

Global Occupational Health Project
With Electronics Watch

Benzene, Toluene and Some of Their Greener Alternatives

Benzene, Toluene, and Alternative Chemicals: Health Effects Review

By Jeremy Hamilton and Michael Kado, MPH
UC Berkeley, School of Public Health, Environmental Health Sciences

Glossary:

AIHA: American Industrial Hygiene Association
ACGIH: American Conference of Governmental Industrial Hygienists
CalOSHA: California Occupational Safety and Health Administration
CDC: Center for Disease Control and Prevention
EPA: Environmental Protection Agency
ECHA: European Chemicals Agency
NIOSH: National Institute of Occupational Health and Safety
OEL: Occupational Exposure Limit
OSHA: Occupational Safety and Health Administration
PEL: Permissible Exposure Limit
Ppm: parts per million
REL: Recommended Exposure Limit
STEL: Short-Term Exposure Limit
TLV: Threshold Limit Value
TWA: Time Weighted Average
Vapors: Substance in the gas phase at lower than its critical temperature

Table of Contents:

1. Summary
2. Human Health Endpoints
3. Occupational Exposure Limits
4. Benzene Health Effects Review
5. Toluene Health Effects Review
6. Controls
7. Alternative Chemicals
 - a. General Replacements
 - b. Specific Replacements: TURI
8. Conclusion

1. Summary:

The following document addresses the use of benzene and toluene as cleaning solvents in the electronics industry, with particular focus on adverse health effects associated with them and potential ways to reduce these hazards. We first explain the health effects that we are concerned about and how they are assessed, including a hazard summary of benzene, toluene, and several possible alternative chemicals. Then, we introduce the idea of occupational exposure limits, which are mentioned at various

points throughout the report. Following that is a full review of the human health effects associated with benzene and toluene. We briefly discuss the hierarchy of controls, and then focus specifically on the strategy of substituting the hazardous chemicals with safer alternatives. One set of potential alternatives is a group of chemicals identified as typical replacements for benzene and toluene by experts in the field of finding and promoting safer chemicals. Another set of potential alternatives comes from an online tool called the CleanerSolutions Database, which is designed to identify relatively safe cleaning products for more specific applications, like cleaning fluxes off of electronics. We then conclude with some final thoughts about our proposed alternative chemicals and where to go from here.

2 Human Health Endpoints

There are various human health endpoints that are of interest when one is assessing the hazards of a chemical. Table 1 lists these endpoints and shows how they compare across benzene, toluene, and several possible alternative chemicals.

Table 1: Summary of hazard information for current and alternative chemicals.

Key		Human Health Group I					Human Health Group II							
H	High Hazard	Carcinogenicity	Mutagenicity & Genotoxicity	Reproductive Toxicity	Developmental Toxicity	Endocrine Activity	Acute Mammalian Toxicity	Systemic Toxicity & Organ Effects	Neurotoxicity	Skin Sensitization	Skin Irritation	Eye Irritation		
M	Moderate Hazard													
L	Low Hazard													
U	Unknown Hazard													
Current Solvents														
Benzene		H	H	H	H	M	L	H	H	M	H	L	H	H
Toluene		U	L	H	H	M	L	M	H	M	H	L	H	L
Alternative Chemicals														
Isopropyl Alcohol		L	L	M	M	U	L	H	L	M	L	M	M	H
Benzyl Alcohol		L	L	L	M	U	M	U	L	M	H	H	L	H
Ethanol		U	L	L	L	U	L	M	L	M	L	L	L	H
Methyl Acetate		L	L	L	M	M	L	M	M	M	M	L	L	H

Group I human health endpoints are considered to be chronic or life-threatening and potentially induced at low doses or transferred between generations. Group II human health endpoints are ones that can typically be mitigated.

The level of hazard presented by a chemical for a particular health endpoint is identified by using two types of sources. First, there are authoritative bodies like the

International Agency for Research on Cancer (IARC), the U.S. National Institute for Occupational Safety and Health (NIOSH), and the European Chemicals Agency (ECHA) that produce authoritative lists which categorize the hazards of some chemicals. Similarly, there are screening lists produced by bodies like The Endocrine Disruption eXchange (TEDX), the Korean National Institute of Environmental Research (NIER), and the New Zealand Environmental Protection Agency (NZ EPA) which also can provide information about chemical hazards. The second source of hazard information is scientific literature, such as studies that show associations between exposure to the chemical and adverse health effect, either directly in humans or indirectly in animals or cell cultures.

For each human health endpoint, the hazard level of a chemical is scored as being in one of four categories: 1. High Hazard (H), 2. Moderate Hazard (M), 3. Low Hazard (L), or 4. Unknown Hazard (U). A high hazard score indicates that there is substantial evidence that the chemical is associated with adverse effects on that endpoint (e.g., carcinogenicity). A moderate hazard score indicates that there is some evidence that the chemical is associated with the adverse health effect, but results may be mixed. A low hazard score indicates that the chemical does not appear on authoritative or screening lists for the health endpoint and that there may be additional scientific literature showing no or minimal association with the health endpoint. An unknown hazard score indicates that there is not enough information available to comment on the hazard level on that particular health endpoint.

The system described above for categorizing health hazards borrows heavily from the GreenScreen® for Safer Chemicals method for chemical hazard assessment which is meant to help identify chemicals of concern and safer alternatives. GreenScreen is a project of the non-governmental organization Clean Production Action. Several GreenScreen assessments were utilized in the preparation of this document.

In addition to the possible alternative chemicals listed in Table 1, we will later discuss possible substitute cleaners found using an online tool from the Toxics Use Reduction Institutes (TURI) called the CleanerSolutions Database. This tool will provide human health effect scores for some of the same endpoints listed above. The TURI Lab bases their scores on quantitative and qualitative data on chemical toxicity. For the purposes of our discussion, we will assume that their classification system is roughly equivalent to the one described above.

Human Health Effects:

In the next section, benzene and toluene will be discussed in terms of their adverse health effects for humans. Before that, some definitions need to be established.

Carcinogen: a substance that is capable of causing cancer in living tissue

Mutagen: a substance that is capable of causing permanent changes in one's genetic material (i.e., mutations), which could lead to adverse health effects like cancer

Genotoxicant: a substance that damages genetic material, which can result in mutations and which can lead to adverse health effects like cancer

Reproductive Toxicant: a substance that is harmful or toxic to the reproductive system, normal reproduction, and fertility

Developmental Toxicant: a substance that causes adverse health effects to the developing child

Endocrine Activity: substances that can interfere with the endocrine system, which includes the function of the hormones in the body and the organs that produce them

Acute Mammalian Toxicity: the ability to cause adverse effects (including death) from a single exposure or dose of a given substance

Systemic Toxicity and Organ Effects: the ability to cause serious, but non-lethal, adverse effects on one or more organs that may not be near the location in the body where exposure to the substance occurred

Neurotoxicity: the ability of a substance to produce adverse health effects to the structure or function of the nervous system, including the brain

Skin Sensitization: the allergic response to a substance after the chemical comes in contact with the skin over a longer duration and is triggered by future exposures

Skin Irritation: when the skin becomes irritated or experiences reversible damage following contact with the substance for up to 4 hours

Eye Irritation: when the eyes become irritated or experience serious (but reversible) damage following contact with substance

3. Occupational Exposure Limits:

Occupational exposure limits (OEL) are an "upper limit of an acceptable concentration of a hazardous substance in workplace air for a particular material or class of materials, typically set by national authorities" (AIHA). OELs are heavily based upon regulatory and authoritative organizations that attempt to strike the balance between protecting human health and feasible levels at which employers can provide without significant financial burden.

In addition, these OELs are determined based on scientific research about at which levels and for how long people. Typical "concentrations of workplace air" are commonly measured using air pumps attached to filter that capture the amount of the contaminant to be counted or using a pump that directly counts the particles in real-time. The units for these air concentration measurements are in parts-per-million (PPM) or (micrograms/m³).

The amount of time a worker is exposed to a certain chemical uses an 8-hour time-weighted-average (TWA) or short-term-exposure-limit (STEL). A TWA is measuring the average concentration of a particular chemical over a typical working day, which is commonly 8 or 10 hours. A STEL is the acceptable average exposure over a short time period, which is usually 15 minutes, given the TWA isn't exceeded as well. Depending on the organization, there are many acronyms that correspond to OELs. Governing bodies such as OSHA, CalOSHA, and other state-run United States occupational health agencies have enforceable Permissible Exposure Limits (PEL) and STEL. (Table 2). Organizations such as NIOSH utilize Recommended Exposure Limits and ACGIH uses Threshold Limit Values (Table 2).

Governing bodies such as OSHA recognize that their PELs are outdated and inadequate for ensuring protection of workers (OSHA). A common way to interpret OEL values between different organizations is to use and reference the most conservative value. Thus, the most conservative value is usually the lowest values of them all.

Organization	Occupational Exposure Limit Name
OSHA	Permissible Exposure Limit (PEL)
CalOSHA	Permissible Exposure Limit (PEL)
ACGIH	Threshold Limit Value (TLV)
NIOSH	Recommended Exposure Limit (REL)

Table 2: Summary of Occupational Governing Bodies and Organizations OEL Terms

4. Benzene

Benzene is commonly used as a cleaning solvent, though there are many concerns about its negative impacts on human health that suggest that safer alternative chemicals should be identified. It is a volatile organic compound, which means that it evaporates very quickly into the air from its liquid state. This means that a person working with liquid benzene can very easily take benzene vapor into their body by accident simply by inhaling it. Workers can also be exposed to benzene in the workplace by coming into contact with it on their skin. It is also possible for workers to unintentionally consume benzene orally if, for example, they work with benzene and then do not wash their hands before eating food. Inhalation is the main exposure route of concern, but dermal and oral exposure are also important. Benzene has been shown to be readily absorbed by humans from all three of these routes of exposure (ATSDR, 1997).

Occupational exposure limits for benzene:

OSHA PEL: 1 ppm

CalOSHA PEL: 1 ppm

NIOSH REL: 0.1 ppm

ACGIH TLV: 0.5 ppm

Health Hazards of Benzene:

Human Health Group 1:

Carcinogenicity

Benzene is scored as “High Hazard” for carcinogenicity because there are many studies associating benzene exposure with leukemia in humans (IARC, 1987) and many authoritative sources including the International Agency for Research on Cancer (IARC), the National Toxicology Program’s Report on Carcinogens (NTP-RoC), and the National Institute of for Occupational Safety and Health (NIOSH) all list benzene as a human carcinogen (Benzene GreenScreen, 2014).

Mutagenicity/Genotoxicity

Benzene is scored as “High Hazard” for mutagenicity/genotoxicity. Mice, rats, and hamsters exposed to benzene all experienced chromosomal abnormalities in their bone marrow cells, and human cells exposed to benzene in vitro had mutations (IARC, 1987). Also the European Chemicals Agency (ECHA) lists that benzene may cause genetic defects (Benzene GreenScreen, 2014).

Reproductive Toxicity

Benzene is scored as “High Hazard” for reproductive toxicity. Evidence has been found that benzene may adversely affect sperm development and ovaries in mice (U.S. EPA, 2002). Also, the state of California’s Proposition 65 list classifies benzene as a male reproductive toxicant.

Developmental Toxicity

Benzene is scored as “High Hazard” for developmental toxicity. Animal studies in rats and mice indicate that exposure to benzene in pregnant females is associated with decreased birth weight and delayed bone development for the offspring (U.S. EPA, 2002; Reprotox, 2013). Benzene is also included on California’s Proposition 65 list as a developmental toxicant.

Endocrine Activity

Benzene is scored as a “Moderate Hazard” for endocrine activity. Benzene is identified as a potential endocrine disruptor on The Endocrine Disruption eXchange (TEDX) screening list of potential endocrine disruptors (Benzene GreenScreen, 2014). Also, it has been proposed that the reproductive and developmental toxicity associated with benzene may be mediated by an endocrine mechanism (U.S. EPA, 2002).

Human Health Group 2:

Acute Mammalian Toxicity

Benzene is scored as “Low Hazard” for acute mammalian toxicity. It is not listed as acutely toxic on any authoritative lists. A risk assessment from the European Union indicated that benzene has acutely toxic effects only at very high doses and concentrations (EU, 2008).

Systemic Toxicity/Organ Effects

For an exposure that is a single dose, benzene is scored as “High Hazard” for systemic toxicity/organ effects. Benzene is listed as a category 1 hazard (the highest hazard category) for target organ/systemic toxicity (single exposure) on screening lists from the Government of Japan and the New Zealand Environmental Protection Agency (Benzene GreenScreen, 2014). The National Institute of Technology and Evaluation (NITE) in Japan also classified benzene as a category 1 hazard for respiratory organs based on human evidence (NITE, 2006).

For exposure to repeated doses, benzene is scored as “High Hazard” for systemic toxicity/organ effects. The same screening lists that classified benzene as a category 1 hazard for single dose exposure also classified it as category 1 for repeated dose exposure. The NITE also classified benzene as a category 1 hazard for organs involved in the production of blood (e.g., bone marrow) based on human evidence (NITE, 2006).

Neurotoxicity

For exposure to a single dose, benzene is scored as “Moderate Hazard” for neurotoxicity. Benzene is mostly associated with reversible narcotic effects, like drowsiness, fatigue, dizziness, and headache (EU, 2008; U.S. EPA, 2009).

For exposure to repeated doses, benzene is scored as “High Hazard” for neurotoxicity. Benzene was classified by the NITE in Japan as being a category 1 hazard based on observations in humans that included frequent headaches, exhaustion, sleep disorders, and memory impairment (NITE, 2006)

Skin Sensitization

Benzene is scored as a “Low Hazard” for skin sensitization. Benzene is not classified as a skin sensitizer on any authoritative lists. Tests on mouse and guinea pig skin showed no signs of skin sensitization when exposed to benzene (ECHA, 2014).

Skin Irritation

Benzene is scored as “High Hazard” for skin irritation. Direct contact with benzene to the skin can result in skin reddening and blistering in humans, and studies in rabbits and rats have also indicated that it is a skin irritant (EU, 2008).

Eye Irritation

Benzene is scored as “High Hazard” for eye irritation. An authoritative list from the European Union lists benzene as causing serious eye irritation. There is also evidence that benzene vapors can be irritating to the eyes in human and may cause inflammation and swelling of the eyelids in animals (EU, 2008).

Summary:

There is evidence from authoritative lists and scientific literature supporting the classification of benzene as “High Hazard” on all of the following human health endpoints: carcinogenicity, mutagenicity/genotoxicity, reproductive toxicity, developmental toxicity, systemic toxicity and organ effects (specifically related to respiratory organs and blood production), neurotoxicity following repeated doses, skin irritation, and eye irritation. Having a “High Hazard” classification for so many endpoints, especially for Human Health Group 1 endpoints, means that substituting out benzene with another safer chemical should be a high priority in order to protect the health of production workers.

5. Toluene:

Toluene is a cleaning solvent in the electronics industry, however there are major concerns about its adverse health effects, which suggests that safer alternative chemicals should be identified and used. Toluene is a volatile organic compound, meaning that it rapidly converts from a liquid into a gas, leaving the user susceptible to breathing in the vapors. The main source of toluene is through inhalation and then through dermal absorption through the skin (ATSDR). Toluene is considered a “greener” solution for electronics cleaning, however there are many health effects associated with its exposure.

OSHA PEL: 200 ppm

CalOSHA PEL: 10 ppm

NIOSH REL: 100 ppm

ACGIH TLV: 20 ppm

Health Hazards of Toluene:

Human Health Group 1:

Carcinogenicity:

Toluene is scored as “Unknown Hazard” in terms of carcinogenicity as there are multiple studies that there is inadequate information towards toluene’s carcinogenicity (IARC 1989). Other bodies of science that have come to the same conclusion are the US EPA 2005, NITE of Japan 2006, and EU in 2003.

Mutagenicity/Genotoxicity:

Toluene is scored as “Low Hazard” for mutagenicity as there are little to no signs of evidence for mutagenicity in short-term exposure (US EPA 2005). Other governing bodies such as NITE/Japan 2006, and EU 2003 came to the same conclusion.

Reproductive Toxicity:

Toluene is scored as “High Hazard” as there is evidence suggesting the reproductive toxicity to exposure to toluene (Prop 65). California’s Proposition 65, which requires businesses to provide warnings to consumers about significant exposure to harmful substances (Prop 65). The US EPA 2005, NITE/Japan 2006, and EU 2003 came to the same conclusions.

Developmental Toxicity:

Toluene is scored as “High Hazard” as there is a large body of evidence suggesting developmental toxicity (Prop 65). This is in accord with NITE/Japan 2006, US EPA 2005, and EU 2003 reports coming to the same conclusion.

Endocrine Activity:

Toluene is scored as “Moderate Hazard” for endocrine activity, as the body of literature is growing, but not robust (TEDX).

Human Health Group 2:

Acute Mammalian Toxicity:

Toluene is scored as a “Low Hazard” for acute mammalian toxicity as there are mixed reports of low activity or unclassifiable activity by NITE/Japan 2006, EU 2003.

Systemic Toxicity/Organ Effects:

Toluene is scored as a “Moderate Hazard” for systemic toxicity and organ effects as there is experimental data supporting for lung and respiratory irritation. This is consistent with EU 2003 and NITE/Japan 2006.

Neurotoxicity:

Toluene is scored as “Moderate Hazard” for neurotoxicity due to the effect of toluene being inhaled into the lungs and affecting the central nervous system, exhibiting sleepiness, fatigue, dizziness, and mild respiratory symptoms (ECHA). In addition, this is agreeance with NITE/Japan 2006 and EU 2003.

Skin Sensitization:

Toluene is scored as a “Low Hazard” as there are multiple studies that show no effects from repeated doses on the skin for animal studies according to REACH, NITE/Japan 2006, and EU 2003.

Skin Irritation:

Toluene is scored as a “High Hazard” as multiple studies have concluded that there is skin irritation in animal models from multiple studies (ECHA and NITE/Japan 2006).

Eye Irritation:

Toluene is scored as a “Low Hazard” based on experimental data with animal studies showing little activity from multiple studies from NITE/Japan 2006 and EU 2003.

Summary:

In summary of toluene and its ratings on health effects, toluene has been shown to have “High Hazard” classification for reproductive toxicity, developmental toxicity, system and organ effects of the lung, neurotoxicity, and skin irritation. Overall getting close to half of the health effects as being classified as “High Hazard”, which is of concern for worker exposures. However, compared to benzene, toluene is shown to be less hazardous to human health.

6. Potential Controls for Benzene and Toluene:

The National Institute of Occupational Health and Safety (NIOSH) a division of the Center for Disease Control and Prevention (CDC), created a visual called, the “Hierarchy of Controls” (Figure 2).

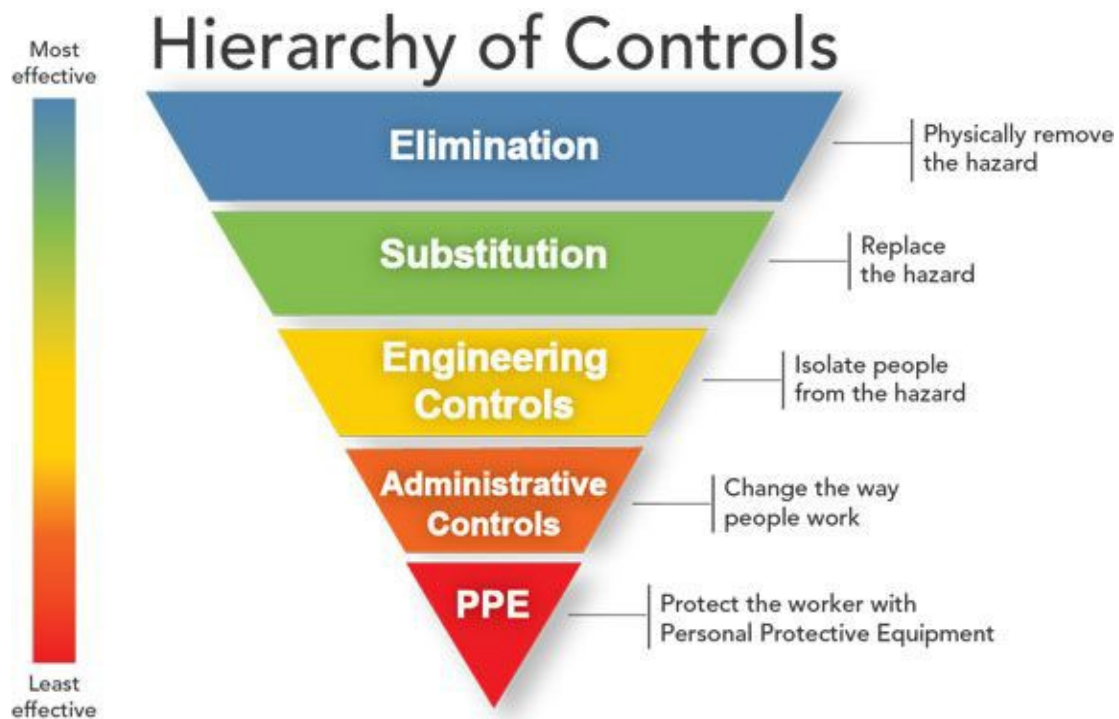


Figure 2: Hierarchy of Controls (CDC).

How to Interpret the Hierarchy:

There are five tiers; Elimination, Substitution, Engineering Controls, Administrative Controls, and PPE. The purpose of the diagram is to be used as a means to determine feasible and effective controls in the job environment. The effectiveness is highest at the top with elimination and the lowest with personal protective equipment (PPE).

Elimination is the most effective because it entirely gets rid of the hazard so no one is exposed. PPE is the least effective because it depends highly on the individual wearing the PPE. Particularly, if the individual chooses to wear it, wears it properly, stores it properly, and remembers to use it to name a few.

The feasibility of implementation of these different tiers are highly contextual based on several factors. A major factor on implementation of controls is cost.

Types of Controls:

Elimination: to physically remove the hazard so that it is no longer present

Substitution: replace the hazard with something less hazardous

Engineering Controls: isolate people from the hazards using

Administrative Controls: change the way people work and interact with the hazard

Personal Protective Equipment (PPE): protect the worker with gear to create a barrier between the person and hazard

Example in the context of Benzene and Toluene use in electronic assembly:

Elimination:

- Currently not possible in the electronics industry

Substitution:

- Replace the benzene and toluene with safer chemicals

Evaluation: this is the method that would be most feasible and cost effective in the short term if there was a an alternative that was as effective as benzene and toluene. It doesn't require a lot of changes in the processing of the electronics and provides a safer alternative for the workers.

Engineering:

- Have local exhaust ventilation where the benzene and toluene are being used
- Use chemicals inside a chemical hood or enclosure

Evaluation: this is the method that would be most feasible and cost effective in the long term. It is high upfront costs for the factory, but the long-term benefits outweigh those of Administrative and PPE.

Administrative:

- Re-assign vulnerable workers to tasks away from benzene and toluene
- Train workers on the hazards of the chemicals and how to safely handle them
- Establish clean areas for eating and taking breaks during the workday

Evaluation: this is a method that would be effective in conjunction with other controls such as substitution and engineering. However, this alone would not have a large impact for the workers, but would still provide some benefit.

PPE:

- Respirator with vapor cartridge
- Gloves

Evaluation: this is a method that would not be effective or feasible in the short or long run. The costs of properly using a respirator with vapor cartridge for so many workers would be enormous. A better option to the respirator would be to deploy an engineering control of a local exhaust vent.

7. Alternative Chemicals:

The goal of alternative chemicals also known as “green solvents” are to reduce adverse human health exposures and health effects and to be able to decrease the amount of energy that goes into the production and reclamation of that chemical (BYRNE).

In consulting over a dozen industry experts, including chemists, industrial hygienists, researchers, and occupational advocacy programs, they suggested both general and specific recommendations for alternative chemicals.

7a. General Recommendations:

After consulting our experts, a few of them suggested general classes and some specific chemicals that could generally replace benzene and toluene, which turned up

Isopropyl Alcohol: CAS #67-63-0

Benzyl Alcohol: CAS #100-51-6

Ethanol: CAS #64-17-5

Methyl Acetate: CAS #79-20-9

Table 1: General Chemical Replacements, Occupational Exposure Limits, and Health Effects Summary

Chemical Name	Occupational Exposure Limit ¹	Health Effects	Difference Compared to Benzene ²	Difference Compared to Toluene ³
Isopropyl Alcohol	OSHA PEL: 400 ppm, CalOSHA PEL: 400 ppm, ACGIH: 200 ppm, NIOSH: 400 ppm	Low carcinogenicity ; Moderate reproductive and developmental toxicity ⁴	n/a	Higher systemic toxicity and eye irritation
Benzyl Alcohol	No OELs at this time	Low carcinogenicity	Higher Skin Sensitization	Higher skin sensitization

¹ OSHA Annotated PELs | Occupational Safety and Health Administration. (n.d.). Retrieved December 6, 2018, from <https://www.osha.gov/dsg/annotated-pels/tablez-1.html>

² GreenScreen Assessment for benzene, PharosProject. Retrieved December 2, 2018, from pharosproject.net

³ GreenScreen Assessment for toluene. PharosProject. Retrieved December 2, 2018, from pharosproject.net

⁴ Isopropanol GreenScreen. Wang, Bingxuan and Whittaker, Margaret H. Isopropanol (CAS# 67-63-0) GreenScreen® for Safer Chemicals (GreenScreen®) Assessment. 2014. Retrieved December 2, 2018. Pharosproject.net

		and reproductive toxicity; Moderate developmental toxicity ⁵		and eye irritation
Ethanol	OSHA PEL: 1000 ppm CalOSHA PEL: 1000 ppm, ACGIH: 1000 ppm, NIOSH: 1000 ppm	Low carcinogenicity and reproductive toxicity; Potentially a developmental toxicant ⁶	n/a	Higher eye irritation
Methyl Acetate	OSHA PEL: 200 ppm CalOSHA PEL: 200 ppm ACGIH: 200 ppm NIOSH: 200 ppm	Potential developmental toxicant ⁷	n/a	Higher eye irritation

The chemicals summarized in Table 1. Are alternatives to benzene and toluene for electronics cleaning. The second column displays the OEL values from various governing and research organizations. Notice that the values for all of the chemicals have relatively higher levels than benzene and toluene, meaning workers can be exposed to more of them before adverse health effects become a concern. The OEL values in column two are in reference to the third column of scientific literature demonstrating low or potential toxic effects for the chemicals.

These alternative chemicals still have adverse health effects associated with their exposure. However, they are an improvement to both benzene and toluene. Columns 4 and 5 compare the “Alternative Chemicals” to both benzene and toluene. The columns highlight if the alternative chemicals has a “Higher” rating than benzene and toluene.

⁵ Benzyl Alcohol GreenScreen. Guerrette, Zach, Rutkiewicz, Jennifer, and Wang, Bingxuan. Benzyl Alcohol (CAS# 100-51-6) GreenScreen® for Safer Chemicals (GreenScreen®) Assessment. 2016. Retrieved December 2, 2018. Business.edf.org

⁶ Ethanol GreenScreen. Linde, Nancy and McGrath, Teresa. GreenScreen® for Safer Chemicals - Assessment for Ethanol (CAS# 64-17-5). 2014. Retrieved December 2, 2018. Pharosproject.net

⁷ Methyl Acetate GreenScreen. Ciotti, Sara, Guerrette, Zach, and Wang, Bingxuan. Methyl Acetate (CAS# 79-20-9) GreenScreen® for Safer Chemicals (GreenScreen®) Assessment. 2017. Retrieved December 2, 2018. Turi.org

Overall, the alternative chemicals show improvement in every major category except eye irritation and some skin sensitization and neurotoxicity for benzyl alcohol.

7b. Specific Recommendations:

The experts we consulted also suggested using a tool created by the Toxics Use Reduction Institute (TURI) at the University of Massachusetts Lowell. The tool is called the CleanerSolutions Database, and it is designed to assist people in searching for cleaning chemicals that are safer and more environmentally friendly alternatives to hazardous solvents.

A drawback of the alternative chemicals suggested in the previous section is that we were not able to assess how well those chemicals could actually perform at cleaning electronic parts. If they are less hazardous but cannot clean well, then they will not be suitable substitutes. The CleanerSolutions Database can help address this issue. In addition to suggesting chemicals that pose lower hazards, the tool also allows the user to search for chemicals based on criteria related to the type of material being cleaned (the substrate) and the type of material that is being removed (the contaminant). This can be done through the “Find a Cleaner” search function.

(There is also search function to “Replace a Solvent” that you specify. However, there have not yet been any tests done by TURI on replacing benzene or toluene used to clean electronics, so this function does not currently have any results readily available.)

Using the “Find a Cleaner” Search Function

1. *Go to the tool*

The “Find a Cleaner” search page of the CleanSolutions Database can be found here: www.cleanersolutions.org/?action=contaminant_search

2. *Enter search criteria (Figure 3)*

You can then use the scroll-down boxes to select one or more contaminants and substrates relevant for your application. (The “Equipment” field refers to how the cleaner will be applied to the substrate.) In our search, we focused on “adhesives”, “fluxes”, and “resins/rosins” as the contaminants and on “electronics” as the substrate. We also checked the box for “Return only effective results” so we would only get chemicals that the TURI lab tested as being effective at cleaning one of the contaminant/substrate combinations we specified.

Figure 3. Find a Cleaner search page in CleanerSolutions Database

CleanerSolutions Database
Toxics Use Reduction Institute · Surface Solutions Laboratory

Find a Cleaner
Search for a cleaner that has successfully removed a contaminant similar to your own. Chances are that the alternative will also work for you. Optionally, you can add substrate and equipment criteria to help narrow your search.

Required Field You must select one or more contaminants.	Optional Fields Filter your search by substrate or equipment type, or leave these fields set to <i>Any</i> to include all results for a given contaminant.	
Contaminant Adhesive Alcohol Buffing/Polishing Compo Calcium/lime Carbon Deposits Clay Coatings Cutting/Tapping Fluids Dirt Films Fingerprints Fluxes	Substrate Chrome Cold Rolled Steel Copper Electronics Fiberglass Galvanized Steel Glass/Quartz Gold Granite Liquid Marble Nickel	Equipment Any High Pressure Spray Immersion/Soak Low Pressure Spray Manual Wipe Mechanical Agitation Media Blasting Plasma Steam Supercritical Extraction Ultrasonics Vapor Degreasing
All Fields Hold down the <i>shift</i> or <i>ctrl</i> keys to select multiple values.		
Optional Search Filters Product Cleaning Type: <input type="text" value="Any"/> Return only effective results: <input checked="" type="checkbox"/>		
<input type="button" value="Reset"/> <input type="button" value="Submit"/>		

3. *Select a product*

Our search returned six different chemicals, some of which were tested multiple times. Click on any of the product names (not the company name) to see more details.

4. *Review safety and health scores and performance test results (Figure 4)*

Figure 4. Product Information page in CleanerSolutions Database with sections of interest highlighted in red

Product Information

Ionox HC 2
Add to Comparison List

Vendor Provided Information
Product information cited in this section is supplied directly by the vendors. The Institute has not verified the accuracy of any of this information and is not liable for any claims made by the vendors. TURI is likewise not responsible for any typographical errors.

Vendor Name: Kyzen Corporation
Product Classification: Alcohol
Recommended Contaminants: Fluxes, Resins/Rosins, solder, Waxes
Recommended Equipment: Immersion/Soak, Low Pressure Spray, Ultrasonics
Recommended Substrates: Aluminum, Brass, Carbon Steel, Ceramics, Copper, Electronics, Galvanized Steel, Glass/Quartz, Iron, Nickel, Plastic, Stainless Steel, Steel
MSDS / TDS: Ionox HC2 MSDS, Ionox HC2 TDS

Safety Screen Help		
Indicator	Value	Points
VOC:	50	8
GWP:	0	10
GDP:	0	10
NFPA H:	2	7
NFPA F:	1	7
NFPA R:	0	7
pH:	10.2	7
Total: 42/50 (higher is better)		

P2OASys Summary Scores | Help

Indicator	Score
Acute Human Effects:	8
Chronic Human Effects:	4
Atmospheric Hazard:	2
Chemical Hazard:	9
Energy/Resource Use:	4
Total: 5.40/10 (lower is better)	

Laboratory Evaluation of Ionox HC 2 | Field Definitions

Client #	Project #	Trial #	Contaminant	Substrate	Equipment	Effective
20	3	0	Fluxes	Copper	Immersion/Soak	✓
20	3	0	Fluxes	Plastic	Immersion/Soak	✓
20	3	0	Fluxes	Teflon	Immersion/Soak	✓
20	3	0	Fluxes	Electronics	Immersion/Soak	✓
34	2	0	Fluxes	Aluminum	Immersion/Soak	✓
34	2	1	Fluxes	Aluminum	Ultrasonics	✓
34	2	2	Fluxes	Electronics	Ultrasonics	✓
38	2	4	Coatings	Steel	Ultrasonics	✗
38	2	5	Coatings	Steel	Ultrasonics	✓

- A. The “Safety Screen” assesses the impact that the chemical will have on the environment. The score is out of 50 and higher is better. This is good information to be aware of, but it does not directly relate to human health.
- B. The “P2OASys Summary Scores” give some idea of the acute and chronic human health effects from this chemical. They are scored from 2 to 10 with 2 being the lowest hazard and 10 being the highest. “Details” about these scores can also be viewed. **(NOTE: Not all chemicals in the**

CleanerSolution Database list P2OASys Summary Scores. Human health effect scores can only be seen for chemicals with this table.)

- C. You can view the results of the performance tests to see which contaminants were effectively cleaned off of which substrates.

Recommended Chemicals from the CleanerSolutions Database

Our search for cleaners that could effectively remove adhesives, fluxes, or resins/rosins from electronics resulted in six chemicals. Of those six, only two of them had human health effect scores available. These were Bio T Max (sold by BioChem Systems) and Ionox HC 2 (sold by Kyzen Corporation).

For Bio T Max, the human health effects are promising. For the chronic health endpoints of mutagenicity, reproductive effects, neurotoxicity, and developmental effect, this product was classified as low hazard. It received a score of 2 (the best possible score) for chronic human effects. For the acute health endpoints of respiratory irritation, dermal irritation, skin absorption, and ocular (eye) irritation, this product was classified as a moderate hazard. It received a score of 6 (an intermediate score) for acute human effects.

The human health effects for Ionox HC 2 are not as good as for Bio T Max, but they still appear to be preferable to solvents like benzene and toluene. Ionox HC 2 is classified as a low hazard for all of the same chronic health endpoints as Bio T Max. However, Ionox HC 2 also presents a moderate hazard for chronic respiratory sensitivity diseases. It also is classified as posing a moderate hazard for most acute health endpoints, however there is one additional concern regarding acute human health effects. According to its material safety data sheet (MSDS), Ionox HC 2 contains < 2% 2-amino ethanol, which has a TLV of 3 ppm. Based on the human health effect scores, Bio T Max would be the first product we would recommend to try as an alternative.

The CleanerSolutions Database can be used to run more searches to find additional alternative chemicals if there are any other substrates or contaminants that would be of interest in the manufacturing of electronic products.

Fig. 5. Bio T Max details

P2OASys Details
Company: Bio Chem Systems
Product: Bio T Max

Acute Human Effects	
Respiratory Irritation	M
Dermal Irritation	M
Skin Absorption	M
Ocular Irritation	M

Chronic Human Effects	
Mutagen	L
Reproductive Effects	L
Neurotoxicity	L
Developmental Effects	L

Fig. 6. Ionox HC 2 details

P2OASys Details
Company: Kyzen Corporation
Product: Ionox HC 2

Acute Human Effects	
PE-TLV:	3 ppm
Dermal Irritation	M
Skin Absorption	M
Ocular Irritation	M

Chronic Human Effects	
Mutagen	L
Reproductive Effects	L
Neurotoxicity	L
Developmental Effects	L
Respiratory Sensitivity - Diseases	M

The CleanerSolutions Database is a useful tool that can help find products that are relatively safe and tested for their effectiveness as cleaners for specific applications. However, there are several drawbacks to depending on this as a source of alternative cleaners. First, it focuses on particular cleaning products sold by certain vendors rather than individual chemicals that might be more available from multiple sources. Also, the fact that many of the listed cleaning products are proprietary means that their full ingredients are often not available. This means that additional literature review cannot easily be done to supplement the health effect scores generated by the TURI Lab. Finally, the TURI Lab has performance test results available for many combinations of substrates and contaminants, but this still may not include all of the combinations of interest for your particular circumstances. So, further testing may need to be done by the user to confirm that the cleaning will be effective for their process.

8. Conclusion:

Although toluene is an improvement as an electronics solvent compared to benzene, there are still adverse health effects associated with their exposure. Toluene has been shown to have high reproductive and developmental toxicity (Prop 65). However, it has not been shown to be a carcinogen (IARC).

After talking to our experts, some recommended general alternatives benzene and toluene, such as isopropyl alcohol, benzyl alcohol, ethanol, and methyl acetate. However, a drawback from these general recommendations is that they may not be applicable to specific processes within the electronics industry or they may not be optimal for the work that is performed. It is important to not only keep in mind the effectiveness of the alternative solvent, but also the cost, and availability of the chemical when replacing something as effective as benzene and toluene. Since some of these alternative chemicals are not as mass produced as benzene and toluene, they may not be as available and may cost more.

We approached this problem with the focus of targeting one control aspect from the hierarchy of controls. We chose substitution as the main option and most effective taking into account feasibility in Southeastern Asian countries. However, it is important to point out that there are potentially other strategies for protecting workers from harmful chemicals during the cleaning of electronics parts, as summarized in our "Controls" section.

Overall, the literature review we conducted was not definitive in identifying a single alternative chemical that meets all the criteria that benzene and toluene perform. We have identified potential candidates that are less hazardous, but further tests need to be performed to determine if they can functionally replace benzene and toluene as effective cleaning agents.

References

- Agency for Toxic Substances and Disease Registry (ATSDR). 1997. Toxicological profile for benzene (Update). Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA.
- Agency for Toxic Substances and Disease Registry (ATSDR) - Toxicological Profile: Toluene. (n.d.). Retrieved December 8, 2018, from <https://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=161&tid=29>
- Benzene GreenScreen. Wang, Bingxuan and Whittaker, Margaret H. Benzene (CAS# 71-43-2) GreenScreen® for Safer Chemicals (GreenScreen®) Assessment. 2014. Retrieved December 2, 2018. Pharosproject.net
- Benzyl Alcohol GreenScreen. Guerrette, Zach, Rutkiewicz, Jennifer, and Wang, Bingxuan. Benzyl Alcohol (CAS# 100-51-6) GreenScreen® for Safer Chemicals (GreenScreen®) Assessment. 2016. Retrieved December 2, 2018. Business.edf.org
- Casarett, L. J., Doull, J., & Klaassen, C. D. (2001). *Casarett and Doull's toxicology : the basic science of poisons*. McGraw-Hill Medical Pub. Division. Retrieved from <https://www.ncbi.nlm.nih.gov/nlmcatalog/101126797>
- CDC - Hierarchy of Controls - NIOSH Workplace Safety and Health Topic. (n.d.). Retrieved December 4, 2018, from <https://www.cdc.gov/niosh/topics/hierarchy/default.html>
- Ethanol GreenScreen. Linde, Nancy and McGrath, Teresa. GreenScreen® for Safer Chemicals - Assessment for Ethanol (CAS# 64-17-5). 2014. Retrieved December 2, 2018. Pharosproject.net
- European Chemicals Agency (ECHA). 2014. REACH Dossier on benzene. Registered substances. Available: http://apps.echa.europa.eu/registered/data/dossiers/DISS-9d862eda-63cd-4c78-e044-0144f67d249/AGGR-cc0ca73f-30c5-4db3-abe2-c3c2f7b5305a_DISS-9d862eda-63cd-4c78-e044-00144f67d249.html#AGGR-cc0ca73f-30c5-4db3-abe2-c3c2f7b5305a
- European Union (EU). 2008. European Union Risk Assessment Report. Benzene. Risk assessment. Final approved version. Available: http://esis.jrc.ec.europa.eu/doc/risk_assessment/REPORT/benzenereport063.pdf

European Union (EU). 2008. European Union Risk Assessment Report. Toluene. Risk Assessment. Final approved version.

International Agency for Research on Cancer (IARC). 1987. Summaries and evaluations. Benzene. Supplement 7: p.120. Available: <http://www.inchem.org/documents/iarc/suppl7/benzene.html>

International Agency for Research on Cancer (IARC). 1999. Summaries and evaluations. Toluene. VOL.: 71 (p. 829) <http://www.inchem.org/documents/iarc/vol71/030-toluene.html>

Isopropanol GreenScreen. Wang, Bingxuan and Whittaker, Margaret H. Isopropanol (CAS# 67-63-0) GreenScreen® for Safer Chemicals (GreenScreen®) Assessment. 2014. Retrieved December 2, 2018. Pharosproject.net

Methyl Acetate GreenScreen. Ciotti, Sara, Guerrette, Zach, and Wang, Bingxuan. Methyl Acetate (CAS# 79-20-9) GreenScreen® for Safer Chemicals (GreenScreen®) Assessment. 2017. Retrieved December 2, 2018. Turi.org

National Institute of Technology and Evaluation (NITE)/Japan. 2006. GHS classification results for benzene. ID194. Japan. Available: http://www.safe.nite.go.jp/english/ghs/ghs_download.html

Prop 65. Change in the Identification of Reproductive Toxicity Endpoints in the Listing of Toluene as Known to Cause Reproductive Toxicity | OEHHA. (n.d.). Retrieved November 25, 2018, from <https://oehha.ca.gov/proposition-65/cnr/change-identification-reproductive-toxicity-endpoints-listing-toluene-known>

Reprotox. 2013. Record for benzene. Available: www.expub.com

Toluene GreenScreen. Pentilla, Brian and Stone, Alex. Greenscreen assessment for Toluene (CAS #108-88-3). 2011. Retrieved December 2, 2018. Pharosproject.net

United States Environmental Protection Agency (U.S. EPA). 2002. Toxicological review of benzene (noncancerous effects). In support of summary information on the integrated risk information system (IRIS). Available: <http://www.epa.gov/iris/toxreviews/0276tr.pdf>

United States Environmental Protection Agency (U.S. EPA). 2009. Benzene. Interim acute exposure guideline levels (AEGLs) for NAS/COT Subcommittee for AEGLs. Available: http://www.epa.gov/oppt/aegl/pubs/benzene_interim_dec_2008_v1.pdf