alternatives can be technically and financially challenging – identifying, testing and scaling new chemistries can be resource intensive and takes time. Acknowledging these challenges, there are resources available to help companies identify currently available safer alternatives and stay abreast of new developments.

This Guide is intended to provide a compilation of these resources and is organized to support users in taking the following key steps towards implementing safer alternatives in their chemical management programs:

Step 1: Identify hazardous chemicals in processes and products

Report Section 3 provides an overview of hazardous chemicals used in electronics manufacturing

Report Section 4 outlines established definitions of safer alternatives and highlights key benefits associated with their use

Step 2: Secure internal support for replacing hazardous chemicals with safer alternatives

Step 3: Identify and implement safer alternatives

Report Section 5 provides resources, tools, and expert guidance for selecting and implementing safer alternatives

Report Section 6 lists organizations working to advance safer alternatives in electronics manufacturing

Step 4: Stay informed on new developments in safer alternatives

3 Raising Awareness: Understanding the Impact of Hazardous Chemicals in Electronics Manufacturing

Early concerns about the potential adverse effects of chemical use in electronics manufacturing emerged following reports of increased risks of negative health outcomes, including spontaneous abortion and cancer, among semiconductor workers (Whittaker et al., 2023; GEC, 2022). Since the 1980s, knowledge has expanded to indicate potentially harmful chemical exposures and environmental releases can occur throughout the life cycle of an electronic product, including during raw material extraction, manufacturing, use, and disposal (Whittaker et al., 2023; GEC, 2022).

Currently, over 500 different chemicals have been identified for use in manufacturing of electronic components, and it has been estimated that a single electronic product can contain over 1,000 chemicals (Whittaker et al., 2023; OECD, 2010; Sepulveda et al., 2010). Given the confidential and dynamic nature of the electronics industry, identifying all chemicals used in production remains challenging. However, it is generally agreed by non-governmental and industry associations that electronics production involves hazardous chemicals which should be targeted for elimination or substitution (Whittaker et al. 2023).

Identifying Hazardous Chemicals

Hazardous chemicals or "chemicals of concern" are chemicals, which due to their inherent properties, present a known or reasonably suspected risk to human health, and/or the environment (GEC, 2022; Becker, 2009). CEPN has set the following High Hazard Criteria to prioritize hazardous chemicals for elimination or substitution for the electronics manufacturing sector[1]:

- California Proposition 65 listed[2]
  - Identifies chemicals that are carcinogens, reproductive toxicants, and/or developmental toxicants

- GreenScreen® for Safer Chemicals Benchmark Score of 1 or List Translator Score of LT-1[3]
  - Identifies chemicals that are carcinogens, reproductive, developmental and/or neurodevelopmental toxicants, mutagens, persistent, bioaccumulative and toxic (PBTs), very persistent and very bioaccumulative (vPvBs), and/or endocrine disruptors.

- ChemFORWARD Hazard Band F[4]
  - Identifies chemicals that are carcinogens, reproductive, and/or developmental toxicants, mutagens, persistent, bioaccumulative and toxic (PBTs), very persistent and very bioaccumulative (vPvBs), very persistent and toxic (vPT), and/or endocrine disruptors, and Chemicals of Regulatory Concern.

- Classified under Globally Harmonized System (GHS) as follows[5]:
  - Category 1 for carcinogenicity
  - Category 1 for reproductive toxicity
  - Category 1 for germ cell mutagenicity
  - Category 1 for specific target organ toxicity, single or repeat dose
  - Category 1A for respiratory or skin sensitization
  - Category 1, 2 or 3 for acute toxicity (oral, dermal, vapors, dust and mist)

Some organizations have also identified entire chemical classes as hazardous since substances with similar chemical structures are expected to behave similarly in the body and environment. Setting goals to restrict or eliminate chemical classes takes a precautionary approach and is intended to avoid "regrettable substitutes",[6] where one chemical of concern is replaced with a similarly structured alternative which is later found to have similar hazardous properties. Regrettable substitutions can occur when hazardous chemicals are replaced with chemical alternatives lacking full hazard assessments and which are later found to be equally or more harmful. Examples of regrettable substitutes in the electronics industry include replacement of the plasticizer bisphenol-A (BPA) with similarly structured and potentially endocrine disrupting bisphenols such as bisphenol-S (BPS) or bisphenol-F (BPF) and replacement of the solvents trichloroethylene and methylene chloride with 1-bromopropane (nPB), a carcinogen (GEC, 2022). Alternatives assessment (see Table 3) includes thorough hazard assessments for potential replacements for hazardous chemicals before adoption to prevent regrettable substitutes.

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1 Clean Electronics Production Network (CEPN), June 2023. Summary of Second Round Priority Chemical Selection Report; https://cleanelectronicsproduction.org/tools-resources/priority-chemicals.

2 Chemicals listed according to the Safe Drinking Water and Toxic Enforcement Act of 1986; https://oehha.ca.gov/proposition-65/proposition-65-list.

3 Clean Production Action (CPA), 2018. GreenScreen® for Safer Chemicals Hazard Assessment Guidance, Version 1.4, January 2018; https://www.greenscreenchemicals.org/.

4 ChemFORWARD Guidance: Chemical Hazard Rating Version 2.4, December 2024; https://www.chemforward.org/our-approach. 3 Clean Production Action (CPA), 2018. GreenScreen® for Safer Chemicals Hazard Assessment Guidance, Version 1.4, January 2018; https://www.greenscreenchemicals.org/.

5 U.N. Globally Harmonized System (GHS) of Classification and Labelling of Chemicals; https://unece.org/about-ghs.

6 Alternatives that have similar or worse adverse public health impacts, adverse environmental impacts, adverse waste or end-of-life effects, or greater materials or resource consumption impacts than the original chemical in the product throughout its life cycle. California Department of Toxic Substances Control, Alternative Analysis Guide, Version 1.1, July 2020.

Although not exhaustive, Table 2 provides a summary of hazardous chemicals known to be used in electronics manufacturing along with information on the primary hazards associated with these chemicals.

Table 2. Hazardous Chemicals Used in Electronics Manufacturing

Type	Example Hazardous Substances	Example Uses	Primary Hazards
Heavy metals/ metalloids	Arsenic, cadmium chromium VI, lead lithium, mercury nickel, cobalt, tantalum	Batteries, light emitting diodes, printed circuit boards, printer inks and toners, fluorescent lamps	Carcinogenicity; Neurotoxicity; Reproductive Toxicity; Developmental Toxicity
Organic solvents	Toluene, xylene(s), methyl ethyl ketone, N-methyl-2-pyrrolidone, trichloroethylene, tetrachloroethylene, methanol, H-hexane, 1-bromopropane	Conformal coatings; cleaners; degreasers; vapor degreasing; cleaning ingot and wafer materials in semiconductors; ingredient in adhesives, paints, coatings, and inks; chemical vapor deposition; semiconductor parts; thinner and stripper for photoresist; process chemicals	Carcinogenicity; Reproductive Toxicity; Developmental Toxicity; Mutagenicity; Neurotoxicity; Acute Toxicity; Systemic Toxicity; Skin Sensitization; Eye/Skin Irritation; Aquatic Toxicity
Flame retardants	Tetrabromobisphenol A (TBBPA), 2,2',6,6'-tetrabromobisphenol A, antimony trioxide	Printed circuit boards, integrated circuits, connectors, cables, plastic clips, mechanical plastic parts such as enclosures, fans, electrolytic capacitors, hard drives, power supplies	Carcinogenicity, Reproductive Toxicity, Developmental Toxicity, Endocrine Disruption, Neurotoxicity, Persistent, Bioaccumulative
Plasticizers	Diethylhexyl phthalate (DEHP), diisononyl phthalate (DINP), diisodecyl phthalate (DIDP)	Cables and casings	Carcinogenicity; Reproductive Toxicity; Developmental Toxicity; Endocrine Disruption
Poly- and perfluoroalkyl substances (PFAS)	A category including > 4,700 PFAS substances, including perfluorooctanoic acid (PFOA), perfluorooctane sulfonate (PFOS), and GenX compounds (also known as 2,3,3,3-Tetrafluoro-2-(heptafluoro propoxy) propionic acid, its salts and its acyl halides)	Lubricants, corrosion resistance, water repellency coatings, Flame retardants, Surfactants, Wire and cable insulation, Semiconductor manufacturing	Carcinogenicity, Developmental Toxicity, Endocrine Disruption, Systemic Toxicity, Eye/Skin Irritation, Persistent, Bioaccumulative
Sources:	Whittaker et al., 2023; GEC, 2022		

While chemical exposures and releases can occur at various stages of the electronics product life cycle, workers face significant risks due to the chemically intensive processes involved in electronics manufacturing and their frequent and direct interaction with these processes (GEC, 2022).

During circuit board manufacturing, chemicals are used for etching, plating, and coating processes, while adhesives and soldering fluxes are used during component assembly. Cleaning agents are used during assembly to remove flux, grease, and other contaminants. These cleaning agents often contain solvents which easily evaporate, placing workers at risk of high exposures via inhalation. Solvents are also used in chemical formulations as carriers and viscosity reducers, for instance for spin coating or spraying photoactive substances, or in solder flux (GEC, 2022).

Although engineering controls including enclosed systems and ventilation can help reduce worker exposures, it is widely recognized that the most effective method for protecting worker health and safety and avoiding injury and illness is to eliminate hazards at the source through elimination and substitution of hazardous chemicals with safer alternatives (OSHA, 2024).

4 Safer Alternatives in Electronics Manufacturing: Benefits and Criteria

Proactive chemical management in the electronics sector has become increasingly important due to evolving and complex regulatory requirements and resulting expectations from brands and their customers. Incorporating consideration of safer alternatives in product design and manufacturing processes provides numerous benefits including:

- Reduced regulatory compliance costs and risks;
- Reduced risk of worker injury and illness;
- Increased market competitiveness by meeting or exceeding customer requirements;
- Reduced risk of supply chain disruption due to regulatory phase outs; and
- Support for Corporate Social Responsibility and sustainability programs and goals.

A Safer Alternatives Success Story - Implementing Safer Cleaners and Degreasers at Apple Final Assembly Sites

Smarter chemistry is one of Apple's three sustainability priorities, and the company has been promoting the use of safer materials and chemicals in its products and manufacturing processesfor many years. To scale and broaden the adoption of safer cleaners and degreasers in electronics manufacturing, Apple teamed with the NGO Clean Production Action to create the GreenScreen Certified™ standard for cleaners and degreasers.

The standard, which incorporates GreenScreen for Safer Chemicals hazard assessment and the U.S. EPA's Safer Choice criteria, provides a comprehensive framework for identifying cleaners and degreasers considered safer for human health and the environment (see Table 5 for more information). Using these criteria, Apple successfully transitioned all its final assembly sites to safer cleaning and degreasing alternatives, a milestone achieved in 2018 and maintained since then (Apple, 2024). In some cases, companies reformulated their products to remove chemicals of concern to meet the requirements, however, in most cases, replacements were currently available materials.

When seeking to incorporate chemical substitution into chemical management programs, businesses need guidance, starting with what is considered a safer alternative. Several government agencies and NGOs leading initiatives to reduce use of hazardous chemicals in products and manufacturing have provided definitions for safer alternatives.

Established Definitions of Safer Alternatives

Definitions of "safer alternative" from government agencies and NGOs leading initiatives to reduce use of chemicals of concern in products and manufacturing:

1. An option, including the option of not continuing an activity, that is healthier for humans and the environment than the existing means of meeting that need. For example, safer alternatives to a particular chemical may include a chemical substitute or a re-design that eliminates the need for any chemical addition.[7]

2. An alternative that is less hazardous to humans or the environment than the existing chemical or chemical process. A safer alternative to a particular chemical may include a chemical substitute or a change in materials or design that eliminates the need for a chemical alternative.[8]

3. An alternative that, in comparison with another product or product manufacturing process, has reduced potential adverse impacts and/or potential exposures associated with one or more Candidate Chemicals, Chemicals of Concern, and/or replacement chemicals, whichever is/are applicable. An alternative means any of the following:

    a. Removal of Chemical(s) of Concern from a Priority Product, with or without the use of one or more replacement chemicals;

    b. Reformulation or redesign of a Priority Product and/or manufacturing process to eliminate or reduce the concentration of Chemical(s) of Concern in the Priority Product;

    c. Redesign of a Priority Product and/or manufacturing process to reduce or restrict potential exposures to Chemical(s) of Concern in the Priority Product; or

    d. Any other change to a Priority Product or a manufacturing process that reduces the potential adverse impacts and/or potential exposures associated with the Chemical(s) of Concern in the Priority Product, and/or the potential adverse waste and end-of-life effects associated with the Priority Product.[9]

4. An alternative that, when compared to a priority chemical that it could replace, would reduce the potential for harm to human health or the environment or that has not been shown to pose the same or greater potential for harm to human health or the environment as that priority chemical.[10]

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7 Referenced in BizNGO's Common Principles for Alternative Assessment from Tickner, J. and Eliason, P. Alternatives Assessment for Chemicals: From Problem-Evaluation to Solutions-Assessment and Implementation: A background paper created expressly for use in the March 31–April 1, 2011 Interagency Discussion on Alternatives Assessment, EPA Potomac Yards Conference Facility, Crystal City, VA. March 24, 2011.

8 Washington Toxic Pollution Law (Chapter 70A.350 RCW).

9 California Safer Consumer Products regulation (California Code of Regulations, Title 22, Sections 69501-69510).

10 Maine Toxic Chemicals in Children's Products regulation (Title 38, Chapter 16-D of Maine Revised Statutes).

To be successful, hazardous chemical replacements must also consider other factors such as performance, cost, and the need to avoid regrettable substitutes. Alternatives assessment provides a structured framework for evaluating hazard, performance and cost comprehensively and is a useful step for organization considering one or more changes to product or process chemistries. Table 3 provides a list of recognized alternative assessment guidelines.

Table 3. Alternative Assessment Guidance

According to BizNGO, alternatives assessment is a process for identifying, comparing and selecting safer alternatives to chemicals of concern (including those in materials, processes or technologies) based on their hazards, performance, and economic viability[11]. A primary goal of alternatives assessment is to reduce risk to humans and the environment by identifying safer choices. The following are examples of recognized guidance for conducting alternatives assessment:

- National Academies of Sciences, Engineering, and Medicine. 2014. A Framework to Guide Selection of Chemical Alternatives. Washington, DC: The National Academies Press. https://doi.org/10.17226/18872.

- Interstate Chemicals Clearinghouse, 2017. Alternatives Assessment Guide (Version 1.1). Retrieved from https://www.theic2.org/alternatives-assessment-guide/.

- OECD Substitution and Alternatives Assessment Toolbox (SAAToolbox): Online portal which compiles resources relevant to chemical substitution and alternatives assessment, including tools and data sources to evaluate potential hazards of chemicals, frameworks, guides, toolkits, and case studies. https://www.oecd.org/en/topics/risk-management-risk-reduction-and-sustainable-chemistry.html

- OECD, 2021). Guidance on Key Considerations for the Identification and Selection of Safer Chemical Alternatives, OECD Series on Risk Management of Chemicals, OECD Publishing, Paris, https://doi.org/10.1787/a1309425-en.

- BizNGO Chemical Alternatives Assessment Protocol, Version 1.1, April 2012. https://www.bizngo.org/images/ee_images/uploads/resources/BizNGOChemicalAltsAssessmentProtocol_V1.1_04_12_12-1.pdf

- Washington State Alternatives Assessment Guide for Small and Medium Businesses, July 2021. https://apps.ecology.wa.gov/publications/SummaryPages/1504002.html.

- U.S. Department of Labor, Occupational Safety and Health Administration, Transitioning to Safer Chemicals, A Toolkit for Employers and Workers. https://www.osha.gov/safer-chemicals

- Clean Electronics Production Network Alternatives Assessment Guide, 2019. https://cleanelectronicsproduction.org/tools-resources/cepn-toolbox/alternatives-assessment-guide-worksheet

In the following sections we discuss tools and resources available to identify safer alternatives, a critical component of alternatives assessment.

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11 BizNGO, 2012. The Common Principles for Alternatives Assessment; https://www.bizngo.org/resources/entry/commons-principles-for-alternatives-assessment.

5 Finding Safer Alternatives: Resources, Tools, and Expert Guidance

Information needs for implementing safer alternatives vary based on a business's products and position in the supply chain. Here we provide a compilation of resources available for finding chemicals and products considered safer for human health and the environment.

5.1   Finding Safer Chemical Ingredients

Suppliers of cleaning agents, adhesives, coatings and other formulated products for electronics manufacturing may benefit from tools and resources to help identify safer chemical ingredients. Such information may be beneficial to research and development teams to not only help prepare for upcoming regulatory restrictions or bans, but also to support company initiatives to market products as safer through recognized certification programs.

Table 4 provides information on organizations that offer recognized assessment frameworks and/or maintain lists of chemicals considered safer for human health and the environment (accepted substances). This information is also available on CEPN's website.

Table 4. Chemical Ingredients - Assessment Frameworks and Accepted Substance Lists

Organization	Assessment Framework	Accepted Substances List	Description	Outcomes	Access
ChemFORWARD	ChemFORWARD SAFER™ Program Guidance	ChemFORWARD SAFER™ Trade Name Listings	ChemFORWARD manages a repository of chemical hazard assessments (CHAs) with a focus on safer alternative chemicals. These CHAs are the basis of trade name level assessments which help value chain members identify safer alternatives currently on the market. All chemical constituents in a ChemFORWARD SAFER™ candidate are reviewed to ensure that each CAS-level substance in the trade name product meets safer chemistry requirements per the program. The SAFER program leverages CHAs that already exist in the ChemFORWARD platform, reducing cost and effort for the ingredient manufacturer and SAFER™ assessor.	A third-party assessor evaluates Trade Name chemical product per SAFER Program Guidance. All ingredients required to be disclosed are evaluated and assigned a ChemFORWARD Hazard Band based on US EPA SCIL rating, GreenScreen Benchmark or a new assessment based on ChemFORWARD requirements. A Trade name product passes or fails the SAFER Program requirements.	The ChemFORWARD SAFER™ Trade Name Listings are publicly available for free. Suppliers participating in SAFER™ must have a subscription to the ChemFORWARD chemical optimization platform. The platform can be used for pre-screening products for the SAFER™ program and viewing complete records once approved. For suppliers, the subscription fee includes use of existing CHAs from the repository toward SAFER™ qualification as well as a defined number of SAFER™ licenses to list approved products.
Clean Production Action	GreenScreen® for Safer Chemicals	GreenScreen for Safer Chemicals is a chemical hazard assessment method. Trade name products are certified based on the method following the GreenScreen Certified Standards (see Table 5).	A chemical hazard assessment methodology used to evaluate chemicals against human health and environment endpoints and assign a range of Benchmark scores.	A third-party assessor evaluates chemicals using GreenScreen for Safer Chemicals and assigns a GreenScreen Benchmark of 1 (Avoid – Chemical of Concern), 2 (Use – But Search for Safer Substitutes), 3 (Use – But Still Opportunity for Improvement) or 4 (Prefer – Safer Chemical).	The method is publicly available for free CPA maintains a registry of GreenScreen Benchmarks; some assessments are available from assessors for free, while some are fee-based Licensed Profilers (qualified assessors) can perform evaluations of unassessed chemicals for a fee.

Organization	Assessment Framework	Accepted Substances List	Description	Outcomes	Access
Enhesa	SciveraLENS®, Chemical Assess	Chemical Assess is a hazard assessment method based on GHS. Chemicals are assigned ratings, but there is not a list of chemicals considered acceptable.	Chemical Assess is an on-line platform which provides chemical hazard assessments developed by in-house toxicologists/assessors. The platform also provides access to regulatory and advisory lists on chemical hazards and regulatory requirements.	Chemicals are assigned a color based on the results of the CHA: Black (Very High Hazard), Red (High Hazard), Yellow (Moderate Hazard), Green (Low Hazard), Gray (Insufficient Data)	Access to Chemical Assess and the underlying methodology is fee-based.
TCO Certified	GreenScreen® for Safer Chemicals, ChemForward®	TCO Certified Accepted Substance List	Substances listed by CAS number or Trade nameapproved for use in TCO Certified products and their manufacture. List includes flame retardants, plasticizers, and stabilizers used in products and cleaning ingredients used in manufacturing.	A third-party assessor evaluates chemicals using GreenScreen for Safer Chemicals or ChemFORWARD. To be listed, substances must achieve a GreenScreen Benchmark of 2, 3 or 4 or a ChemForward hazard band of A, B or C.	Publicly available for free
U.S. Environmental Protection Agency, Safer Choice Program	Safer Choice Criteria for Safer Chemical Ingredients	Safer Chemical Ingredients List (SCIL)	A list of chemical ingredients, arranged by functional-use class, that the Safer Choice Program has evaluated and determined to be safer than traditional chemical ingredients. The list is designed to help manufacturers find safer chemical alternatives that meet the criteria of the Safer Choice Program.	A third-party assessor evaluates chemicals against Safer Choice Criteria and assigns: Full Green Circle (Chemical has been verified to be of low concern), Half Green Circle (Chemical is expected to be of low concern based on experimental/modeled data), Yellow Triangle (Chemical Safer Choice Criteria for functional class, but has some hazard profile issues), Grey Square (Chemical may not be acceptable for use in Safer Choice products)	Publicly available for free

5.2   Finding Safer Chemical Products

In addition to assessment schemes for identifying chemicals with lower hazard profiles and accompanying accepted substances lists, several non-governmental organizations and companies also certify chemical products as safer based on specific hazard-based criteria (see Table 5). Lists of certified products are a useful resource to organizations seeking to phase out products used in manufacturing which contain one or more hazardous chemical ingredients and replace them with those that are safer for workers and the environment. Such lists may also benefit procurement professionals seeking to incorporate green chemistry criteria into their purchasing policies and processes. This information may also assist chemical suppliers interested in certifying their products to gain new markets.

CEPN's website also maintains an up-to-date list of organizations certifying safer products to support chemical substitution efforts in the electronics manufacturing sector.

Table 5. Organizations Listing and Certifying Safer Products for Electronics Manufacturing

Standard/ Specification Setting Organization	Standard/ Specification	Certifier	Description	Outcomes	Access
ChemFORWARD	Approved industry-leading certification programs	Depends on the program	The ChemWorks Safer Cleaners registry lists products that have been evaluated as safer cleaners and degreasers by experienced toxicology firms based on industry-leading certification programs. As part of the initiative, Apple has contributed to developing a rapid-screening framework (CleanScreen) and a shared repository of CHAs for ingredients commonly found in cleaners which is available via ChemFORWARD's chemical optimization platform.	Cleaners listed on the ChemWorks registry have been evaluated by a qualified assessor and meet an approved certification standard. Current approved standards are GreenScreen Certified for Cleaners and Degreasers, U.S. EPA Safer Choice Standard, and ToxFMD Screened Chemistry.	The ChemWorks Safer Cleaners Registry is freely available
ChemSec	ChemSec Marketplace	ChemSec	A searchable, online platform where suppliers can advertise their alternatives to hazardous chemicals. The Terms and Conditions indicate the human health and environmental criteria which must be met for listing in the platform. Listed alternatives do not contain intentionally added hazardous substances, or contaminants, with SVHC properties above 0.1% (1000 ppm).	ChemSec evaluates information provided by suppliers such as Safety Data Sheets, Technical Data Sheets and third-party labels, publicly available data and QSAR tools to ensure products meet the Terms and Conditions. Analytical testing is not required. ChemSec moderates the site and remove advertisements that don't meet the criteria, but it is beyond their scope to do in-depth assessments.	The Marketplace is freely available. Advertising is also currently free. Users can search by Material Article Category, Sector of Use, technical function, third party label, regulation or standard.
Clean Production Action	GreenScreen Certified™ for Cleaners and Degreasers (Meets IPC-1402)[11]	Clean Production Action	Products are evaluated against the human health and environmental criteria specified in the GreenScreen Certified™ for Cleaners and Degreasers Standard. Products which meet the criteria receive a certificate and can use the GreenScreen Certified logo. The standard applies to all industrial applications, but the primary focus is the electronics sector. Products must meet disclosure, RSL, hazard, analytical testing and skin and eye irritation requirements. Products must be PFAS-free.	Products can be certified to three levels with increasingly stringent requirements: Silver, Gold or Platinum	A list of certified products is available for free on CPA's website. Fees apply for certifying products

Standard/ Specification Setting Organization	Standard/ Specification	Certifier	Description	Outcomes	Access
TCO Certified	TCO Certified	TCO Certified	Trade Name products which have been evaluated against the GreenScreen Certified™ for Cleaners and Degreasers Standard and meet the Gold or Platinum level requirements are eligible to be included on the TCO Certified Accepted Substance List. The listed products are approved for use in TCO certified products and their manufacture.	A third-party assessor evaluates a chemical product against the GreenScreen Certified™ for Cleaners and Degreasers Standard. To be listed, substances must meet Gold or Platinum level requirements.	The TCO Certified Accepted Substance List is freely available
Toxics Use Reduction Institute (TURI), University of Massachusetts, Lowell	CleanerSolutions™	TURI	A database maintained by TURI's Cleaning Laboratory to assist in the search for safer cleaning processes by identifying, developing and promoting safer alternatives to hazardous solvents. The database provides access to the lab's 30 years of testing information on cleaners. The database links performance evaluations to specific testing parameters and environmental assessments performed at the TURI's laboratory. TURI's Pollution Prevention Options Analysis System (P2OASyS™) is used to evaluate the environmental, health and safety concerns of a product.	Products are evaluated using TURI's P2OASyS™ online tool and assigned an overall Safety Score of Lower Concern (2<4), Medium Concern (4<6), High Concern (6<8), and Very High Concern (8-10). The database also includes information on cleaning effectiveness.	CleanerSolutions is freely available. Companies outside of Massachusetts must pay for lab testing of cleaning products.

Standard/ Specification Setting Organization	Standard/ Specification	Certifier	Description	Outcomes	Access
ToxServices	ToxFMD Screened Chemistry® (Meets IPC-1402)	ToxServices	Products which have been evaluated against and meet ToxFMD Screened Chemistry® criteria. A Screened Chemistry assessment evaluates all chemicals required to be disclosed for human health and environmental toxicity and fate hazards using robust chemical hazard assessment methodologies such as GreenScreen® for Safer Chemicals and ChemFORWARD. Analytical testing is required to provide assurance the formulation complies with the current version of the ZDHC MRSL. In addition to the overall chemical hazard assessment, all assessed chemicals, with the exception of water, are assessed for skin sensitization potential.	Products are assigned a Screened Chemistry score of 0 to 50 points. ToxFMD Acceptable means the formulation complies with ZDHC MRSL and has a Score of ≥20. Formulations which pass the criteria receive a ToxFMD Certificate and Scorecard.	Awarded certificates in the electronics manufacturing sector are shared with the Clean Electronics Production Network and ChemWorks where they can be accessed for free
U.S. Environmental Protection Agency, Safer Choice Program	Safer Choice and Design for Environment (DfE) Standard (Meets IPC-1402)[12]	U.S. EPA Safer Choice Program	Products are evaluated against human health and environmental criteria specified in the Safer Choice and Design for Environment Standard. Products that meet the criteria are listed on EPA's website and can bear the Safer Choice label. The Standard is intended to cover a broad scope of products including detergents and cleaners. While the Standard includes review criteria for both the whole product and each product ingredient, certification applies only to the finished product.	A product either passes or fails to meet the Standard criteria	A list of certified products is available for free on U.S. EPA's website Fees apply for certifying products

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12 The IPC-1402 Standard for Greener Cleaners Used in Electronic Manufacturing was created to set pragmatic, minimum criteria for identifying cleaning products used in electronics manufacturing that are safer for workers and the environment.

5.3   Steps for Implementing Safer Alternatives

While assessment frameworks and lists of approved substances and certified products offer valuable insights, businesses also require a clear roadmap for integrating these safer alternatives into their chemical management programs. The two resources below outline step-by-step strategies for implementing safer alternatives:

- ChemCoach, from the NGO Chemsec provides an interactive process flow outlining steps to take to replace hazardous chemicals with safer alternatives. Although focused on endocrine disruptors, the steps can be used for all hazardous chemicals.
- The U.S. Occupational Safety and Health Administration (OSHA)'s "Transitioning to Safer Chemicals, A Toolkit for Employers and Workers" also provides a series of steps for implementing safer alternatives within organizations.

6 Tracking Progress in Safer Alternatives

Electronics brands have maintained Restricted Substance Lists (RSLs) and Manufacturing Restricted Substance Lists (MRSLs) for decades to communicate supplier expectations, meet regulatory requirements and implement sustainability initiatives focused on worker and environmental protection.[13] Positive lists of safer chemicals are becoming more commonly used in the electronics industry to provide guidance on safer solutions to restricted and banned chemicals, such as the TCO Certified Accepted Substance List, US EPA SCIL and ChemFORWARD database. Most work to identify safer chemicals has been on chemical ingredients classified as plasticizers, solvents, surfactants and flame retardants (Whittaker et al. 2023).

For example, ChemWorks, a collaboration of electronics brands, NGOs and certification programs, was created to scale the availability and accelerate the adoption of safer cleaners and degreasers. ChemWorks, created with support from Apple and managed by the NGO ChemFORWARD, has two main components: a registry of certified safer cleaners and degreasers for use in electronic assembly facilities, and a free screening process and report for formulators to help them optimize their formulations based on a shared repository of chemical hazard assessments and safer alternatives (ChemWorks, 2024).

Green Chemistry for Sustainability is an initiative and supporting online database to connect people and resources globally to accelerate research, innovation and the commercialization of sustainable processes and products. This online resource includes a searchable directory of green chemistry and engineering technologies that are currently commercially available or are in the process of becoming commercially available and that are applicable across a broad range of sectors and industries, including electronics.

CEPN works with its mult-stakeholder members to identify Priority Chemicals - process chemicals to be prioritized for elimination of substitution in electronics manufacturing. Currently, CEPN's Priority Chemicals are focused on solvents used in manufacturing cleaning products. CEPN's selection process for these Priority Chemicals included nominating a starting list of chemicals using CEPN member companies' Manufacturing Restricted Substances Lists (MRSL) as well as other publicly available MRSLs, aggregated and anonymized data collected using CEPN's Process Chemical Data Collection (PCDC) Tool and soliciting nominations from a broad cross section of stakeholders. The nominated chemicals were then researched and screened against 1) CEPN's High Hazard Criteria; 2) use in the electronics industry as solvents in manufacturing processes; and 3) a high-level review of potential availability of safer alternatives. CEPN's Priority Chemicals offer a good starting point for electronics manufacturers seeking to eliminate hazardous chemicals within their operations and replace them with safer alternatives.

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13 CEPN maintains a compilation of links to publicly available MRSLs from electronics companies at: Electronics Companies' MRSLs : Clean Electronics Production Network.

Staying Informed

Driven by expanding regulatory requirements as well as greater customer requirements in support of Corporate Social Responsibility initiatives, efforts to transition to safer chemicals in electronics manufacturing will continue to expand. Industry initiatives, trade associations, and NGOs provide venues for businesses to collaborate and stay abreast of the latest developments in safer alternatives. Table 6 provides a list of various organizations leading work in safer alternatives for the electronics manufacturing sector as well as ways for business to get involved.

Table 6. Organizations Leading on Safer Alternatives for the Electronics Sector

Organization	Description	Ways to Get Involved
Change Chemistry	Change Chemistry is a collaboration of more than 125 members that aim to make safer and sustainable chemistry widely available in the marketplace. Members span diverse industries from leading chemical companies, brand manufacturers, and large retailers to innovative startups. Change Chemistry also engages with policymakers, non-profit organizations, and consulting firms to advance their mission to drive the commercial adoption of green and sustainable chemistry.	Become a member Participate in a program or project Take advantage of resources and events
ChemFORWARD	ChemFORWARD unites businesses, governments, and NGOs who share the following vision: A world where all chemicals are vetted before use so that no more hazardous chemicals enter circulation, and existing hazardous chemicals can be systematically drawn down and replaced with verified safer alternatives, and ultimately sustainable chemistry.	Keep up to date on the work of the Electronics Safer Chemistry Collaborative Stay abreast of news related to safer chemistry
Clean Electronics Production Network (CEPN)	The Clean Electronics Production Network unites diverse stakeholders to understand, address, and eliminate workers' exposure to toxic chemicals in the electronics supply chain. CEPN comprises more than 20 member organizations including electronics brands and suppliers, environmental organizations, labor and worker representatives, ecolabels, academics and public servants. CEPN members commit to working together in the service of a shared goal of moving toward zero exposure of workers to toxic process chemicals in electronics manufacturing.	Become a member Take advantage of tools and resources, including those for identifying safer alternatives Subscribe to CEPN's newsletter

Organization	Description	Ways to Get Involved
Clean Production Action (CPA)	Clean Production Action designs and delivers strategic solutions for green chemicals, sustainable materials and environmentally preferable products. CPA's unique role is to translate the systems-based vision of clean production into the tools and strategies NGOs, governments and businesses need to advance green chemicals, sustainable materials and environmentally preferable products.	Stay informed on GreenScreen for Safer Chemicals and the GreenScreen Certified standards Participate in BizNGO's Chemicals Management Work Group and/or the Chemical Footprint Project
IPC	IPC is a global non-profit, member-driven trade association dedicated to furthering the competitive excellence and financial success of its members, who are participants in the electronics industry. IPC is a leading source for industry standards, training, industry intelligence and public policy advocacy, with a focus on helping OEMs, EMS, PCB manufacturers and suppliers build electronics better. IPC members represent all facets of the electronics industry, including design, printed board manufacturing, electronics assembly, test, and advanced packaging.	Become a member Make use of resources focused on sustainability in the electronics industry
Responsible Business Alliance (RBA)	The Responsible Business Alliance (RBA), formerly the Electronic Industry Citizenship Coalition (EICC), is a nonprofit comprised of electronics, retail, auto and toy companies committed to supporting the rights and well-being of workers and communities worldwide affected by global supply chains. RBA members commit and are held accountable to a common Code of Conduct and utilize a range of RBA training and assessment tools to support continuous improvement in the social, environmental, and ethical responsibility of their supply chains.	Become a member Keep up to date on the Responsible Environment Initiative, Chemical Management focus area activities

Organization	Description	Ways to Get Involved
TCO Certified	TCO Certified is a global sustainability certification for IT products; criteria cover climate, chemical substances, circularity and supply chain responsibility. The TCO Certified Accepted Substance List identifies chemical substances and products assessed and determined to be safer based on established criteria.	Keep up to date on TCO Certified Accepted Substance List
Washington State Department of Ecology	The Washington State Department of Ecology is the government agency which implements the state's Toxic Pollution Law, whose goal is to reduce the use of toxic chemicals in consumer products by restricting or eliminating those chemicals when safer alternatives are available.	Take advantage of training on safer alternatives including on-demand webinars, virtual and in-person classes

7 Conclusion

Production of electronic products requires a myriad of chemicals, some of which are hazardous. Exposure to hazardous chemicals can occur throughout the life cycle of an electronics product and workers are particularly at risk due to the frequency and types of activities they perform. Replacing hazardous chemicals with safer alternatives is one of the most effective ways to protect worker health and safety. Using safer alternatives not only helps reduce the risk of worker injury and illness but also provides a proactive and efficient means of meeting regulatory and customer requirements. As presented in this guide, there are numerous resources available to help organizations incorporate safer alternatives into their chemical management programs.

We encourage readers to take the following actions to support the adoption of safer chemicals in their products, processes, and across the entire electronics manufacturing supply chain:

- Form an internal team of impacted stakeholders interested in implementing safer alternatives and share this guide as an educational resource;
- Enlist top management support for incorporating safer alternatives in your chemicals management programs;
- Review the resources summarized in this guide, including training;
- Utilize the step-by-step guides listed in Section 5.3 to create a roadmap for implementing safer alternatives in your business; and
- Support research and development efforts to identify and scale safer chemical alternatives.
- If you're interested in learning more, contact our teams at sustainability@ipc.org and info@cleanelectronicsproduction.org

8 References

Apple, 2024.Apple Environmental Progress Report. Accessed at: https://www.apple.com/environment/.

BizNGO Chemical Alternatives Assessment Protocol, Version 1.1, April 2012. https://www.bizngo.org/images/ee_ images/uploads/resources/BizNGOChemicalAltsAssessmentProtocol_V1.1_04_12_12-1.pdf

BizNGO, 2012. The Common Principles for Alternatives Assessment. Accessed at: https://www.bizngo.org/resources/entry/commons-principles-for-alternatives-assessment.

California Department of Toxic Substances Control, Alternative Analysis Guide, Version 1.1, July 2020. Accessed at: https://dtsc.ca.gov/scp/alternatives-analysis/.

California Health and Safety Code, 1986. Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65), Sections 25249.5–25249.14. Sacramento, CA: California Office of Environmental Health Hazard Assessment (OEHHA).

California Safer Consumer Products regulation (California Code of Regulations, Title 22, Sections 69501-69510). Accessed at: https://dtsc.ca.gov/scp/safer-consumer-products-regulations/.

Clean Electronics Production Network (CEPN), 2023. Summary of Second Round Priority Chemical Selection Report. Accessed at: https://cleanelectronicsproduction.org/tools-resources/priority-chemicals.

Clean Electronics Production Network, 2019. Alternatives Assessment Guide. Accessed at: https://cleanelectronicsproduction.org/tools-resources/cepn-toolbox/alternatives-assessment-guide-worksheet.

Clean Production Action (CPA), 2018. GreenScreen® for Safer Chemicals Hazard Assessment Guidance, Version 1.4, January 2018. Accessed at: https://www.greenscreenchemicals.org/.

Global Electronics Council, 2022. State of Sustainability Research for Chemicals of Concern. Accessed at: https://globalelectronicscouncil.org/resources/state-of-sustainability-research/state-of-sustainability-research-chemicals-of-concern/.

Interstate Chemicals Clearinghouse, 2017. Alternatives Assessment Guide (Version 1.1). Accessed at: https://www.theic2.org/alternatives-assessment-guide/.

IPC, 2022. IPC-1402 Standard for Greener Cleaners Used in Electronic Manufacturing. Accessed at: https://www.ipc.org/TOC/IPC-1402_TOC.pdf.

Maine Toxic Chemicals in Children's Products regulation (Title 38, Chapter 16-D of Maine Revised Statutes). Accessed at: https://legislature.maine.gov/statutes/38/title38ch16-Dsec0.html.

National Academies of Sciences, Engineering, and Medicine. 2014. A Framework to Guide Selection of Chemical Alternatives. Washington, DC: The National Academies Press. https://doi.org/10.17226/18872.

Organization for Economic Cooperation and Development (OECD), 2024. Substitution and Alternatives Assessment Toolbox (SAAToolbox). Accessed at: https://www.oecd.org/en/topics/risk-management-risk-reduction-and-sustainable-chemistry.html.

Organization for Economic Cooperation and Development (OECD), 2021. Guidance on Key Considerations for the Identification and Selection of Safer Chemical Alternative, OECD Series on Risk Management, No. 60, Environment, Health and Safety, Environment Directorate, OECD.

Organization for Economic Cooperation and Development (OECD), 2010. Chemicals Used in the Electronics Industry. Series on Emission Scenario Documents, No. 25. https://doi.org/10.1787/9789264221062-en.

Sepulveda, A., Schluep, M., Renaud, F. G., Streicher, M., Kuehr, R., Hagelüken, C., Gerecke, A. C., 2010. A review of the environmental fate and effects of hazardous substances released from electrical and electronic equipment during recycling: Examples from China and India. Environmental Impact Assessment Review, 30(1), 28–41. https://doi.org/10.1016/j.eiar.2009.04.001.

United Nations, 2023. Globally Harmonized System of Classification and Labelling of Chemicals (GHS) (10th rev. ed.). Geneva, Switzerland: United Nations Economic Commission for Europe (UNECE). Accessed at: https://unece.org/about-ghs

United States Department of Labor, Occupational Safety and Health Administration (OSHA), 2024. Transitioning to Safer Chemicals, A Toolkit for Employers and Workers. Accessed at: https://www.osha.gov/safer-chemicals.

Washington State Alternatives Assessment Guide for Small and Medium Businesses, July 2021. Accessed at: https://apps.ecology.wa.gov/publications/SummaryPages/1504002.html.

Washington Toxic Pollution Law (Chapter 70A.350 RCW). Accessed at: https://app.leg.wa.gov/rcw/default.aspx?cite=70A.350.

Whittaker, M. H., Heine, L., and Fong, A. (2023). Chemicals Used in the Electronics Industry. Patty's Industrial Hygiene and Toxicology, 7th Edition. DOI:10.1002/0471125474.tox170.

About IPC International, Inc.

IPC is a global industry association based in Bannockburn, Ill., dedicated to the competitive excellence and financial success of its 3,200+ member companies which represent all facets of the electronics industry, including design, printed board manufacturing, electronics assembly, and test. As a member-driven organization and leading source for industry standards, training, market research and public policy advocacy, IPC supports programs to meet the needs of an estimated $2 trillion global electronics industry. IPC maintains additional offices in Washington, D.C.; Atlanta, Ga.; Miami, Fla.; Mexico City, Mexico; Munich, Germany; Brussels, Belgium; Bangalore and New Delhi, India; Bangkok, Thailand; and Shanghai, Shenzhen, and Taipei, Greater China.

About Clean Electronics Production Network

The Clean Electronics Production Network (CEPN) is a collaborative multi-stakeholder innovation network launched in 2016 as part of the Center for Sustainability Solutions at Green America to address complex workplace health and safety challenges in the electronics supply chain. More than 20 member organizations make up the network, including electronics brands and suppliers, environmental NGOs, labor and worker representatives, ecolabels and representatives from academia and government agencies.