A Protocol for Prioritizing Chemicals of Concern in the Electronics Industry

2018

An Overview

Prioritizing potentially problematic chemical substances is key to effectively focusing green chemistry efforts in electronics manufacturing. Existing scientific tools and policy frameworks, however, do not provide immediately applicable and transparent methods that companies can use to identify chemicals of concern. We have developed a Chemical Prioritization Protocol to systematically evaluate chemicals of interest and support Apple's Safer Materials Program. Electronics companies can use this Protocol to proactively identify chemicals that may warrant chemical management actions. Chemical prioritization can guide further efforts to make products and materials safer for manufacturing workers, customers, recyclers, and the planet. The Chemical Prioritization Protocol is a multi-criteria evaluation framework that synthesizes a wide range of relevant information about chemical hazard, use, exposure potential, and public concern into a simple set of quantitative indicators. This paper presents the design and application of the Protocol.

1. Introduction

Apple leads the industry in reducing or eliminating the hazardous substances commonly used in electronics, and is committed to the health and safety of people who make and use Apple products. This means proactively restricting hazardous substances and using safer materials in its products and processes. Apple relies on toxicological and environmental sciences, public policy, and industry insight to prioritize which substances to restrict or substitute. With ever-greater attention focused on the safety of materials used across products and manufacturing processes, chemical management decisions increase in complexity and scope. The need for a data-driven methodology to support the evaluation and prioritization of chemical substances has motivated the development of this Chemical Prioritization Protocol.

1.1. The need for a new framework

We reviewed existing frameworks that could be used for chemical prioritization, including risk assessment and hazard assessment methodologies, list-based screening tools, ecolabel certification criteria, and public policy frameworks. We found each of these tools to be unsuitable on its own. Many existing frameworks either do not have sufficient depth, lack a detailed method of use, or do not evaluate all of the factors that we consider relevant to prioritizing chemical substances for action. For example, sophisticated hazard assessment frameworks such as the GreenScreen® for Safer Chemicals offer great depth and comparative power but focus exclusively on one aspect of a substance.[1] Some excellent alternatives analysis frameworks (e.g., NRC) exist that incorporate a wide range of chemical safety and sustainability concerns, but they are mostly designed for deep, context-specific assessments that are more appropriate at a later stage of material selection than chemical prioritization.[2]

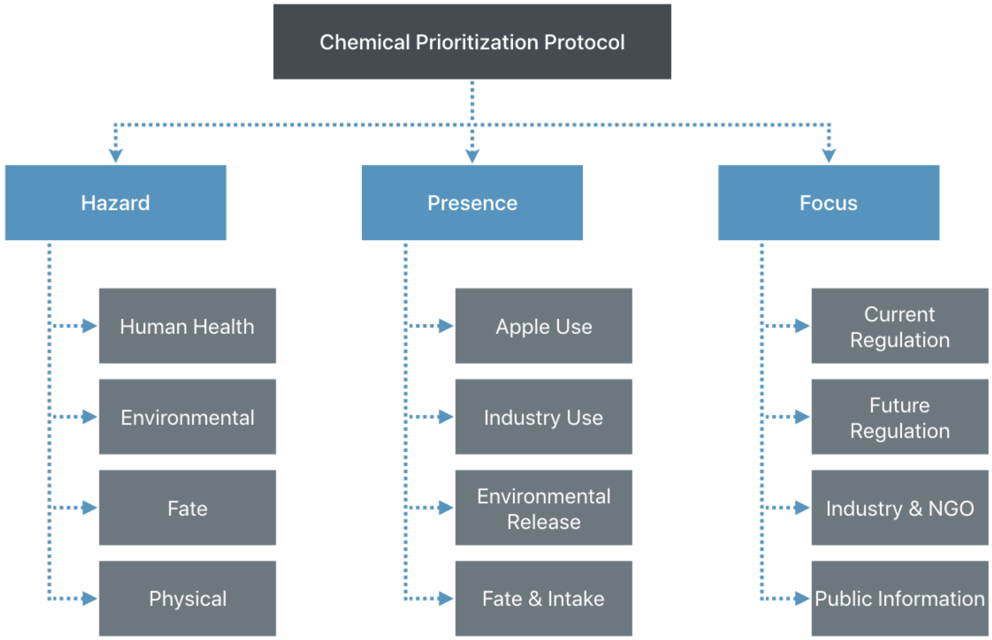

Figure 1: Modular structure of the Chemical Prioritization Protocol

2. Design of the Chemical Prioritization Protocol

The Chemical Prioritization Protocol is a multi-criteria decision aid that helps identify substances that may be problematic. It can be used to evaluate and compare chemical substances on a scale from high to low priority, based on factors that are relevant to decision-making in the design of safer products and materials. It is designed to generate findings that are easily understandable, and to make meaningful use of available data even when those data are incomplete or imperfect.

2.1. Scope and domain of applicability

The Chemical Prioritization Protocol evaluates chemicals with three major considerations in mind:

- **Hazard:** The inherent ability of the substance to cause harm to health and the environment
- **Presence:** The presence of the substance in technical systems (electronic products and supply chains) and in the environments that are affected by chemical hazards
- **Focus:** The nature and degree of industrial, regulatory, and civil society concerns about the substance

All substances that may exist in products, workplaces, or manufacturing processes can be prioritized. The Protocol was designed to be used by electronics companies, but it can be used to evaluate chemicals used in any manufacturing sector. Some parts of the Protocol address company-specific manufacturing, supply chain, and policy factors, and these parts are designed to be flexible and adaptable to each company's unique position.

2.2. Structure

The Chemical Prioritization Protocol is a framework of evaluative criteria and decision logic. There are three evaluation modules addressing the three primary considerations identified above (Hazard, Presence, and Focus). Each evaluation module is organized into separate components (Figure 1), which integrate various metrics, criteria, and data sources (see Appendices A and B for criteria, evaluation methods, and data sources). These criteria are based on established science and assessment methods whenever possible.

Evaluating substances involves applying the Protocol’s technical criteria to generate detailed numeric scores. The Protocol’s scoring system includes simple rules for aggregating these scores to calculate an overall prioritization score for each module. All three module scores have a range of zero to ten, where zero is the lowest priority and ten is the highest.

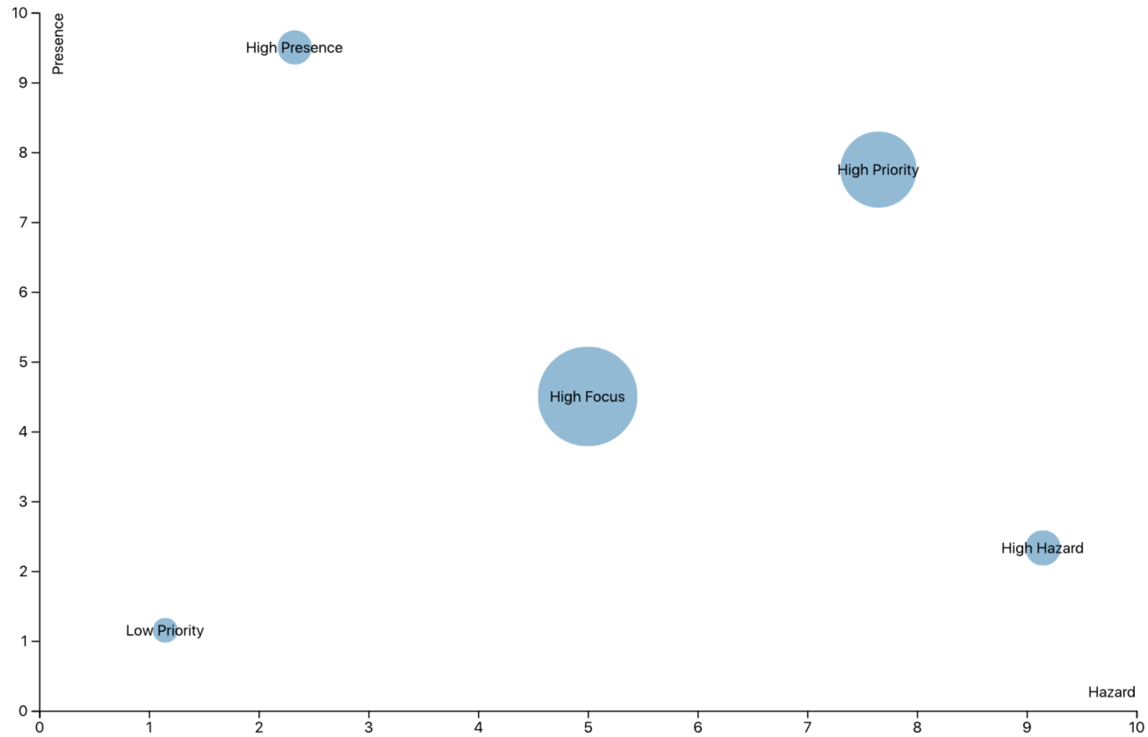

Figure 2. Example plot showing prioritized substances. Hazard and presence are on the horizontal and vertical axes, respectively, while focus level determines the circle size (larger circle size = higher focus). Data availability is represented by the color intensity of the circles (darker color = more robust data set).

2.3. Prioritization logic

The three module scores (Hazard, Presence, and Focus) are distinct, representing independent dimensions of chemical priority. To prioritize substances, we suggest creating a scatter plot using hazard and presence as the horizontal and vertical axes, respectively, and representing the focus score using the radius of each point. This allows all three scores to be represented simultaneously without diluting or compromising them as independent metrics. High-priority substances will generally appear as large circles toward the top right, and low-priority substances as small circles toward the bottom left. An example plot is shown above. The scatter plot (Figure 2) provides an informative high-level presentation of chemical prioritization results. However, the specific breakdown of scores produced by each of the Protocol’s evaluation modules can also be visualized to give more detailed insight into each chemical’s position in the overall prioritization. We consider this level of transparency to be essential to supporting chemical prioritization decision-making.

3. Prioritization case studies

We have applied the Chemical Prioritization Protocol to a range of substances to investigate its effectiveness in differentiating between higher- and lower-priority chemicals. Here we present three case studies showing the application of the Protocol to the following sets of chemicals.

- **Trial substances:** We constructed a set of 45 substances that are deliberately diverse, varying in kind (organic, inorganic, etc.), levels of concern (chemicals of concern, benign substances, unknowns), and data availability (well-studied to unknown; i.e., substances with data gaps).
- **Apple Regulated Substances Specification (RSS):** We selected 40 representative substances from the Apple RSS, 069-0135-J (https://www.apple.com/environment/safer-materials/). The RSS describes Apple's global restrictions on the use of certain chemical substances or materials in Apple's products, accessories, manufacturing processes, and packaging used for shipping products to Apple's end customers. The selected substances are considered to be higher priority for avoidance or substitution.
- **ZDHC MRSL:** We selected 40 representative substances from the Zero Discharge of Hazardous Chemicals Manufacturing Restricted Substances List (ZDHC MRSL, version 1.1). We chose this list because it is comparable to the Apple RSS in terms of representing higher-priority substances, but selected with emphasis on a different industry (textiles).

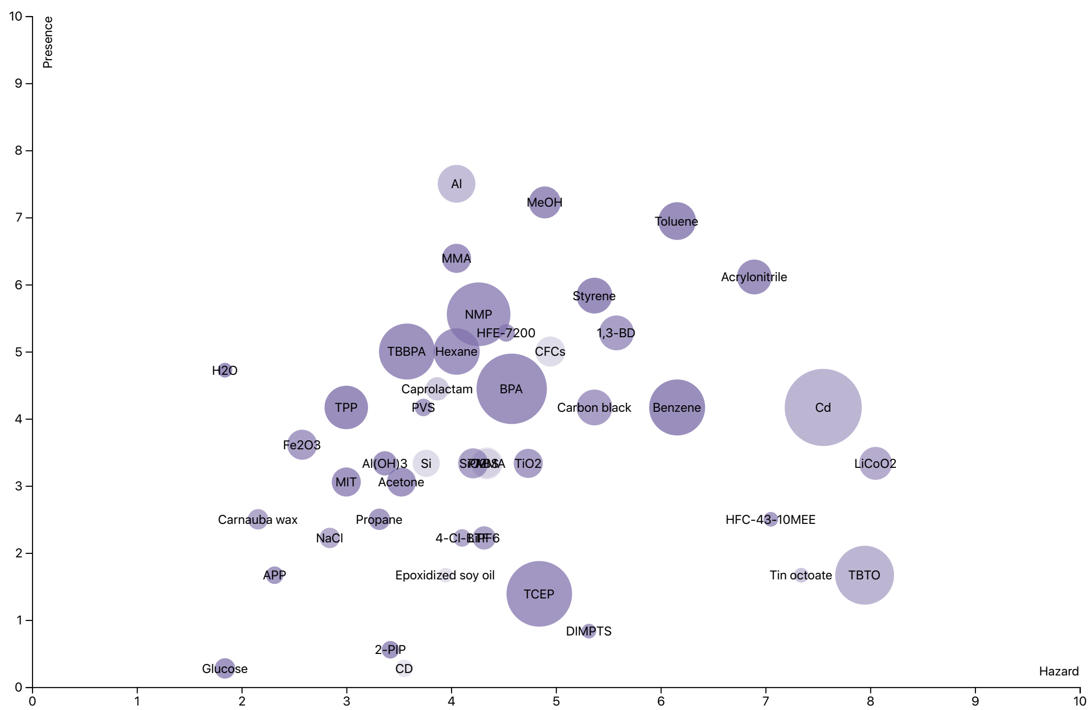

Figure 3. Prioritization of test substances.

3.1. Results

Figure 3 shows the prioritization results for the set of 45 trial substances, illustrating how the Protocol differentiates between chemicals. Low-hazard substances such as water, glucose, and natural waxes received low hazard module scores, while toxic substances like cadmium (Cd) and tributyltin oxide (TBTO) received high scores. Substances associated with significant use and industrial emissions in electronics manufacturing scored high in presence. Finally, substances associated with a high degree of concern among policymakers and civil society, like the polymer precursor bisphenol A (BPA), received high focus scores.

Most substances from the Apple RSS scored higher on all three dimensions than substances that are not on the RSS. This is consistent with expectations for a set of substances that have been selected for their high hazard and significant industrial use in the electronics sector. Furthermore, many of these substances also received high focus scores, consistent with the fact that many of the same chemicals restricted by Apple are receiving attention from policymakers, advocates, and civil society. Likewise, among ZDHC MRSL substances, most had higher hazard and focus scores than substances not on the MRSL. However, the Protocol produced lower presence scores for many textile-specific compounds.

Overall, prioritization scores calculated using the Protocol for these sets of substances are broadly consistent with conventional expert assessments of chemical hazard and priority.

4. Development of technical criteria

In the following sections we provide an overview of the Chemical Prioritization Protocol's technical criteria and discuss the rationale behind their development.

4.1. Hazard

Hazard is a substance's potential to harm human or environmental health. The Hazard module builds on established chemical assessment methods to provide a multifaceted evaluation of hazard. It is designed to produce a simple yet systematic score that encompasses human health hazards, environmental hazards, environmental fate (persistence and bioaccumulation), and physical hazards. The evaluation methodology is applicable over a wide range of data availability, and the scoring system provides indicators of uncertainty originating from data gaps or conflicting hazard data sources.

4.1.1. Multi-endpoint scoring system

Hazard evaluation is based on specific criteria for different hazard endpoints—measurable biological or ecological effects representing a particular kind of hazard. The endpoints and criteria used in this module are based on internationally accepted scientific and regulatory standards. We have adapted and extended a peer-reviewed scientific methodology for translating multi-endpoint hazard assessments into numeric score ranges.[3]

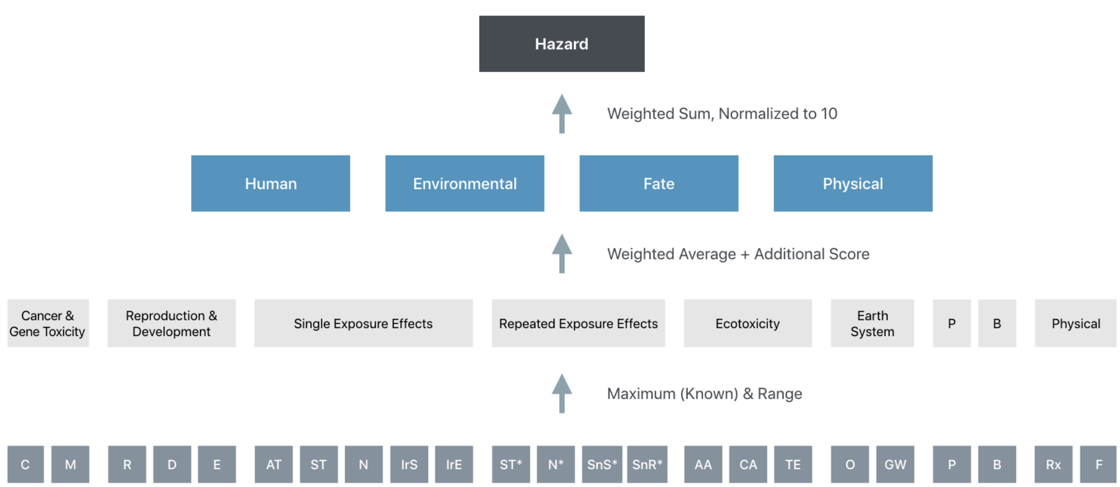

Figure 4. Overview of Hazard evaluation logic. Each row represents a different level of scoring. From top to bottom: module, component, endpoint group, and endpoint.

The scoring logic aggregates the endpoint-level scores into successively fewer and broader scores, ultimately producing a single overall hazard score. The scoring system includes decision logic for identifying highly hazardous substances as well as adjustable relative weightings of the different hazard endpoint groups (Figure 4).

For many chemicals, available data are insufficient to assess all endpoint-specific hazard levels. This module is designed to account for uncertainty due to missing or conflicting data sources. First, the hazard scoring system uses uncertainty ranges to provide a measure of the possible range of hazard properties for each endpoint. This avoids the need to make unsubstantiated assumptions of safety or of worst-case hazard in the absence of data. It also enables the module to use any available evidence, including incomplete data, to produce a systematic hazard score. Second, the scoring system also includes a metric of data completeness, which can be used to assess the prevalence of data gaps for each substance. Using this system, it is possible to distinguish between "unknown" chemical hazards and those that are well understood, even if they have similar overall scores.

4.1.2. Relationship to other frameworks

We developed these technical criteria and scoring logic based on existing chemical hazard assessment methods and standards—primarily the UN Globally Harmonized System and the GreenScreen® for Safer Chemicals by Clean Production Action.[4] The most relevant comparison is with the GreenScreen® (GS). The Protocol hazard criteria are adapted directly from the peer-reviewed GS technical criteria. However, we have found that the GS "Benchmark" system (which assigns substances a categorical score of 1, 2, 3, or 4) does not make fine-enough distinctions between substances to be useful for prioritization. Therefore, we have substituted the GS sequential decision logic (testing against thresholds) with a continuous evaluation function (aggregating scores). Nevertheless, we based aspects of the Protocol's scoring logic for identifying high-priority hazard properties on the GS benchmark criteria.

To compare the results of our methodology with those of the GS methodology, we calculated hazard scores for approximately 100 substances for which Apple has sponsored full GS assessments. The Hazard module score was generally consistent with the GS Benchmark. Variability between GS and our hazard score was consistent with rational expectations based on differences between the systems.

4.2. Presence

Presence indicates the likelihood that a substance might be found in electronic products and supply chains or the global environment. The Presence module evaluates the following facets of a substance's presence in systems of production.

- Use as a manufacturing input, meaning that the substance is either present in products or packaging materials, or is used in manufacturing processes even if it doesn't end up in a finished product. The Protocol prioritizes those substances that are used in the highest quantities and in the most relevant scope of analysis: Chemical use by the company conducting the prioritization is the most relevant, but broader use by the electronics industry also affects prioritization.
- Release into the environment. The Protocol prioritizes substances that are the most prevalent in industrial pollution and waste. This means substances emitted or transferred as waste in the highest quantities, with added emphasis on electronics-related sectors.
- Intrinsic factors that affect human and environmental exposure. This module evaluates chemical persistence, bioaccumulation and bioavailability, and inhalation exposure potential. The criteria are based on existing frameworks for exposure-based prioritization of chemicals from government and peer-reviewed science (for example, see Mitchell et al.).[5]

When evaluating use and environmental release, the Protocol gives greater priority to substances that are associated with the electronics industry and related manufacturing sectors, and even greater emphasis on substances directly used by the company performing the prioritization. The evaluation criteria draw on multiple forms of evidence, ranging from global emissions reporting programs and scientific databases to specialized business knowledge. For example, we leverage Apple's Full Material Disclosure (FMD) program to identify substances used in Apple products and materials. FMD is an Apple initiative that requires suppliers to disclose the entire chemical composition, chemicals intentionally added, and known impurities and residual materials in the parts, components, and materials used in Apple products.

4.3. Focus

Focus reflects the level of concern in the public sphere about a substance. While complex and difficult to define, this factor is important because public concerns about chemical substances have the potential to become significant issues with real effects on chemical use in industry. We are not aware of any existing methodology to evaluate public focus on chemicals. We identified the following key indicators:

- The degree to which regulatory agencies are controlling or are likely to control a given substance
- How public-interest advocates and industry groups have evaluated or acted on the substance
- The existence and particular context of public information about the substance

We describe how the Focus module evaluates each of these aspects below. The Focus module draws on a variety of complementary data sources to evaluate government, nongovernmental, industry, and pubic information on substances. The scoring system emphasizes direct links to consumer electronics and relevant product sectors.

4.3.1. Current and future regulations

The Focus module prioritizes substances that regulators around the world have identified as being of greatest concern in a wide cross-section of public policies, and substances that are likely to be significantly affected by upcoming developments in regulatory programs. The Current Regulation component evaluates how substances are currently regulated: The criteria reference examples of regulated substance lists and categorize them into broad levels of priority that are internally consistent. The score for each substance is determined by which types of regulations affect it. For example, we consider total restriction of a chemical to reflect a greater degree of focus than a notification requirement. Relevant policy contexts for Current Regulation include consumer product–focused laws, workplace safety regulations, and general chemicals policies.

The Future Regulation component includes a scoring matrix that evaluates upcoming regulatory initiatives on three independent factors: the risk of disrupting business operations (regulatory impact), the status and likelihood of the initiative being implemented, and the time horizon for the regulation coming into force. Substance scores are determined by these factors, if the substance falls into the scope of any emerging initiatives. This assumes that the Protocol user has access to resources for tracking emerging regulatory initiatives worldwide and is able to evaluate regulatory risks to its own operations.

4.3.2. Industry and NGO focus

To evaluate nongovernmental stakeholders' level of attention to a chemical, this component of the Protocol considers a number of different kinds of public actions that reflect those concerns. Substances score highly if there are several kinds of evidence of public concern. These include voluntary industry efforts to restrict or phase out a substance (RSLs), environmental or public health–oriented NGO campaign communications about chemicals, and expert reviews that identify chemicals of concern based on scientific analysis. Within NGO campaigns, the criteria distinguish between advocacy efforts focused on electronic products or manufacturing (scored higher), on other consumer product sectors, or more broadly on environmental policy analysis.

4.3.3. Public information

Criteria for the Public Information component are based on how public information has mentioned a given chemical over a defined period of time. The criteria account for several possible contexts of public information, ranging in specificity from being directly about the company's products, about the electronics industry, or about more general topics. By separating public information, such as media coverage, into a number of different contexts, chemicals with a wide range of public information coverage or highly relevant public information coverage are scored higher. However, the criteria do not account for the affective ("positive" or "negative") nature of the coverage.

5. Conclusion

We have developed the Chemical Prioritization Protocol, a framework for prioritizing chemicals of concern in the electronics industry. The Protocol adapts and extends established methodology for chemical hazard assessment. It also provides novel metrics for electronics industry–specific factors relevant to chemical prioritization, including policy and social factors. It integrates these into an innovative and transparent multi-criteria prioritization model. The Protocol provides three easily understandable independent metrics that can be visualized simultaneously. Combined with the knowledge generated by full material disclosure and toxicological assessment, this Protocol can inform better decision-making in Apple's efforts to develop and use safer materials.

Acknowledgments

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Appendix A

Criteria Summary, Evaluation Methods, and Data Sources for Module Components

Component	Criteria Summary	Evaluation Methods	Data Sources
Human Health Hazard	Criteria for 14 human toxicological endpoints	Numeric scoring system based on criteria from GreenScreen® 1.3 and GHS	GreenScreen® and Scivera assessments, scientific literature, GHS classifications
Environmental Hazard	Ecotoxicity endpoints, ozone depletion, and global warming potential	Numeric scoring system based on criteria from GreenScreen® 1.3 and GHS	GreenScreen® and Scivera assessments, scientific literature, GHS classifications
Environmental Fate	Persistence and bioaccumulation	Numeric scoring system based on criteria from GreenScreen® 1.3	Chemical assessments, measured and computed molecular properties
Physical Hazard	Reactivity and flammability	Numeric scoring system based on criteria from GreenScreen® 1.3 and GHS	GreenScreen® and Scivera assessments, scientific literature, GHS classifications

Component	Criteria Summary	Evaluation Methods	Data Sources
Apple Use	Use in Apple products and materials	Tiered scoring based on Apple product, material, and chemical data	Apple Full Material Disclosure and Life Cycle Assessment Programs
	Use in Apple manufacturing processes	Tiered scoring based on quantified chemical use in Apple manufacturing	Apple Supplier Social Responsibility Chemical Mapping Program
Industry Use	Use in electronics manufacturing industry	Screening against lists of known industry product and process chemicals	US EPA Chemical and Product Categories Database
Environmental Release	Known environmental releases, especially from electronics manufacturing	Screening against national-level industrial emissions inventories	National-level pollutant release and transfer reporting databases, including US TRI
Fate and Intake	Characteristics that affect human intake and environmental fate	Numeric scoring system based on GreenScreen® 1.3 and other frameworks	Chemical assessments, measured and computed molecular properties

Component	Criteria Summary	Evaluation Methods	Data Sources
Current Regulation	Substances affected by existing regulations focused on consumer products, occupational health, or broad prioritization of chemicals	Tiered screening against categorized lists of government-regulated substances	Public government documents
Future Regulation	Potential for future regulatory actions	Global knowledge base of tracked regulatory initiatives	Apple Restricted Substances Program
Industry and NGO Focus	Substances identified as high-priority in NGO and industry sectors	Screening against knowledge base of NGO campaigns, assessments, RSLs	Industry and NGO publications and resources
Public Interest Focus	Public interest, including media coverage, of chemical substance	Frequency of appearance in public interest and media reports, with more weight given to associations with the electronics industry and Apple in particular	Results compiled from literature database searches (ProQuest Dialog)

Appendix B

Detailed Data Sources for Hazard, Presence, and Focus Modules

Hazard Component	Data Source	Data type
Multi-Endpoint Hazard	Apple-commissioned hazard assessments	Full GreenScreen® Assessments
	GreenScreen® Store, IC2 Hazard Assessment Database, Pharos, and other sources	Full GreenScreen® Assessments
	Scivera Lens	Scivera hazard scores
	US EPA CompTox Chemistry Dashboard	Chemical identifiers and structures, DSSTox Predicted Property Data (full download)
	ECHA CLP (Reg 1272/2008), Annex VI (Table 3.1)	GHS classifications by substance, legally binding in the EU
	New Zealand EPA Chemical Classification and Information Database	HSNO classifications by substance
	Various government sources	GHS classifications by substance
	US EPA ACToR Database	Hazard classification lists
	ECHA Information on Chemicals	Curated data for REACH registered substances
	OECD QSAR Toolbox	Toxicological data and prediction tools
	US EPA Clean Air Act, Ozone-depleting substances	Categorized lists of ozone-depleting substances and global warming potentials
	EC Regulation on substances that deplete the ozone layer (Reg 1005/2009)	Categorized lists of ozone-depleting substances
	UNFCCC Global warming potentials	List of gases with known global warming potential
	IPCC Third Assessment Report, Ch 6, Table 6.7	List of halocarbons with known global warming potential
	US EPA Report on PFC heat transfer fluids	Global warming potentials and physical properties for PFC heat transfer fluids used in the electronics sector

Presence Component	Data Source	Data Type
Apple Products and Materials	Apple Full Material Disclosure (FMD) Initiative – Environmental Technologies	Chemical composition of materials and parts used in Apple products
	Apple Life Cycle Assessment (LCA) Program – Environmental Technologies	Material and elemental composition of Apple products on a mass basis
	Apple Analytical Testing – Environmental Technologies	Chemicals identified in products and materials by analytical testing
	Apple Product Life Cycle Management	Product specifications and bills of materials
Apple Manufacturing Processes	Apple Supplier Chemical Mapping – Supplier Social Responsibility	Reporting of process chemicals used at FATP sites
Industry Use	Chemicals Used in the Electronics Industry, an OECD Emission Scenario Document	Expert review of chemical use in the electronics industry
	US EPA CPCat Database and forthcoming "CPDat" resource	Substance associations with consumer product and industrial sector categories

Environmental Release	US EPA Toxics Release Inventory	Reported environmental releases in the USA
	Japan Ministry of Environment Pollutant Release and Transfer Register Data Page	Reported and estimated environmental releases in Japan
	OECD Centre for Pollutant Release and Transfer Registers Data	Reported environmental releases in OECD countries.
Fate and Intake	US EPA CompTox Chemistry Dashboard	Chemical identifiers and structures, DSSTox Predicted Property Data (full download)
	Other public sources: US NLM PubChem Compound Database; OECD QSAR Toolbox	Chemical structures, properties, and other information

Focus Component	**Data Source**	**Data Type**
Current Regulation	European Commission RoHS Annex II	List of restricted substances under the RoHS Directive 2011/65/EU
	ECHA Authorisation List (REACH Annex XIV)	List of substances subject to authorization under REACH, Regulation (EC) 1907/2006
	ECHA Biocidal Active Substances	Biocidal Active Substances and their approval status under the Biocidal Products Regulation (EU) 528/2012
	Japan NITE Chemical Risk Information Platform (CHRIP)	Web app to retrieve lists of chemicals regulated under the Chemical Substances Control Law (CSCL), Industrial Safety and Health Act (ISHA), and Law for the Control of Household Products Containing Harmful Substances (LCHP)
	California Safer Consumer Products Program	Candidate Chemicals, Priority Products
	WA Children's Safe Products Act: Chemicals of High Concern to Children Reporting List	Chemicals of High Concern to Children
	Maine Safer Chemicals in Children's Products	Chemicals of Concern; Chemicals of High Concern; Priority Chemicals
	Minnesota Toxic Free Kids Act	Chemicals of High Concern; Priority Chemicals
	Vermont Chemicals Disclosure Program for Children's Products	Chemicals of High Concern to Children
	European Commission CosIng Database	Lists of substances in Annexes II & III of the Cosmetics Regulation (EC) No 1223/2009
	List of MAK and BAT Values 2016, Chapter 2	List of substances with MAK values
	US OSHA Annotated Permissible Exposure Limits (see Table Z-1)	List of substances with OSHA and Cal/OSHA PELs, NIOSH RELs, and ACGIH TLVs
	ToxPlanet ListExpert	Secondary source of regulatory lists
	Pharos Chemical and Material Library	Secondary source of regulatory lists
Future Regulation	Apple Restricted Substances Program – Environmental Technologies	Assessments of globally emerging laws and policies affecting chemicals in products

Industry and NGO Focus	ChemSec SIN List and The 32 to Leave Behind	Substances identified to meet REACH SVHC criteria based on hazard assessment
	Cradle to Cradle Certified™ Banned List of Chemicals	Substances banned for use in Cradle to Cradle Certified™ products as intentional inputs above 1000 ppm
	HP General Specification for the Environment (GSE): Substances and Material Requirements	Specification for banned and restricted substances in all HP products
	Zero Discharge of Hazardous Chemicals (ZDHC) Manufacturing Restricted Substances List v1.1+	Substances banned from intentional use in facilities that process textile materials and trim parts in apparel and footwear
	Greenpeace: Toxic Tech (2005); Green gadgets: Designing the future (2014)	Reports identifying substances of concern used in the electronics industry
	Greenpeace Detox campaign	Recent campaign concerning toxics in apparel industries
	Greenpeace China: Chemicals Calling for Priority Action	An analysis of the Inventory of Existing Chemical Substances in China (2010)
	Campaign for Safe Cosmetics: Chemicals of Concern	Substances in personal care products, identified by a coalition of NGOs
	Safer Chemicals, Healthy Families: Hazardous Hundred	NGO priority list for interstate regulation
	Pharos Chemical and Material Library	Secondary source of industry & NGO RSLs
Public Information Focus	Internet news searching	Literature searching
	ProQuest Dialog™ News & Trade Collection	Advanced literature searching

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