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October 8, 2018

Mr. Brian Penttila Project
Manager
Washington Department of Ecology
300 Desmond Drive SE
Lacey, WA 98503

Reference: State of Washington Department of Ecology Contract No. 1300207, Amendment 5; Establishing a Green Chemistry Center; Task 2.2, Phthalates Chemical Hazard Assessments, Final Report on Alternatives to Five Phthalates of Concern to Puget Sound

Dear Mr. Penttila:

Enclosed please find TechLaw, Inc.'s (TechLaw's) final version of the Washington State Alternatives to Five Phthalates of Concern to Puget Sound report per Task 2.2 of the above referenced contract.

We appreciate the opportunity to support Washington Department of Ecology on this assignment. If you have any questions, please feel free to contact me at 703-818-3201.

Sincerely,

Mark Heaney

Mark Heaney
Program Manager

Enclosures
cc: Ken Zarker, WA Department of Ecology
Lauren Heine, Northwest Green Chemistry

Washington State Alternatives to Five Phthalates of Concern to Puget Sound Final Report

Submitted to:
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Task No.	**: 2.2**
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October 8, 2018

Alternatives to Five Phthalates of Concern to Puget Sound

FINAL REPORT
October 8, 2018

This project has been funded wholly or in part by the U.S. Environmental Protection Agency under a National Estuary Program (NEP) cooperative agreement with the Washington State Department of Ecology.

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Northwest Green Chemistry
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Executive Summary

The Washington Department of Ecology (Ecology) contracted TechLaw, along with its subcontractor, Northwest Green Chemistry (NGC) (the project team), to identify potential functional and inherently less toxic alternatives to five phthalates deemed priority toxic pollutants for Puget Sound. The five phthalates of concern are:

- Bis(2-ethylhexyl) phthalate (DEHP), CAS # 117-81-7
- Butylbenzyl phthalate (BBP), CAS# 85-68-7
- Diethyl phthalate (DEP) CAS# 84-66-2
- Dimethyl phthalate (DMP) CAS# 131-11-3
- Di-n-butyl phthalate (DBP) CAS# 84-74-2

The project team first considered the functional uses of the five phthalates of concern, narrowing the list based on a qualitative assessment of their potential to result in phthalate exposure to Puget Sound. The alternatives were grouped according to functional use. DEHP, DBP and BBP are primarily used as plasticizers and/or fast fusers. DEP and DMP are used primarily as fragrance solvents and/or fixatives. The project team then identified a broad suite of 110 potential alternatives that could substitute as plasticizers/fast fusers (54 alternatives) or solvents/fixatives (56 alternatives) through:

- Industry global search engines and databases that provide information on commercially available materials and ingredient (i.e. UL Prospector[1], SpecialChem[2])
- Scientific literature
- Product and technical data sheets
- Review of existing alternatives assessments and chemical hazard assessment reports
- Interviews with stakeholders, including manufacturers of phthalates and phthalate alternatives, manufactures of products that use phthalates and phthalate alternatives, and relevant non-profit organizations (NGOs)
- Market reports

The project team then narrowed the list of alternatives to those that are currently used in the marketplace, and/or are perceived by stakeholders to be functional substitutes for one or more of the five phthalates of concern. This information was gathered through qualitative surveys of a representative cross section of stakeholders, including chemical manufacturers, members of environmental health advocacy organizations and plastic manufacturers.

The five phthalates of concern and alternatives were screened for existing chemical hazard assessment summaries and reports using the Chemical Hazard Data Commons[3], GreenScreen List Translator (GS LT),[4] and the Interstate Chemicals Clearinghouse Chemical Hazard Assessment Database (IC2 CHAD).[5] Chemicals with high hazards for carcinogenicity, mutagenicity, reproductive or developmental toxicity, endocrine disruption, and combinations of persistence with bioaccumulation potential and/or aquatic toxicity, were eliminated from further consideration. In addition, skin and respiratory sensitizers (allergens) were eliminated from further consideration in fragrance applications.

The remaining chemicals were grouped based on the comprehensiveness of available hazard information. Category A alternatives have publicly accessible, full chemical hazard assessment reports and meet minimum hazard criteria. Category B alternatives have full chemical hazard assessment reports that have been reviewed by an authoritative third party (i.e., US EPA Safer Choice Program) but the reports are not publicly available. Category C alternatives are not found on key hazard lists, but they lack full chemical hazard assessment reports.

The screening process resulted in an 'Active List', comprised of sixteen plasticizer or fast fuser alternatives and four fragrance solvent or fixative alternatives (Table ES1) that are considered functional and potentially inherently less hazardous. Recommended next steps for the Active List include: 1) accelerate adoption of Category A alternatives; 2) generate publicly accessible chemical hazard assessment reports for promising Category B and C alternatives; and 3) identify phthalate applications that cannot be substituted with the identified alternatives.

Table ES1. Active List of potential alternatives to the five phthalates of concern

Plasticizers/fast fuser alternatives			
CAS #	**Common name (Abbreviation)**	**Abbreviation**	**Category**
166412-78-8 474919-59-0	Diisononyl cyclohexanedicarboxylate	DINCH, D9NCH	A
6422-86-2	Bis (2-ethylhexyl) terephthalate	DEHT, DOTP	A
102-76-1	Triacetin	GTA	B
736150-63-3	Acetylated monoglycerides derived from fully hydrogenated castor oil	COMGHA	B
27138-31-4	Dipropylene glycol dibenzoate		B
8013-07-8	Epoxidized soybean oil	ESBO	C
77-90-7	Acetyl tributyl citrate	ATBC	C
33703-08-1	Diisononyl adipate	DINA	C
103-23-1	2-ethylhexyl adipate	DEHA, DOA	C
15834-04-5	Pentaerythritol tetravalerate		C
1962-75-0	Dibutylterephthalate	DBT	C
68082-35-9	Methyl esters of epoxidized soybean oil fatty acids		C
91082-17-6	Alkylsuphonic phenyl ester	ASE	C
53306-54-0	Di(2-propylheptyl) phthalate	DPHP	C
3319-31-1	Tris (2-ethylhexyl) trimellitate	TOTM, TEHTM	C
120-55-8	Diethylene glycol dibenzoate	DEGD	C
Fragrance fixative/solvent alternatives			
CAS #	**Common name**		**Category**
25265-71-8	Dipropylene glycol		B
77-93-0	Triethyl citrate		B
102-76-1	Triacetin	GTA	B
110-27-0	Isopropyl myristate		B

1. Introduction

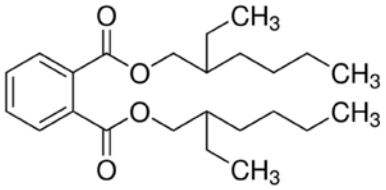
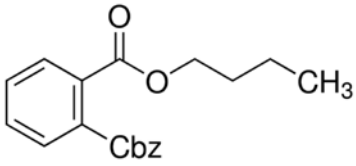
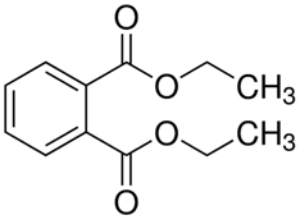
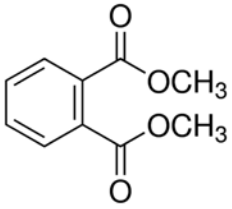
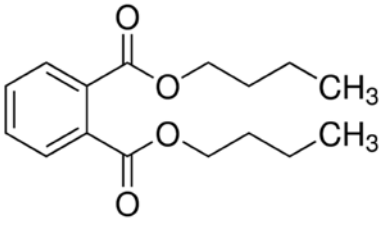
As part of the Urban Waters Initiative, the Washington State Department of Ecology (Ecology) assesses sediment quality throughout selected urban bays that adjoin Puget Sound. Commencement Bay was sampled in 1999, 2008, and 2014 and despite substantial clean-up efforts, increased concentrations of butylbenzylphthalate (BBP) and bis(2-ethylhexyl)phthalate (DEHP) were found at several stations, at levels that exceeded the Washington State Sediment Quality Standard. A similar survey found increasing levels of DEHP in Elliott Bay. These data suggest that phthalate contamination in certain regions of Puget Sound is ongoing.[6]

As the lead organization for administering the *Toxic and Nutrients Prevention, Reduction, and Control* cooperative agreement for Puget Sound under the National Estuary Program, Ecology contracted TechLaw, along with its subcontractor, Northwest Green Chemistry (NGC) (the project team), to identify functional and potentially less hazardous alternatives to five phthalates deemed priority toxic pollutants for Puget Sound, focusing on uses of those phthalates likely to result in exposure to Puget Sound. The term functional refers to alternatives that meet performance and cost requirements that allow them to substitute for one or more of the phthalates of concern. Less hazardous refers to the inherent hazard properties of the chemicals based on comprehensive chemical hazard assessment.

In 2011, Ecology released a report of primary sources of selected chemicals and quantities in the Puget Sound Basin. Total phthalates released were estimated at 34 tons/year in the study area. Phthalates released from fragrances (primarily diethyl phthalate (DEP)) were estimated at 33% of the total with an additional 6% from other personal care products. Release of DEHP from PVC was estimated at 20% of the total. Notably, the total of 34 tons/year did not include release of DEHP from buried cable, which was estimated at 23 tons/year. [7] The five phthalates addressed in this report (see Table 1) were selected by Ecology. They are on the list of 126 Clean Water Act priority pollutants[8] derived from US EPA's National Toxics Rule.[9] The five phthalates discussed in this report are also included as part of the Toxic and Nutrients Prevention, Reduction, and Control Agreement for Puget Sound under the National Estuary Program. They are priority pollutants in Washington, and they are considered chemicals for which there are opportunities for source reduction.[10]

Phthalates are a class of organic chemicals that are esters of phthalic acid. Phthalates are categorized as high and low, depending on their molecular weight[11]. **High phthalates** have 9-13 carbon atoms in their chemical side chains, which gives them increased permanency and durability. Examples of high phthalates include diisononyl phthalate (DINP), diisodecyl phthalate (DIDP) and dipropylheptyl phthalate (DPHP). High phthalates are commonly used in polyvinyl chloride (PVC) products such as wire and cable coatings, flooring, wall covering, self-adhesive films, synthetic leather, coated fabrics and roofing and automobile applications. **Low phthalates** have 3-8 carbon atoms in their chemical side chains. The most common types of low phthalates include DEHP and dibutyl phthalate (DBP). Low phthalates are commonly used in medical devices, general purpose PVC, adhesives, inks and cosmetics.[12] All five of the phthalates of concern in this report are low phthalates.

Table 1. The five phthalates of concern

Common name	Abbrev. used here	CAS #	Structure	Function(s)
bis(2-ethylhexyl) phthalate	DEHP	117-81-7		Plasticizer
butylbenzyl phthalate	BBP	85-68-7		Plasticizer Fast fuser
diethyl phthalate	DEP	84-66-2		Fixative Solvent
dimethyl phthalate	DMP	131-11-3		Fixative Solvent
di-n-butyl phthalate	DBP	84-74-2		Plasticizer Fast fuser (also used in adhesives, as dye solvent, textile lubricant)

The term phthalate commonly refers to ortho-phthalates in both scientific literature and legislation; ortho-phthalates are derived from phthalic acid (as opposed to its isomers, isophthalic acid and terephthalic acid), and the resulting ester bonds are off of neighboring carbons on the benzene ring. Around six million tons of phthalates are produced worldwide each year. These phthalates are used for diverse purposes, but the primary purpose is as plasticizers for flexible PVC. About 80% of phthalates are used as plasticizers, of which about 80-90 % are used to make flexible PVC.[13,14]

Ortho phthalates (phthalates) are used ubiquitously in consumer products and in the built environment and subsequently result in exposure to humans and the environment. Phthalates typically form weak bonds to their substrates, so they leach out of products and into the environment over time. Exposure to humans may occur through direct contact with phthalate containing products or indirectly through air, dust, and food. Discharge to Puget Sound may occur through volatilization from products into air or dust, dissolution and transport in surface water directly to Puget Sound, or through wastewater treatment plants, which do not fully remove phthalates.[15]

Hazards associated with (ortho) phthalates and the potential for widespread exposure to phthalates through their ubiquitous use, have led to public concerns and regulatory oversight. Some members of the phthalate chemical class are classified as carcinogens, reproductive, developmental, and systemic toxicants, endocrine disruptors, immune toxicants, and aquatic toxicants. A summary of hazard assessment classifications, based on publicly accessible hazard assessment reports, is presented for a set of phthalate plasticizers and/or fast fusers (Appendix I). Not all phthalates have the same inherent hazard and exposure properties; they vary in part with molecular weight and the length of side chains. However, as a chemical class, the burden of proof for low hazard and exposure potential lies with providing evidence that individual phthalates are indeed exceptions to the class.

2.0 Phthalate functional uses

Phthalates are versatile chemicals used in a wide variety of product applications, including:

- Footwear and apparel
- Personal care products
- Building materials and construction
- Packaging
- Healthcare products
- Automotive
- Household goods
- Medical devices
- Fragrances
- Miscellaneous (aquaculture, exercise equipment, pesticides, food, etc.)

Two general functional use categories were identified that represent broad uses of phthalates in products and that are relevant to Puget Sound:

- Plasticizers/fast fusers: Plasticizers soften inherently rigid plastic materials like PVC, while fast fusers act a processing aid to plasticizers. Phthalates used for this purpose are found in diverse plastic products used in automobiles, building materials, road paint, footwear and apparel, packaging, medical equipment, and more.
- Fragrance fixatives/solvents: Fragrance fixatives help to maintain a consistent scent over time. Fragrance solvents dissolve, or are miscible with, diverse fragrance ingredients. While perfumes and personal care products are often the focus of fragrances, phthalates are found in a wide range of scented products.

Manufacturers have different performance requirements for chemicals used in different product applications. For example, manufacturing requirements may vary with respect to processing time, temperature, and end product durability. As no single chemical can meet all performance requirements within either functional use category, it is important to identify multiple inherently less hazardous and functional alternatives to cover different requirements.

2.1 Plasticizers and fast fusers

The use of phthalates as plasticizers and fast fusers represents the largest and most ubiquitous use of phthalates overall. As many plasticizers are also fast fusers and vice versa, these are addressed in the shared category of plasticizers and fast fusers.

Plasticizers are used primarily in PVC formulations to make inherently rigid PVC material softer and more flexible and may comprise up to 60 percent (or more) of the total weight.[16] As a general rule, the softer the resulting PVC product, the greater the quantity of phthalates in it. Phthalates are used as plasticizers in non-PVC plastics as well, such as polyurethanes, though the most common use is with PVC. Phthalates are just one of several classes of plasticizers, but they accounted for approximately 65% of the world consumption of plasticizers in 2017, down from approximately 88% in 2005.[17] While world consumption of phthalate plasticizers is forecast to continue growing, the consumption of lower molecular weight phthalates is expected to decline in many regions

Fast fusers improve the processability of plastic and aid with gelation. Some also function as plasticizers on their own. Fast fusers are necessary for specific processing and functional requirements, and it may be possible for a manufacturer to avoid the use of a fast fuser by selecting an alternative plasticizer or by modifying the processing method (e.g. higher heat, longer times).

As plasticizers/fast fusers, phthalates are present in a myriad of different products. Major product categories that use phthalates include automobiles, building materials (e.g. paints and coatings, flooring, wires and cables, sealants, wall coverings), household products (e.g. shower curtains, table cloths), road paint, asphalt, footwear and apparel (gloves, shoes, rain gear),

packaging (e.g. food, toys), children's products (e.g. toys, childcare items), cosmetics, personal care products (e.g. fragrances), coated fabrics (e.g. banners) and medical equipment.

The softening effect of plasticizers tends to decrease with increasing length of functional groups.[18] When phthalates with long functional groups replace those with short functional groups, a greater quantity of phthalate may be required to achieve the same final product flexibility. Volatility also impacts plasticizer selection; a less volatile plasticizer will remain in the material longer, resulting in greater longevity with the same flexibility. As phthalates volatilize from products, the product loses its softness and flexibility, becoming brittle.

DEHP is considered a versatile, good-performing and low-cost plasticizer and it is considered the industry standard for processability. DBP is considered a specialty plasticizer often used in combination with other plasticizers. It is also used in the adhesives industry, as a solvent for many oil-soluble dyes, in textile fiber lubrication, and more. The higher volatility of DBP can make it less desirable as a plasticizer as this results in lower retention time in the product. BBP has unique plasticizer properties because of its chemical asymmetry and is mostly used for plasticizing PVC.[19] Both DBP and BBP are more efficient at mixing with the resin during processing (gelling ability) and are considered fast fusers as well as plasticizers.[20]

Current manufacturing equipment for products that rely on phthalates are tuned to the temperature and time requirements of currently used phthalates, such as DEHP. Most common plasticizer substitutes for DEHP, such as DINCH and DEHT, also require a fast fuser to achieve parallel processing performance. DEHT and DINCH may not be direct drop-in replacements (i.e. one to one replacement with no other formulation changes). Some manufacturers of alternatives have created blends, such as the DEHT/DBT (Versamax Plus) blends offered by Eastman, formulated to achieve parallel processing performance to DEHP.

2.2 Fragrance solvents and fixatives

The use of phthalates as fragrance fixatives or solvents in products represents the largest use of DEP, though DMP is marketed for this purpose as well. A fragrance solvent functions by dissolving or being miscible with diverse fragrance ingredients. A fragrance fixative helps blend disparate fragrance ingredients by preventing more volatile ingredients from evaporating before less volatile ingredients to help maintain a consistent scent over a longer period of time.

The most common use of DEP is as a fragrance solvent and most resources report that it has limited fixative properties[21]. DEP is valued due to its low cost, low odor, and versatility as a solvent for diverse fragrance ingredients.

According to a 2010 report from the US Food and Drug Administration (FDA), almost a quarter of all cosmetics (for adults and children) have been found to contain DEP. [22] In a 2007 report from the EU Scientific Committee on Consumer Products, up to 90% of perfumes were found to contain DEP.[23] Notably, the FDA report found that, while DMP and DBP have historically been

heavily used in cosmetics (in hair sprays and nail polishes respectively), neither are heavily used today, while DEP use continues to be common.

Preferred alternatives are those that do not have a strong odor that would unfavorably alter the fragrance profile and inhibit formulation of the fragrance to achieve the desired results. Historically, odorous natural fixatives were used, such as frankincense, myrrh, musk, civet, and ambergris. Today, these substances raise sustainability concerns from their sourcing. For example, ambergris comes from sperm whales and musk from civet cats.[24] Other historical fragrance fixatives include natural resins, waxes, or resinoids that do not function well as solvents. The preferred alternative(s) to DEP must also function as a solvent.

3.0 Approach

3.1 Identification of Alternatives

The project team began by identifying a broad range of possible chemical alternatives to DEHP, DBP and BBP for use as plasticizers and/or fast fusers, and alternatives to DEP and DMP (and in some cases, DBP) for use as fragrance solvents or fixatives. We created this starting list by researching the following sources:

- Industry global search engines and databases that provide information on commercially available materials and ingredient (i.e. UL Prospector[25], SpecialChem[26])
- Scientific literature
- Alternatives assessment reports and chemical hazard assessment reports[27,28,29,30,31,32,33,34,35,36,37,38]
- Interviews with a cross section of stakeholders, including manufacturers of phthalates and phthalate alternatives, manufactures of products that use phthalates and phthalate alternatives, and environmental health advocacy non-profit organizations (NGOs)
- Manufacturer websites and Product/Technical Data Sheets (PDSs/TDSs)
- Economic and market reports

3.2 Performance screening

The initial broad set of alternatives developed above was narrowed down to a shorter set of alternatives considered to be functional with respect to cost and performance, and currently used in the marketplace. This information was gathered through qualitative surveys of a representative cross section of stakeholders, including chemical manufacturers, members of environmental health advocacy organizations and plastic manufacturers. Stakeholders were provided with the initial broad list of potential alternatives for review prior to the interviews. They were asked to identify potential alternatives that are:

- Currently adopted in the marketplace, or
- Potential future functional alternatives that have not yet been adopted.

The information gleaned from these interviews provided practical insights into how ingredients are selected for use in various products. For example, while a number of potential alternatives are marketed as fragrance solvents or fixatives, in practice, they may be too waxy, too fragrant, or too expensive to be useful for major applications. Using the information and insights gained from these interviews, the list of potential alternatives was narrowed to:

- Include alternatives currently in use
- Include alternatives identified as promising, that are not significantly used, such as alternatives that are new to the market
- Exclude alternatives that were generally identified as not able to meet performance or cost requirements.

3.3 Hazard screening

All of the potential alternatives, regardless of market adoption, were screened for existing chemical hazard assessment information. The Chemical Hazard Data Commons[39] was used to search for the presence of the alternative chemicals on regulatory or authoritative hazard lists and to screen chemicals using the GS List Translator (GS LT). The Chemical Hazard Data Commons also provides access to full chemical hazard assessment reports when they are publicly available. The project team used the Interstate Chemicals Clearinghouse Chemical Hazard Assessment Database (IC2 CHAD) as another resource to find freely available, full GreenScreen for Safer Chemicals (GS) chemical hazard assessment reports. If a full GS report was available, then it was given priority over results from GreenScreen List Translator (GS LT). If the full GS was expired or abbreviated/modified, the full GS result is shown in parallel with GS LT results. All GS chemical hazard assessment reports used for this report are freely and publicly available online at the IC2 CHAD with the exception of the modified GreenScreen for DEHP, which can be found in Harmon & Otter 2018.[40] The project team searched the US EPA Safer Chemical Ingredients List (SCIL) to identify inherently safer alternatives as designated by the US EPA Safer Choice Program. Additional sources of information included CleanGredients[41], NGO reports, and regulatory information on allergens that require reporting in the European Union.

3.3.1 GreenScreen for Safer Chemicals (GS)

GreenScreen for Safer Chemicals (GS) is a publicly accessible method that provides guidance for classifying hazards for eighteen hazard endpoints for a given chemical.[42] GS classification criteria are based primarily on the Globally Harmonized System for Classification and Labeling (GHS). Table 2 summarizes the hazard endpoints included in the GS method. Persistence, bioaccumulation potential and endocrine disruption are not standalone endpoints in the GHS system, but they are included as hazard endpoints in GS. Technically, persistence and bioaccumulation potential are inherent properties that determine exposure. But they are typically included as *hazard* endpoints in comprehensive chemical hazard assessment reports. The GHS system does not include classification criteria for endocrine activity/disruption.

Table 2. Hazard endpoints included in the GreenScreen for Safer Chemicals (GS) method

Group I Human Health	**Environmental Toxicity & Fate**
• Carcinogenicity	• Acute Aquatic Toxicity
• Mutagenicity	• Chronic Aquatic Toxicity
• Reproductive Toxicity	• *Persistence*
• Developmental Toxicity	• *Bioaccumulation*
• *Endocrine Activity*	**Physical Hazards**
Group II and II* Human Health	• Reactivity
• Acute Toxicity Systemic Toxicity	• Flammability
• Systemic Toxicity, Repeated Dose *	
• Neurotoxicity	
• Neurotoxicity, Repeated Dose *	
• Skin Sensitization *	
• Respiratory Sensitization *	
• Skin Irritation	
• Eye Irritation	

Endpoints marked with an asterisk (*) are based on repeated exposure. Italicized endpoints are included in GS but are not found as standalone endpoints in the GHS system. Classification levels for each endpoint vary from low (L) to high (H) (and in some cases very low (vL) to very high (vH)). If data are insufficient or not available to classify the chemical for a hazard endpoint, then that hazard endpoint is classified as a data gap (DG). The level of confidence for each classification is further designated using *italic font* to indicate lower confidence, and **bold font** to indicate higher confidence.

In the GS methodology, once all individual hazard endpoints are classified, they are then summarized in a hazard table. An algorithm is applied to the hazard classifications to calculate an overall GS Benchmark (GS BM) score, ranging from GS BM1 to GS BM4:

- GS BM 1: Avoid – Chemical of High Concern
- GS BM 2: Use but Search for Safer Substitutes
- GS BM 3: Use but Still Opportunity for Improvement
- GS BM 4: Prefer – Safer Chemical
- GS BM U: Unspecified due to insufficient data (data gaps for key hazard endpoints)

The GS BM algorithm also includes consideration of the chemical's feasible environmental transformation products. Highly hazardous transformation products can modify the final GS BM score. GS assessments are valid for three years. After this, they are considered expired unless they are updated to include any new information. The project team included classifications from some expired GS reports but supplemented these with current GS LT results.

The benefits of using GS for chemical hazard assessment are that it is a transparent, systematic, and scientifically robust system based on GHS. In addition, access to the method guidance and criteria are freely available. However, there are a number of limitations:

1) The GS method aggregates hazard classifications across exposure routes and across different aquatic species. For example, if there are data for one exposure route (e.g. oral exposure) for one hazard endpoint (e.g. acute mammalian toxicity), but there are data gaps for the other exposure routes (dermal, inhalation), then the hazard classification for that particular endpoint is designated only by the oral exposure route. This may be problematic if exposure occurs via inhalation or dermal routes and the associated hazards are unknown. Likewise, the method aggregates hazard classification for aquatic toxicity, indicating one hazard classification regardless of whether the data apply to fish, algae or daphnia. 2) The GS BM algorithm aggregates hazards in a way that reduces granularity and can potentially lead to poorly informed decisions. For example, two chemicals may both score as GS BM 2, but one chemical may have multiple moderate Group I and high Group II hazards, while the other may have a single moderate or high Group II hazard. Reporting a GS BM score without providing access to the individual hazard classifications can be a disservice to those who need to make decisions about whether or not to use a chemical. The summary hazard table, and ideally, the full hazard assessment report should be used to inform decisions based on what is known, and not known, about a chemical. 3) A GS chemical hazard assessment report can be expensive because it requires significant time and expertise to produce. Professional toxicologists can be hired to produce a full GS report, and they include license fees that result in higher costs. As such, a limited number of full GS reports are freely and publicly available.

3.3.2 GreenScreen List Translator (GS LT)

GS LT is a subset and offshoot of the full GS method. It classifies chemicals based only on whether or not they are included on regulatory, authoritative and/or screening hazard lists according to the GS method. For example, if a chemical is listed by the International Agency for Research on Cancer (IARC) as a Group I carcinogen, then the chemicals is classified as high for carcinogenicity using GS LT guidance. If a chemical is not found on a hazard list, it may mean that the chemical has low hazard for that endpoint. It also may mean that the chemical has not been fully assessed for that endpoint, and classification is unknown. GS LT is useful in identifying known hazard properties of chemicals, but it is typically not as useful in confirming low hazard endpoint classifications. Results from GS LT screening are presented in a hazard table, similar to a full GS. If a chemical is not classified for a hazard endpoint based using GS LT then the table cell is left blank.

GS LT screening is a fast and inexpensive screening tool; but it can be overly conservative. For example, in some cases, hazard classifications are applied to all chemicals within a chemical class, and to all forms of a chemical (e.g. silica, regardless of its particle size or shape). For more accurate information, a comprehensive chemical hazard assessment can clarify what is known, and not known, about chemical hazards associated with a chemical.

Using GS LT guidance, three possible overall chemical scores can result. The scores are indicated as GS LT rather than GS BM to clearly differentiate which method was used. GS LT results are reported as:

1. GS LT-1: Equivalent to GS BM 1 (Avoid – Chemical of High Concern)
2. GS LT-P1: Possible GS BM 1, further evaluation needed
3. GS LT-UNK: Insufficient data to classify using List Translator, further evaluation needed

There is no GS LT equivalent for GS BM 2, 3, or 4 as it cannot identify safer chemicals. GS LT should only be used to identify known hazardous chemicals and chemicals suspected to be hazardous. GS LT-UNK indicates a lack of listing on hazardous lists and is not evidence of safety.

3.3.3 US EPA Safer Chemical Ingredients List (SCIL) and CleanGredients

The USEPA Safer Chemical Ingredients List (SCIL) is a list of chemical ingredients, arranged by functional-use class, and presented by CAS registration number that the USEPA Safer Choice Program has evaluated and determined to be safer than traditional chemical ingredients.[43] The SCIL was initially created for use in the cleaning products sector and includes alternative solvents and fixatives. While SCIL does not include plasticizers/fast fusers as a functional category, there are some chemicals on the SCIL that are also used as plasticizers and fast fusers.

The SCIL is designed to help manufacturers find safer chemical alternatives that meet the criteria of the Safer Choice Program. Chemicals are marked using a combination of color and symbol:

- Green circle: Chemical has been verified to be of low concern based on experimental and modeled data.
- Green half circle: Chemical is expected to be of low concern based on experimental and modeled data; additional data would strengthen the Safer Choice Program's confidence in the chemical's safer status.
- Yellow triangle: Chemical has met Safer Choice criteria for its functional ingredient-class, but has some hazard issues. Specifically, a chemical with this code is not associated with a low level of hazard concern for all human health and environmental endpoints even though it may be a best-in-class chemical and among the safest available for a particular function, the function fulfilled by the chemical should be considered an area for safer chemistry innovation.
- Grey square: Chemical is not acceptable for use in products that are candidates for the Safer Choice label.

While the methodology and criteria used in the Safer Choice program are publicly available, peer reviewed, and scientifically robust, the USEPA does not release the chemical hazard assessment reports or the underlying data that support SCIL classifications.

CleanGredients® is a paid subscription program managed by Green Blue Institute. [44] Like the SCIL, CleanGredients lists chemical ingredients arranged by functional use class that meet the criteria associated with the Safer Choice Program. Chemicals are evaluated by third-party Safer Choice profilers. The difference between SCIL and CleanGredients is that CleanGredients lists chemical products as sold (branded ingredients) by manufacturer and brand name, not as theoretically pure substance defined by individual CAS numbers. Branded ingredients are also more likely to be formulations than pure substances. In this case, all constituents in the branded ingredient/product must meet the Safer Choice criteria. Unlike SCIL, CleanGredients does include a functional use category for plasticizers.

3.4 Summary of inclusion/exclusion criteria

The project team eliminated chemicals alternatives from further consideration if they scored as GS BM 1 or GS LT-1. GS BM 1 and GS LT-1 criteria eliminate chemicals classified as:

- High for any Group I Human Health endpoints:
  - Carcinogenicity
  - Mutagenicity
  - Reproductive toxicity
  - Developmental toxicity
  - Endocrine disruption
- Persistent, bioaccumulative, and aquatically toxic in combination
  - Very persistent and very bioaccumulative
  - Very persistent and aquatically toxic
  - Very bioaccumulative and aquatically toxic
  - Persistent, bioaccumulative, and aquatically toxic

Additional exclusion criteria were added based on stakeholder recommendations. Some stakeholders recommended excluding chemicals with additional hazards linked to consumer concerns (i.e.. fragrance solvents or fixatives that are skin sensitizers (allergens) or respiratory sensitizers). Some manufacturers also viewed pending regulatory review (or action) as a possible reason for exclusion or caution. For example a number of plasticizers identified as potential phthalate alternatives are currently undergoing review based on the Community Rolling Action Plan (CoRAP) in the European Union. [45] Chemicals are sponsored by Member States for CoRAP evaluation based on risk-based criteria including hazard information, exposure information and tonnage. Review can resolve outstanding questions about chemical hazards and determine whether or not the chemical merits risk management such as harmonized classification and labeling, or restriction and authorization.

Chemicals found on the USEPA Safer Choice Program's SCIL and CleanGredients were viewed by stakeholders as reasons for inclusion.

Exclusion criteria for fragrance solvent or fixative alternatives:

- Scores as GS BM 1 or GS LT-1

- Causes skin or respiratory sensitization
- Is one of the 26 allergenic substance that require reporting on the label in the EU based on Cosmetics Regulation 1223/2009[46], [47]
- Has a strong odor that interferes negatively with the formulation
- Identified as not reasonably price competitive
- Does not meet performance requirements

Inclusion criteria for fragrance solvent or fixative alternatives:

- Listed on the Safer Choice SCIL list with a green circle, green half circle or yellow triangle
- Listed on CleanGredients
- Recommended by a fragrance formulator as a direct substitute for DEP or DMP as a fragrance fixative/solvent
- Marketed as a direct substitute for the five phthalates as a fragrance solvent/fixative

Exclusion criteria for plasticizer/fast fuser alternatives:

- Scores as GS BM 1 or GS LT-1
- Does not meet performance requirements
- Identified as not reasonably price competitive

Inclusion criteria for plasticizer/fast fuser alternatives:

- Listed on the Safer Choice SCIL list (although for another functional use category)
- Listed in CleanGredients
- Identified as an inherently less hazardous functional alternative in other alternative assessment or market reports
- Recommended by stakeholders as a direct substitute for the five phthalates as a plasticizer/fast fuser
- Marketed as a direct substitute for DEHP, BBP or DBP as a plasticizer/fast fuser
- Commonly used in Europe

Chemicals that pass the performance and hazard screening criteria describe above were added to the **Active List**. Chemicals on the Active List are further grouped into three hazard categories based on the availability of hazard information

Category A alternatives – Viable performance and a publicly available chemical hazard assessment report, achieving GS BM 2 or higher. To be in Category A, an alternative must have a publicly available comprehensive chemical hazard assessment report that achieves a GS BM score of 2 or higher. These alternatives are considered to be both functional with respect to performance and of relatively lower hazard than the chemicals they would replace. As discussed previously, an important caveat is that BM2 is a broad category that includes a range of hazards. The decision to use a chemical should be based on the specifics of its hazard profile and not on its aggregate GS BM score.

Category B alternatives – Viable performance and low relative hazard based on proprietary third party review. To be in Category B, an alternative must have a comprehensive chemical hazard assessment reviewed by a credible third-party, but the resulting assessment is not publicly available. Category B alternatives include those listed on the U.S. EPA SCIL with a full green circle, a half green circle or a yellow triangle or on CleanGredients. Category B chemicals are functional alternatives, and initial hazard screening results are promising, but more publicly accessible data are needed to verify if they are of inherently lower hazard, particularly for the intended application.

The project team considered including chemical alternatives vetted by other third parties such as plasticizers listed on the TCO Certified Accepted Substance List[48] and chemicals listed in the ChemSec Marketplace[49] as candidates for Category B. However, we decided to include only chemicals listed on the USEPA SCIL and on CleanGredients because 1) both were developed in partnership and with oversight by the USEPA Safer Choice Program; 2) both require the preparation of chemical hazard assessments by qualified assessors; and 3) both receive additional oversight and quality control by USEPA Safer Choice Program. The USEPA Safer Choice Program also provides the important service of resolving conflicting results between different assessors. Chemicals listed on the TCO Accepted Substance List or the ChemSec Marketplace may be inherently safer alternatives, but they lack additional expert quality control that is particularly important since the hazard assessments are not publicly available.

Category C alternatives – Viable performance but lacking comprehensive chemical hazard assessment data. To be in Category C, an alternative is not listed on any regulatory or hazard lists of high concern based on GS LT. For some chemicals in this category, publicly available comprehensive chemical hazard assessment reports are available, but there are numerous data gaps, resulting in a score of GS BM U (Undetermined). Category C chemicals are functional alternatives, but they need publicly accessible chemical hazard assessment reports to verify if they are of inherently lower hazard. For chemicals with full chemical hazard assessment reports but with numerous data gaps, key data gaps should be filled.

4.0 Results

The project team narrowed down an initial list of 110 potential alternatives to an Active List comprised of sixteen plasticizer/fast fusers and four fragrance solvents/fixatives.

4.1 Plasticizers and fast fusers

The full list of 54 potential alternatives identified as plasticizers or fast fusers is found in Appendix II. Summary hazard assessment results for all potential plasticizer/fast fuser alternatives are available in Appendix VI and as a worksheet in a supplemental Microsoft Excel workbook.

Functional Screening

Based on market reports and stakeholder interviews, eighteen of the initial 54 alternatives identified are currently being used as plasticizers/fast fusers and are considered leading

functional alternatives to DEHP, BBP and DBP. Five of them, triacetin, diethylene glycol dibenzoate, dipropylene glycol dibenzoate, alkylsuphonic phenyl ester, and epoxidized soybean oil (ESBO), are functional but are more commonly used for other purposes. Hazard evaluation results for the eighteen functional alternatives are presented in Table 3. (Note that for some chemicals, there are duplicate hazard summary tables provided either because there are multiple CAS numbers for the same chemical (in which case results are listed for each CAS #), and/or because GS assessment was available but expired (in which case it was supplemented with GS LT results).)

Hazard Screening

Of the eighteen functional alternatives, COMGHA, dipropylene glycerol dibenzoate, and triacetin are listed with full green circles on SCIL (although for functional uses other than plasticizers/fast fusers). Bis (2-ethylhexyl) terephthalate, called DEHT by Eastman Chemical, and DOTP by BASF, are both listed on CleanGredients. Specifically, CleanGredients includes Eastman Chemical Company's Eastman 168 SG (CAS numbers 6422-86-2 and 63468-13-3) and BASF's Palitinol® DOTP (CAS number 6422-86-2).

DINP and DIDP were dropped from further consideration based on hazard screening criteria (GS LT-1), despite being considered functional. The remaining sixteen functional alternatives are, at minimum, not currently known to have high hazard, and at best, have comprehensive publicly available chemical hazard assessment results that achieve GS BM 2 or higher. The remaining sixteen alternatives were added to the Active List and categorized based on available chemical hazard assessment information (Table 4).

Two of the alternatives to phthalates as plasticizers/fast fusers, DINCH and DEHT, met qualifications for Category A, meaning that there are publicly available comprehensive chemical hazard assessments that achieve GS BM2 or higher aggregate hazard scores. Three of the alternatives to phthalates are plasticizers/fast fusers that met qualifications for Category B, meaning that chemical hazard assessments have been performed and reviewed by a credible third party, but the assessment reports and hazard profiles are not publicly available. An additional eleven alternatives to phthalates as plasticizers/fast fusers met qualifications for Category C, which means that they are not present on any lists indicating they are highly hazardous, but either full chemical hazard assessment reports are not available or if they do, numerous data gaps exist.

Five of the plasticizers/fast fusers, TOTM, DEHA, diethylene glycol dibenzoate, dipropylene glycol dibenzoate and DPHP, are currently undergoing evaluation as part of the European Union's Community Rolling Action Plan (CoRAP). The status of each chemical in the CoRAP process can be found on the ECHA Substance Evaluation Database.[50]

Table 3. Hazard assessment screening results for eighteen functional alternative plasticizers and fast fusers currently in use

CAS #	Common name	Abbreviation	CHA type	CHA score	Carcinogen	Mutagen	Reproductive	Development	Endocrine	Acute	Systemic	Systemic Repeat	Neurotoxicity	Neurotoxicity Repeat	Skin Sensitization	Respiratory Sensitization	Skin Irritation	Eye Irritation	Acute Aquatic	Chronic Aquatic	Persistence	Bioaccumulation	Reactivity	Flammability	US EPA SCIL
6422-86-2	Bis (2-ethylhexyl) terephthalate	DEHT, DOTP	GS BM	3dg	L	L	L	L	DG	L	L	L	L	DG	L	L	L	L	L	L	vL	L	L	L	CleanGredients
166412-78-8	Diisononyl cyclohexanedicarboxylate	DINCH, D9CH	GS BM	2	L	L	L	L	M	L	L	L	L	L	L	L	M	L	L	L	M	L	L	L	unlisted
474919-59-0	Diisononyl cyclohexanedicarboxylate	DINCH, D9CH	GS BM	2	**L**	**L**	L	**L**	**M**	**L**	**L**	**L**	**L**	**L**	**L**	*L*	**M**	**L**	**L**	**L**	*M*	**L**	*L*	**L**	unlisted
1962-75-0	Dibutylterephthalate	DBT	GS LT	NoGS												M			pC						unlisted
3319-31-1	Tris (2-ethylhexyl) trimellitate	TOTM, TEHTM	GS BM	U	DG	L	M	L	DG	L	M	L	L	DG	L	DG	L	L	L	L	M	vL	L	L	unlisted
3319-31-1	Tris (2-ethylhexyl) trimellitate	TOTM, TEHTM	GS LT	UNK																					unlisted
103-23-1	2-ethylhexyl adipate	DEHA	GS LT	P1	M	pC	M		H-M								M	pC	pC		pC	pC			unlisted
77-90-7	Acetyl tributyl citrate	ATBC	GS LT	P1															pC						unlisted
33703-08-1	Diisononyl adipate	DINA	GS LT	UNK																					unlisted
8013-07-8	Epoxidized soybean oil	ESBO	GS LT	UNK													M								unlisted
15834-04-5	Pentaerythritol tetravalerate	-	GS LT	UNK															pC						unlisted
91082-17-6	Alkylsuphonic phenyl ester	ASE	GS LT	UNK																					unlisted
736150-63-3	Acetylated monoglycerides derived from fully hydrogenated castor oil	COMGHA	GS LT	NoGS																					Green [Circle] - Surfactants
68082-35-9	Methyl esters of epoxidized soybean oil fatty acids	-	GS LT	UNK																		vH			unlisted
120-55-8	Diethylene glycol dibenzoate	DEGD	GS LT	P1						L															unlisted
27138-31-4	Dipropylene glycol dibenzoate	-	GS LT	P1														pC							Green [Circle] - Emollients
102-76-1	Triacetin	-	GS LT	UNK						M															Green [Circle] - Fragrances
53306-54-0	Di (2-propylheptyl) phthalate	DPHP	Expired GS BM	U	DG	**L**	**L**	**L**	*M*	**L**	DG	**L**	DG	DG	**L**	DG	**L**	**L**	**L**	*L*	L	**vL**	**L**	**L**	unlisted
53306-54-0	Di (2-propylheptyl) phthalate	DPHP	GS LT	UNK	**M**																				unlisted
68515-48-0	Diisononyl phthalate	DINP-1	GS LT	1	H		M-L	H-M	H-M								H	H							unlisted
28553-12-0	Diisononyl phthalate	DINP-2 and DINP-3	Expired GS BM	1	DG	L	H	H	H	L	DG	M	DG	DG	L	L	L	M	L	L	vL	vL	L	L	unlisted
28553-12-0	Diisononyl phthalate	DINP-2 and DINP-3	GS LT	UNK	M											M									unlisted
26761-40-0	Diisodecyl phthalate	DIDP	GS LT	1	M		M-L	H	H-M																unlisted

Table 4. Active List of alternative plasticizers and fast fusers currently in use

Plasticizers/fast fuser alternatives			
CAS #	**Common name (Abbreviation)**	**Abbreviation**	**Category**
166412-78-8 474919-59-0	Diisononyl cyclohexanedicarboxylate	DINCH, D9NCH	A
6422-86-2	Bis (2-ethylhexyl) terephthalate	DEHT, DOTP	A
102-76-1	Triacetin	GTA	B
736150-63-3	Acetylated monoglycerides derived from fully hydrogenated castor oil	COMGHA	B
27138-31-4	Dipropylene glycol dibenzoate		B
8013-07-8	Epoxidized soybean oil	ESBO	C
77-90-7	Acetyl tributyl citrate	ATBC	C
33703-08-1	Diisononyl adipate	DINA	C
103-23-1	2-ethylhexyl adipate	DEHA, DOA	C
15834-04-5	Pentaerythritol tetravalerate		C
1962-75-0	Dibutylterephthalate	DBT	C
68082-35-9	Methyl esters of epoxidized soybean oil fatty acids		C
91082-17-6	Alkylsuphonic phenyl ester	ASE	C
53306-54-0	Di(2-propylheptyl) phthalate	DPHP	C
3319-31-1	Tris (2-ethylhexyl) trimellitate	TOTM, TEHTM	C
120-55-8	Diethylene glycol dibenzoate	DEGD	C

4.2 Fragrance solvents and fixatives

The full list of 56 potential alternatives identified as fragrance solvents or fixatives is found in Appendix III. Summary hazard assessment results for ALL potential fragrance solvent/fixative alternatives are available in Appendix VII and as supplementary excel files.

Functional screening

Stakeholders and market research identified eight of the 56 alternatives as currently being used as fragrance fixatives/solvents that can replace DEP. Dipropylene glycol covers the majority of uses, followed by triethyl citrate. An additional two chemicals, water and ethanol, are heavily used as fragrance solvents for some applications and are included here. However, they are not direct replacements for DEP.

Hazard screening

Summary hazard assessment results for DEP, DMP, DBP, and the eight functional fragrance solvent or fixative alternatives are presented in Table 5. Four of the eight alternatives are listed on the USEPA SCIL, indicating that they are likely safer alternatives. Dipropylene glycol and triacetin are listed as solvents with full green circles. Isopropyl myristate is listed as a fragrance chemical with a half green circle and triethyl citrate is listed as a fragrance chemical with a yellow triangle. Dipropylene glycol, as produced by one manufacturer, is also included on CleanGredients.

Benzyl alcohol was identified as a skin sensitizer via a comprehensive chemical hazard assessment report, and both benzyl alcohol and benzyl benzoate are on the list of 26 allergens that require labeling in the European Union and were excluded from further consideration for the Active List.[51]

Table 5. Hazard assessment screening results for DEP, DMP, DBP and eight functional alternative fragrance solvents and fixatives currently in use

CAS #	Common name	Abbreviation used in this report	CHA type	CHA score	Carcinogenicity	Mutagenicity	Reproductive	Developmental	Endocrine	Acute	Systemic	Systemic Repeat	Neurotoxicity	Neurotoxicity, Repeat	Skin Sensitization	Respiratory Sensitization	Skin Irritation	Eye Irritation	Acute Aquatic	Chronic Aquatic	Persistence	Bioaccumulation	Reactivity	Flammability	U.S. EPA SCIL	E.U. Allergen	Phthalate Alternative Status
84-66-2	Diethyl phthalate	DEP	GS LT	P1	H-L				H-M	M		pC			H	M	H	M	H		vH-H				unlisted	Yes	CoC
131-11-3	Dimethyl phthalate	DMP	GS LT	P1	H-L				H-M	H						M		H	M		vH-H				unlisted	unlisted	CoC
84-74-2	Di-n-butyl phthalate	DBP	GS LT	1	M		H	H	H	L				vH-M	H	M		H	vH	H	pC	pC			unlisted	unlisted	CoC
25265-71-8	Dipropylene glycol	-	GS LT	UNK				M-L		pC							M	H							Green [Circle] - Solvents	CleanGredients	B
77-93-0	Triethyl citrate	-	GS LT	UNK															pC						Yellow [Triangle] - Fragrances	unlisted	B
102-76-1	Triacetin	-	GS LT	UNK						M															Green [Circle] - Fragrances	unlisted	B
110-27-0	Isopropyl myristate	-	GS NoGS			pC				pC							pC		pC						Half Green [Circle] - Solvents	unlisted	B
100-51-6	Benzyl alcohol	-	GS BM	2	L	L	L	M	DG	M	DG	H	M	L	H	DG	L	H	L	L	vL	vL	L	L	unlisted	Yes	Eliminated
120-51-4	Benzyl benzoate	-	GS LT	P1						M					pC				H						unlisted	Yes	Eliminated
7732-18-5	Water	-	GS BM	4	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	H	L	L	L	Green [Circle] - Solvents	unlisted	A
64-17-5	Ethanol (non-oral)	-	GS BM	2	*L*	**L**	*L*	*M*	DG	**L**	*M*	**L**	**M**	*M*	**L**	DG	**L**	**H**	**L**	**L**	**L**	**vL**	**L**	**H**	Green [Circle] - Antimicrobial Additives	unlisted	A

Water and ethanol were also dropped from the list of functional phthalate alternatives because they are not considered replacements for DEP. However, there are situations discussed later in this report where fragrance formulations can be designed to be soluble in water and ethanol.

The final four functional and potentially less hazardous alternative solvents/fixatives are included on the Active List (Table 6). All of them are in Category B with respect to available hazard assessment information.

Table 6. Active List of alternative fragrance solvents and fixatives currently in use

CAS #	Common name	Category
25265-71-8	Dipropylene glycol	B
77-93-0	Triethyl citrate	B
102-76-1	Triacetin (GTA)	B
110-27-0	Isopropyl myristate	B

5.0 DISCUSSION

The purpose of this project was to identify a set of functional and potentially less hazardous alternatives to five phthalates of concern to the State of Washington that are used in products likely to result in contamination to Puget Sound. By identifying functional and potentially inherently less hazardous alternatives, we hope to help accelerate the substitution of phthalates of concern with inherently safer alternatives.

The project team was not asked to perform chemical hazard assessments or to commission chemical hazard assessment reports. Rather, we were asked to use existing hazard screening tools and existing chemical hazard assessment reports to screen alternatives that are currently being adopted in the marketplace. Clearly, much more information is available via REACH dossiers, completed CoRAP reports, product safety data sheets and the toxicological literature. However, to gather and review that information would be to begin the process of chemical hazard assessment. That work is clearly recommended as a next step, particularly for Category B and C chemicals on the Active List.

5.1 Plasticizers and fast fusers

A total of sixteen functional and potentially less hazardous alternatives were added to the Active List. The most popular non-phthalate plasticizers are the general-purpose plasticizers, DEHT and DINCH. DEHT is more widely used in the United States while DINCH appears to be more popular in Europe. Both are excellent alternatives for making plastics flexible and can replace phthalates in almost all plasticizer applications; they are also generally viewed as inherently less hazardous alternatives (Category A).

Manufacturers of chemical alternatives emphasized the importance of engaging their technical support for successful substitution. It is not uncommon for an initial substitution attempt to fail. While DEHT and DINCH are versatile alternatives, they may not be direct 'drop-in' replacements in many applications. A direct drop-in replacement is a one-to-one replacement that would require no other formulation changes. Some chemical manufacturers have invested time and expertise to understand and optimize troubleshooting steps needed to replace phthalates with their alternatives; and they are willing to provide technical assistance throughout the process. While some operations may have the expertise in-house to complete this troubleshooting process and succeed at the substitution, others may substantially benefit from working with a manufacturer willing to provide technical assistance during the substitution process. DINCH and DEHT both impact processability and may require the addition of fast fusers, and in some cases, compatibilization aids as well. Eastman offers a blend of DEHT and DBT (Versamax Plus) claimed to have parallel processing to DEHP and will provide technical support during substitution. BASF also provides technical support for substitution, helping to advance the increased adoption of DINCH, particularly in Europe.

Of the remaining fourteen functional and potentially inherently less hazardous plasticizers/fast fusers, three of these are in Category B. Being in Category B indicates that the chemical has been vetted by a third party using a chemical hazard assessment. However, the assessment is not publicly available. Publicly accessible chemical hazard assessment reports are needed to inform decision making, especially given the vast variety of uses of products with plasticizers. An additional eleven chemicals are in Category C, which indicates that the chemical is not on any high hazard lists. In some cases, Category C chemicals have comprehensive chemical hazard assessments, but there are numerous data gaps. Further work is needed to generate publicly accessible chemical hazard assessments for these chemicals, and to fill key data gaps. The combined sixteen alternatives to phthalates as plasticizers and fast fusers are anticipated to cover the majority of applications.

Based on market research, the following summaries provide some insight into existing and emerging alternatives:

- Stakeholders reported that the use of pentaerythritol tetravalerate (Prevalen from Perstorp) is increasing, particularly in flooring and other internal building supplies; it was considered a promising plasticizer that is newer to market.
- There is interest in alternative plasticizers with biobased content.
    - PolyOne offers Reflex100, a plasticizer composed of methyl esters of epoxidized soybean oil fatty acids that is certified to 94-99% bio-based content by the USDA BioPreferred standard.
    - COMGHA, comprised of acetylated monoglycerides derived from fully hydrogenated castor oil, is offered by Danisco (DuPont Group) as Grindsted Soft-n-Safe; it is 80% bio-based (HBN 2014).
- Some citrates are currently used, such as ATBC, but citrate usage as a plasticizer in PVC is limited by their high solubility in water. Phthalates, terephthalates, and trimellitates are insoluble in water, which is a key performance issue.

- Some alternatives replace traditional functions of DBP and BBP:
    - The dibenzoates are used extensively as substitutes for phthalates, though typically in adhesives, where DBP has been used. Kalama Chemical offers the K-Flex line of plasticizers with varying ratios of certain dibenzoates that could be considered a 1:1 replacement for phthalates like BBP and DBP.
    - Similarly, triacetin is used extensively in adhesives in food contact applications. In general, specialty phthalates such as DBP were more commonly used for these purposes, but since the hazards of DBP have become more publicly acknowledged, its usage in this space has decreased significantly. Today, it is more common to find dibenzoates or triacetin in adhesives than to find phthalates.
- Some of the alternatives are used as compatibilizers. Both alkylsulphonic phenyl ester (ASE), Mesomoll) and epoxidized soybean oil (ESBO) are used for this purpose. ESBO is commonly found in PVC formulations, including those plasticized using DEHP, in low quantities due to its stabilizing properties.

5.1.1 Applications for which existing alternatives may not be sufficient

Stakeholders identified three categories of applications for which these two non-phthalate plasticizers, DINCH and DEHT, may not fully replace phthalates. These include:

- Medical blood bags for red blood cells
- High temperature applications
- Food contact applications.

Medical blood bags for red blood cells (RBCs). The use of DEHP in blood bags significantly extends the longevity of RBCs. Previous research has shown that DEHP improves stored red blood cell (RBC) morphology, deformability, osmotic fragility, and microvesicle release without impacting 2,3-diphosphoglycerate (2,3-DPG) or adenosine triphosphate (ATP) levels. 2,3-DPG is important for mediating oxygen release by hemoglobin. These protective effects are thought to be mediated by preserving the RBC plasma membrane during storage.[52] The use of alternative preservation packages and regular mixing can achieve the same longevity using DINCH. [53] Alternative preservation packages can achieve the same longevity for DEHT, depending on the exact mix of PVC/DEHP/Additives used for comparison, though some differences were observed.[54] The chemical hazard of the alternative preservation packages should be explored in order to understand if this mixture is preferable to DEHP. Overall, medical devices lag behind other product categories when it comes to substituting phthalates for alternatives.[55]

High temperature applications. Neither DEHT nor DINCH are suitable for high temperature applications. Neither passes the UL heat requirements for wire and cable, but TOTM and other trimellitates are suitable alternative plasticizers that can. Unfortunately, the trimellitates are expensive in comparison to phthalates like DEHP. For high temperature applications, some manufacturers have turned to other phthalates, particularly DINP, DIDP, and DPHP. While DIDP and DINP appear to have similar hazard properties to DEHP, DPHP may be a safer phthalate pending further chemical hazard assessment verification.

Food contact applications. DEHT is approved for food contact in the United States, but other additives are often required to meet performance requirements and may not be approved for food contact. Hexamoll DINCH is approved for food contact in Europe (EFSA), Canada, Japan, China, Korea, and Australia. However, it has not yet been cleared through the US Food and Drug Administration. With regards to food contact, DEHA is a common alternative to phthalates. It is currently used heavily in food film wrap, though the quantity used has been decreasing, particularly in Europe, as potential health impacts have been revealed. A recent (2018) investigation reported that the phthalates, diisononyl phthalate and diisodecyl phthalate and DEHP continue to be used in food packaging and processing materials available in the US. However, the investigators reported that overall, it appears that manufacturers are switching away from phthalates as their primary plasticizer to alternative compounds including ESBO, ATBC, DEHT, DINCH, DEHA and DINA.[56]

5.1.2 Alternatives to chemical substitution

Not all alternatives require direct chemical substitution (i.e. replacing the phthalate of concern in the material with a different chemical or chemical mixture). Plasticizers are only necessary for a flexible application if a rigid polymer is selected as the base. In some situations, material substitution - replacing PVC/phthalate mixture with a different polymer altogether or even a non-plastic material - may achieve the required cost, performance, and hazard objectives.

While the PVC polymer is inert and general regarded as non-hazardous, PVC production has numerous life cycle impacts of concern and is dependent on chlorine production. Healthy Building Network recently published a phase 1 report on chlorine and building materials that includes a detailed inventory of chlorine production technologies, markets, and pollution.[57] It further links chlorine production tightly to the manufacture of PVC. And plasticizers are just one type of performance additive used to optimize PVC performance.

Phthalates are most commonly used with PVC but can be used as plasticizers with other materials. In a report by Toxicology Excellence for Risk Assessment (TERA), commissioned by the Consumer Product Safety Commission (CPSC), the authors considered eleven phthalates (including DEHP, DBP, and BBP), none of which were used in metals, wood, or ceramics. Only DBP was used in glass as a component of an inner layer of safety glass. However, the phthalates were found in a variety of other materials, including textiles, paper, inks, coloring, paints, lacquers, varnishes, adhesives, sealers, binding agents, fillers, and non-PVC plastics.

In a related report by TERA and commissioned by CPSC looking at a similar list of ten phthalates (again including DEHP, DBP, and BBP), plastic types were identified that do not contain any of these ten phthalates. The purpose of this work was to identify materials that could be exempted from third party testing to assure compliance with section 108 of the Consumer Product Safety Improvement Act of 2008 (CPSIA).[58] Based on this work, the CPSC determined that polypropylene (PP), polyethylene (PE), high-impact polystyrene (HIPS), acrylonitrile butadiene styrene (ABS), crystal and general-purpose polystyrene (GPPS or GPS), medium-impact polystyrene (MIPS), and super-high-impact polystyrene (SHIPS), with specified additives, would not contain the six phthalates statutorily prohibited in the CPSIA (which includes DEHP,

DBP, and BBP). While these materials may be limited as alternatives to plasticized PVC, their use ensures that they do not contain phthalates as plasticizers.

5.2 Fragrance solvents/fixatives

Some stakeholders reported that overall, the fragrance industry has moved and continues to move away from DEP in favor of alternatives. The number one substitute for DEP in fragrances was identified as dipropylene glycol, followed by triethyl citrate. Both of these chemicals are odorless. They are both listed on the US EPA SCIL (with a full green circle and a yellow triangle, respectively). Dipropylene glycol is also listed on CleanGredients. Benzyl benzoate is also considered a good substitute for DEP from a performance perspective, but it is listed as a known fragrance allergen in the European Union and was therefore dropped from the Active List of functional and inherently less hazardous alternatives identified in this report.

Isopropyl myristate, triacetin, and benzyl alcohol are also used to some extent, but all have deficits when compared with DEP as a fragrance solvent. Isopropyl myristate is large molecule compared to those typically used for a fragrance solvent. While it has lower volatility than generally desired, it is listed on the US EPA SCIL as a half-green circle and is included in the final list of alternatives. Triacetin is also a large molecule and it is relatively expensive. It is listed on the US EPA SCIL as a full green circle and is included in the final list of alternatives. Benzyl alcohol is a skin sensitizer according to a current GS chemical hazard assessment report and is also on the EU list of known fragrance allergens. It is rarely used at high enough levels to replace DEP due to its sensitizing properties.

Many of the chemicals initially identified as potential alternatives to DEP as fragrance fixatives were odorous natural products, many of them resins or resinoids. Aside from the odor, they do not function well as solvents and are typically expensive compared to DEP.

5.2.1. Alternatives to chemical substitution

The most common solvents used for fragrances in perfumes are water and alcohol, typically ethanol, both of which are represented with full green circles on the US EPA SCIL. One alternative to using DEP is to carefully select fragrance ingredients that are soluble in water and alcohol. If all fragrance ingredients are soluble in this mixture, the use of an additional solvent such as DEP is unnecessary. However, in some cases, this may limit the palette and the desired scent may not be achievable.

An alternative approach to formulating without phthalates is to use directly compatible fragrance ingredients. Many fragrance compounds have been used to provide the solvent/fixative function in fragrances, in addition to desired odor. It is important to note that many of these alternatives are natural products, which may have sustainable sourcing challenges; and they are typically significantly more expensive than DEP. Many fragrances require dilution to avoid being too overpowering, so a compatible solvent may still be necessary.

Finally, an option for avoiding DEP as a fragrance solvent or fixative is to formulate products without fragrances. About 15% of the Safer Choice certified products listed on the Safer Choice website are fragrance-free.[59] While the use of fragrance is a driver in purchasing decisions for many consumer goods, particularly personal care products, the market has been changing in recent years. Consumers increasingly, though not necessarily accurately, associate fragrance ingredients with potential chemical sensitivities[60]. As a result, fragrance-free has becoming a marketing strategy.

5.3 Barriers to adoption

Stakeholders, particularly those who manufacture alternatives to phthalates, identified some barriers to the adoption of even the most promising alternatives. Without resolving the challenges posed by these barriers, substitution efforts are likely to stall. Advancing the Active List and following the recommendations for next steps there must be paired with addressing these other barriers to adoption.

Cost. Phthalates are relatively inexpensive, even considering the large quantities required for plasticizing. It is challenging for alternatives, especially novel chemistries, to match the price point of a chemical that has been in use for numerous years and that has been optimized for key applications. Comparing cost is complicated by differences in how ingredients and products are sold. Chemical ingredients like plasticizers are often sold by weight, while products may be sold by weight, units, or volume. Different quantities of an alternative may be needed than the original phthalate, and this may also change the amount of PVC or other ingredients used. Additional additives may be required to achieve the same processing and performance requirements. As a result, it is challenging for users to compare costs between the original phthalate(s) and reformulating and redesigning products with alternatives.

Reformulation time. In order to maintain the same processing properties and final product properties, reformulation will likely be necessary when substituting a phthalate plasticizer with an alternative. Even changing suppliers for the same chemical can result in the need for formulation adjustments, due to minor differences in purity, contaminants, and form. Changing to a new chemistry will result in formulation changes, and the need for research and development to re-optimize the formula. Increased reformulation time incurs additional costs.

Belief that phthalates are safe. Some stakeholders expressed a belief that phthalates as used in products are safe based on their personal assessment of the chemical hazard and exposure data. While these stakeholders currently sell or use phthalate alternatives, they do so predominantly for their customers who seek phthalate alternatives. They are unlikely to invest additional time in substitution without clear market demand, as they are not convinced that the current phthalates used are harmful to consumers, workers, or the environment. Additionally, they anticipate easing regulatory burdens as they expect that more data on phthalate hazards will reveal that they are less hazardous than they are currently perceived to be.

Lack of relevant certifications or registrations. Newer alternatives may lack desirable qualifications currently held by certain phthalates. For example, some manufacturers choose to use only food contact materials, even if the product is not designed for food contact. Chemicals approved for food contact are perceived as safer chemicals and this information can be used in marketing. A newer chemical may be safer, but if it is not currently registered for food contact, its adoption by customers who prefer food contact approved chemicals may be limited.

Liability concerns. A manufacturer may prefer to specify which chemicals to avoid, and not which chemicals to include, due to liability concerns. While this ensures that a hazardous chemical of concern is removed from the product, it does not ensure that a safer alternative is used instead. Based on the stakeholder interviews, it is expected that other potentially hazardous phthalates are likely substitutes if the sole specification is DEHP-free.

Global supply chain. The supply chain is global, and manufacturers struggle to communicate across it and to enforce requirements. This can result in manufacturers or retailers in the U.S. importing components or products that contain phthalates, despite specifying that they do not. In addition, products produced elsewhere may be cheaper and may contain unrestricted phthalates, putting US manufacturers at a disadvantage.

Performance requirements. Finally, there are likely some very specific performance properties that cannot currently be matched with the alternatives listed here. As an example, mentioned previously, no single alternative alone is sufficient to replace the use of DEHP in medical red blood cell bags. Some alternatives will work, but only with the use of additional additives. The chemical hazard of the additives should be assessed to determine if the mixture is relatively less hazardous. There are likely to be other narrow uses for which additional alternatives or substitution strategies are needed.

5.4 Drivers for adoption.

Environmentally preferable procurement can encourage chemical substitution with safer alternatives. Example strategies include ‘red lists’, ecolabels and ‘positive lists’ (greener chemical lists). Red lists are restricted substances lists that may be adopted by industry sectors to clearly specify which chemicals to avoid. They may also be incorporated into ecolabels. Red lists can be effective in driving market change away from the listed chemical. However, they do not identify safer alternatives; thereby increasing the potential of eliminating use of a phthalate only to replace it with another, equally hazardous or perhaps simply less well-studied chemical that has not been restricted. One stakeholder noted an increase in requests to avoid red list chemicals, specifically, those specified as problematic on the Environmental Working Group’s database, Skin Deep.[61] Certain phthalates are found on red lists worldwide including in the textile sector (Zero Discharge of Hazardous Chemicals[62]) and in association with ecolabels used in the building sector (International Living Future Institute).[63]

In contrast to red lists are eco-certifications and positive lists. The USEPA Safer Choice Program certifies cleaning and other products based on the use of inherently low hazard and best-in-

class chemicals. CleanGredients and the SCIL support Safer Choice by identifying inherently less hazardous ingredients for use in formulating products eligible for Safer Choice certification. CleanGredients and SCIL are leading models of 'positive lists' of chemicals with inherently low hazard. Currently there are two plasticizers listed on CleanGredients. While, technically these are the same chemical, they are manufactured by Eastman Chemical as Eastman 168 and by BASF as BASF Palatinol DOTP. SCIL and CleanGredients list chemical ingredients that meet robust hazard criteria and that are third party verified. Positive lists developed by independent and credible entities can help manufacturers, by adding additional credibility to their claims about health and environmentally preferable attributes.

The new ChemSec Marketplace is another vehicle for bringing attention to inherently less hazardous chemicals and includes plasticizers and solvents.[64] Chemicals on the ChemSec Marketplace are vetted to ensure that they do not have the hazard characteristics of substances of very high concern. TCO Development recently added plasticizers to their Accepted Substance List. Plasticizers that achieve GS BM2 or higher are approved for use in electronic wire and cable applications seeking TCO Development product certification. Ironically DMP is on the TCO Development Accepted Substances List because it achieves a score of GS BM 2. Unfortunately, neither the hazard table nor the full GS report is publicly available to inform decision making about the specific hazards and data gaps associated with DMP and the other chemicals on the Accepted Substances List.

6.0 Summary and recommended next steps

The five phthalates of concern were grouped based on their function as either plasticizers/fast fusers or fragrance solvents/fixatives, two major applications in products. The project team reduced the broad initial list of potential alternatives to a smaller list of alternatives that are being currently used in the marketplace based on market research and interviews with a cross section of stakeholders. Then, by screening the chemicals for their inherent hazard using a prescribed set of publicly available reports and hazard classification screening tools, the project team further reduced the list to the resulting Active List. These functional and potentially less hazardous alternatives were grouped into three categories.

Category A alternatives have publicly available comprehensive chemical hazard assessment reports that achieve a GreenScreen Benchmark score of 2 or higher. These alternatives are considered to be both functional with respect to performance and of relatively lower hazard than the chemicals they would replace. An important caveat however, is that regardless of a chemicals' GS BM score, manufacturers should always consider its specific hazard profile as it relates to the intended use of the chemical in a product.

The project team identified two alternatives that meet the criteria for Category A, both of which serve as plasticizers or fast fusers:

- DINCH, D9NCH (Diisononyl cyclohexanedicarboxylate, CAS # 166412-78-8, 474919-59-0)
- DEHT, DOTP (Bis (2-ethylhexyl) terephthalate, CAS # 6422-86-2)

Recommended next steps for Category A alternatives include identifying opportunities to accelerate their adoption in product applications for which they are well suited. Future work could include identifying applications that have the greatest potential to impact Puget Sound. Washington Department of Ecology is currently funding research by Zero Waste Washington to test products used in the external, built environment (coatings, road paints, structural plastics, etc.) for phthalates. Pending the results of this research, products found to be more significant sources of phthalates could be prioritized for substitution.

The project team identified three alternative plasticizers/fast fusers and four alternative fragrance solvents/fixatives that meet the criteria for Category B. The alternative plasticizer/fast fusers include:

- Triacetin (GTA) (CAS# 102-76-1)
- COMGHA (Acetylated monoglycerides derived from fully hydrogenated castor oil, CAS# 736150-63-3)
- Dipropylene glycol dibenzoate (CAS# 27138-31-4)

The alternative fragrance solvents/fixatives include:

- Dipropylene glycol (CAS# 25265-71-8)
- Triethyl citrate (CAS# 77-93-0)
- Triacetin (GTA) (CAS# 102-76-1)
- Isopropyl myristate (CAS# 110-27-0)

These alternatives are functional alternatives listed on the U.S. EPA Safer Chemical Ingredient List (SCIL) with a full green circle, a half green circle or a yellow triangle and/or they are listed on CleanGredients.

Recommended next steps for Category B alternatives include generating publicly accessible, full chemical hazard assessments to elucidate their hazard profiles and to inform decision making.

The project team identified eleven alternatives that meet the criteria for Category C:

- Pentaerythritol tetravalerate (CAS # 15834-04-5)
- DBT (Dibutylterephthalate, CAS # 1962-75-0)
- Methyl esters of epoxidized soybean oil fatty acids (CAS # 68082-35-9)
- ASE (Alkylsuphonic phenyl ester, CAS # 91082-17-6)
- DPHP (Di(2-propylheptyl) phthalate, CAS # 53306-54-0)
- TOTM, TEHTM (Tris (2-ethylhexyl) trimellitate, CAS # 3319-31-1)
- DEGD (Diethylene glycol dibenzoate, CAS # 120-55-8)
- ESBO (Epoxidized soybean oil, CAS # 8013-07-8)
- ATBC (Acetyl tributyl citrate, CAS # 77-90-7)
- DINA (Diisononyl adipate, CAS # 33703-08-1)
- DEHA, DOA (2-ethylhexyl adipate, CAS # 103-23-1)

For Category C alternatives, hazard list screening revealed that they are not listed on any regulatory or hazard lists of concern. However, they either have no publicly available chemical hazard assessment reports available or chemical hazard assessment results indicate numerous data gaps that make the overall hazard unknown.

Recommended next steps for Category C alternatives are to prioritize these chemicals for full chemical hazard assessment reports. For Category C chemicals with chemical hazard assessment reports and significant data gaps, further work could be done to obtain additional test information and to update the assessment using predictive toxicology tools.

The outcomes of this work can be used to:
1) accelerate the substitution of inherently less hazardous alternatives,
2) prioritize additional chemical hazard assessment work, and
3) encourage continued work to identify applications that still need functional and inherently safer alternatives to phthalates in order to reduce phthalate loading to Puget Sound.

Accelerate adoption. Accelerating adoption of functional, lower hazard alternatives is a supply chain challenge. Manufacturers of products containing phthalates need to be aware of the regulatory and/or market drivers for substitution of phthalates. Information on the availability of functional and inherently less hazardous alternatives could be made publicly available through organizations committed to advancing safer alternatives and through environmentally preferable procurement. Manufacturers of alternatives to the five phthalates could step up their education and technical assistance efforts not only with customers but also with government, retailers and others in the supply chain to drive successful substitution efforts. Industry associations could be effective vehicles to disseminate information to their members in specific sectors. To improve adoption it is helpful to understand which product and industry sections have momentum toward substitution and where there is inertia that inhibits change. Better understanding of sources of phthalates to Puget Sound could help to prioritize which product applications to focus substitution efforts.

Environmentally preferable procurement can also be a powerful vehicle to advance adoption of functional and inherently less hazardous options. Procurement is supported by credible third-party standards, ecolabels and databases. For example, CleanGredients includes a limited number of plasticizers that meet criteria for the Safer Choice label. Expanding the number of alternatives in CleanGredients could help to increase awareness and provide needed confidence that the alternatives are indeed less hazardous and less likely to undergo regulatory restrictions. Certification programs help not only formulators and processors, but also retailers and consumer product manufacturers to make informed decisions.[65] The ChemSec Marketplace is a free and publicly available platform that includes chemical products that avoid substances of high concern. This platform is useful for both education and marketing. It is rapidly becoming a trusted, platform for identifying inherently less hazardous alternatives. The TCO Accepted Substances List is also a vehicle that could drive targeted substitution.

Generate more publicly available chemical hazard assessment reports. The Category B and C alternatives in this report need comprehensive and publicly accessible chemical hazard assessment reports to ensure that users have enough information to make informed decisions.[66] Publicly accessible comprehensive chemical hazard assessment reports would also be useful for the five phthalates. REACH dossiers for DMP[67] and DEP,[68] two of the five priority pollutants addressed in this report, suggest the possibility of lower hazard classifications than may warrant extensive substitution efforts. Recent use of the GS method resulted in assigning DMP a score of GS BM 2, justifying its inclusion on the TCO Development Accepted Substances List. The use of GS BM 2 as a criterion for identifying safer alternatives should be examined and challenged. GS BM scores should not be reported without being accompanied, at a minimum, by summary hazard tables; and ideally, with full chemical hazard assessment reports. This is necessary so that users can see the specific chemical hazards and the data gaps that are relevant to how they intend to use the chemical.

Identify applications where substitution and alternatives assessment should be prioritized. Future work should prioritize the substitution of phthalates with functional, less hazardous alternatives in product that are most impactful to Puget Sound. In addition, not every application that currently uses one or more of the five phthalates can be addressed by substituting with the alternatives identified in this report. Future work could increase understanding of where substitution remains a challenge. Scoping available alternatives for specific applications may help uncover both additional functional alternatives and needs. Some alternatives may be emerging and not yet well-known in the market place. Where functional and inherently safer alternatives do not currently exist, future work could include a design challenge, using platforms such as Innocentive to stimulate innovation.[69]

Appendix I

Hazard profiles of example phthalates used as plasticizers/fast fusers

Some higher molecular weight phthalates are being adopted as potential substitutes to the phthalates of concern. A summary of hazard assessment classifications based on publicly accessible hazard assessment reports is presented below for a set of phthalate plasticizers or fast fusers. All of the phthalates, except DPHP, scored as GS BM 1, GS LT 1 or LT P1 (possible Benchmark 1). See the hazard section of the report for a discussion of the screening methodologies, including limitations.

CAS #	Common name	Abbreviation	CHA type	CHA score	Carcinogenicity	Mutagenicity	Reproductive	Developmental	Endocrine	Acute	Systemic	Systemic Repeat	Neurotoxicity	Neurotoxicity, Repeat	Skin Sensitization	Respiratory Sensitization	Skin Irritation	Eye Irritation	Acute Aquatic	Chronic Aquatic	Persistence	Bioaccumulation	Reactivity	Flammability
84-74-2	Di-n-butyl phthalate	DBP	GS LT	1	M		H	H	H	L				vH-M	H	M		H	vH	H	pC	pC		
84-69-5	Diisobutyl Phthalate	DIBP	GS LT	1			M	H-M	H	pC						M			vH		pC	pC		
71888-89-6	Diisoheptyl phthalate	DIHP	GS LT	1				H								M								
85-68-7	Butylbenzyl phthalate	BBP	GS LT	1	M		H-M	H	H	L						M	M		vH	H	pC	vH		
117-81-7	Bis (2-ethylhexyl) phthalate	DEHP	GS LT	1	H		H	H	H					vH-L		M		M	vH	H	pC	pC		
117-81-7	Bis (2-ethylhexyl) phthalate	DEHP	Mod. GS BM	1	**M**	**L**	**H**	**H**	**H**	**L**	**M**		**L**	**L**	**L**	*L*	**L**	**L**	**L**	**L**	**vL**	**L**	**L**	**L**
117-84-0	Diocty Phthalate	DNOP	GS LT	P1			M-L	H-M	H-M							M					pC	pC		
68515-48-0	Diisononyl phthalate	DINP (DINP-1)	GS LT	1	H		M-L	H-M	H-M							M	H	H	pC					
28553-12-0	Diisononyl phthalate	DINP (DINP-2 and DINP-3)	Expired GS BM	1	DG	L	H	H	H	L	DG	M	DG	DG	L	L	L	M	L	L	vL	vL	L	L
28553-12-0	Diisononyl phthalate	DINP (DINP-2 and DINP-3)	GS LT	UNK	M											M								
53306-54-0	Di(2-propylheptyl) phthalate	DPHP	Expired GS BM	U	DG	**L**	**L**	**L**	*M*	**L**	DG	**L**	DG	DG	**L**	DG	**L**	**L**	**L**	*L*	**L**	**vL**	**L**	**L**
53306-54-0	Di(2-propylheptyl) phthalate	DPHP	GS LT	UNK	**M**																			
26761-40-0	Diisodecyl phthalate	DIDP	GS LT	1	M		M-L	H	H-M							M	pC	pC			pC	pC		
68515-49-1	Diisodecyl phthalate	DIDP	GS LT	1	M		M-L	H	H-M							M	pC	pC			pC	pC		
3648-20-2	Diundecyl phthalate	DUP	GS LT	P1					H-M							M				M				

Appendix II

Full list of candidate plasticizers and fast fusers

1. Dipropylene glycol dibenzoate (CAS# 27138-31-4)
2. Triacetin (CAS# 102-76-1)
3. Acetylated monoglycerides derived from fully hydrogenated castor oil (COMGHA) (CAS# 736150-63-3)
4. Bis (2-ethylhexyl) terephthalate (DEHT) (CAS# 6422-86-2)
5. Diisononyl cyclohexanedicarboxylate (DINCH) (CAS# 166412-78-8 and 474919-59-0)
6. Dibutylterephthalate (DBT) (CAS# 1962-75-0)
7. Tris (2-ethylhexyl) trimellitate (TOTM) (CAS# 3319-31-1)
8. 2-ethylhexyl adipate (CAS# 103-23-1) (DEHA)
9. Acetyl tributyl citrate (ATBC) (CAS# 77-90-7)
10. Diisononyl adipate (DINA) (CAS# 33703-08-1)
11. Epoxidized soybean oil (ESBO) (CAS# 8013-07-8)
12. Pentaerythritol tetravalerate (CAS# 15834-04-5)
13. Alkylsuphonic phenyl ester (ASE) (CAS# 91082-17-6)
14. Methyl esters of epoxidized soybean oil fatty acids (CAS# 68082-35-9)
15. Diethylene glycol dibenzoate (CAS# 120-55-8)
16. Di (2-propylheptyl) phthalate (DPHP) (CAS# 53306-54-0)
17. Diocty Phthalate (DNOP) (CAS# 117-84-0)
18. diundecyl phthalate (DUP) (CAS# 3648-20-2)
19. Di-2-ethylhexyl azelate (DOZ) (CAS# 103-24-2)
20. Di-butyl adipate (DBA) (CAS# 105-99-7)
21. Di-butyl sebacate (DBS) (CAS# 109-43-3)
22. Triethylene glycol dibenzoate (CAS# 120-56-9)
23. Isosorbide Diesters (CAS# 1215036-04-6)
24. Butylated hydroxytoluene (BHT) (CAS# 128-37-0)
25. Dioctyl sebacate (DOS) (CAS# 122-62-3,)
26. Acetyltri-n-hexyl citrate (ATHC) (CAS# 24817-92-3)
27. Di-isodecyl sebacate (DIDS) (CAS# 28473-19-0)
28. Di(2-ethylhexyl) phosphate (DEHPA) (CAS# 298-07-7)
29. Isodecyl benzoate (CAS# 131298-44-7)
30. Isononyl Benzoate (CAS# 670241-72-2)
31. Propylene glycol dibenzoate (CAS# 19224-26-1)
32. Di(butoxyethoxyethoxyethtyl) glutarate (CAS# 65520-42-5)
33. Epoxidized soybean fatty acid (CAS# 68082-34-8)
34. 2,2,4-trimethyl-1,3 pentanediol diisobutyrate (TPIB, TXIB) (CAS# 6846-50-0)
35. 1,2,4-Benzenetricarboxylic acid, tri-C7-9-branched and linear alkyl esters (CAS# 68515-60-6)
36. Epoxidized propylene glycol dioleate (CAS# 68609-92-7)
37. Tributyl Trimellitate (CAS# 1726-23-4)
38. Acetyl triethyl citrate (CAS# 77-89-4)
39. Tributyl Citrate (CAS# 77-94-1)
40. Tri(2-ethylhexyl) phosphate (TEHPA) (CAS# 78-42-2)
41. Epoxidized linseed oil (CAS# 8016-11-3)
42. n-Butyryltri-n-hexyl Citrate (CAS# 82469-79-2)
43. o-toluene sulfonamide (OTSA) (CAS# 88-19-7)
44. Trioctyl trimellitate (CAS# 89-04-3)
45. 1,2,4-Benzenetricarboxylic acid, mixed decyl and hexyl and octyl esters (CAS# 68130-50-7)
46. Hexanedioic acid, polymer with 2,2-dimethyl-1,3-propanediol and 1,2-propanediol, isononyl ester (CAS# 208945-13-5)
47. Adipic acid and polyhydric alcohols (CAS# 208945-12-4)
48. Naphthenic Hydrocarbon (CAS# 64742-53-6)
49. Diisononyl phthalate (DINP) (CAS# 68515-48-0, DINP-1; CAS# 28553-12-0, DINP-2 and DINP-3)
50. Diisodecyl phthalate (DIDP) (CAS# 26761-40-0,)
51. Diisobutyl Phthalate (DIBP) (CAS# 84-69-5)
52. Diisoheptyl phthalate (DIHP) (CAS# 71888-89-6)
53. Diisodecyl phthalate DIDP) (CAS# 68515-49-1)
54. Tricresyl Phosphate (TCP) or Tritolyl Phosphate (CAS# 1330-78-5)

Appendix III

Full list of candidate fragrance solvents or fixatives

1. Dipropylene glycol (CAS# 25265-71-8)
2. Triacetin (CAS# 102-76-1)
3. Isopropyl myristate (CAS# 110-27-0)
4. Triethyl citrate (CAS# 77-93-0)
5. Polyethylene glycol (CAS# 25322-68-3)
6. Hexanoic acid (CAS# 142-62-1)
7. Cyclopentadecanolide (CAS# 106-02-5)
8. Ethylene brassylate (CAS# 105-95-3)
9. Phenoxyethanol (CAS# 122-99-6)
10. Water (CAS# 7732-18-5)
11. Ethanol (CAS# 64-17-5)
12. (3aR-(3aalpha,5abeta,9aalpha,9bbeta))-Dodecahydro-3a,6,6,9a-tetramethylnaphtho(2,1-b)furan (CAS# 6790-58-5)
13. (4E)-4-[(2Z)-But-2-en-1-ylidene]-3,5,5-trimethylcyclohex-2-en-1-one (CAS# 13215-88-8)
14. 2-ethylhexyl palmitate (CAS# 29806-73-3)
15. Acetyl triethyl citrate (CAS# 77-89-4)
16. Ambroxide (unspecified stereochemistry) (CAS# 6790-58-5 and 3738-00-9)
17. Benzoin (CAS# 119-53-9)
18. Benzyl acetate (CAS# 140-11-4)
19. Bergamot oil (furocoumarin free)(Citrus bergamia Risso et Poiteau) (CAS# 8007-75-8)
20. C12-15 Alkyl benzoate (CAS# 68411-27-8)
21. Commiphora myrrha resin extract (CAS# 84929-26-0)
22. Diisobutyl adipate (CAS# 141-04-8)
23. Frankincense oil (CAS# 8016-36-2)
24. Frankincense resin (CAS# 8050-07-5)
25. Galbanum essential oil (CAS# 8023-91-4)
26. hydrolyzed jojoba (CAS# 85186-93-2)
27. Hydroxyciol (CAS# 107-74-4)
28. Isobutyl stearate (CAS# 646-13-9)
29. Labdanum oil (CAS# 8016-26-0)
30. Labdanum resin (CAS# 84775-64-4)
31. Macadamia integrifolia seed oil (CAS# 129811-19-4)
32. Methyl 2-[{(4-(4-hydroxy-4-methylpentyl)-1-cyclohexenyl)methylene}amino}benzoate (CAS# 67634-12-2)
33. Methyl hydrogenated rosin (CAS# 8050-15-5)
34. Methyl rosinate (CAS# 68186-14-1)
35. Musk lactone (CAS# 3391-83-1)
36. Myrrh (CAS# 9000-45-7)
37. Opopanax (1 of 3 CASRN) (CAS# 93686-00-1; gum, CAS# 9000-78-6; resin, CAS# 93384-32-8)
38. PPG-10 Methyl glucose ether (CAS# 61849-72-7)
39. shea butter glycerides (CAS# 97488-91-0)
40. Sucrose acetate isobutyrate (1 of 3 CASRN) (CAS# 126-13-6, 137204-24-1, 27216-37-1)
41. Tocopherol (CAS# 1406-66-2)
42. Tolu balsam (CAS# 9000-64-0)
43. jojoba (CAS# 61789-91-1)
44. jojoba ethoxylated (CAS# 159518-81-7)
45. Benzyl alcohol (CAS# 100-51-6)
46. Benzyl benzoate (CAS# 120-51-4)
47. Amyl cinnamic aldehyde (CAS# 122-40-7, ACA)
48. Cinnamic alcohol (CAS# 104-54-1)
49. Diisobutyl Phthalate (DIBP) (CAS# 84-69-5)
50. Galaxolide (CAS# 1222-05-5)
51. Glyceryl hydrogenated rosinate (CAS# 65997-13-9)
52. Hexyl cinnamal / α-n-Hexyl-β-Phenylacrolein (CAS# 101-86-0)
53. Musk xylol (2,4,6-trinitro-5-tert-butyl-m-xylene) (CAS# 81-15-2)
54. Peru Balsam (CAS# 8007-00-9)
55. Tonalide (CAS# 1506-02-1)
56. Benzyl salicylate (CAS# 118-58-1)

Appendix IV

Stakeholders Interviewed

Mike Belliveau, Environmental Health Strategies Center
Monika Becker, Green Chemistry & Commerce Council (GC3)
Scott Boito, Eastman Chemical Company
Bill Carroll, Indiana University and formerly with Occidental Chemical Corporation
James Ewell, Green Blue Institute (CleanGredients)
Patrick Harmon, BASF Corporation
Emily McBride, Emerald Kalama Chemical
Kevin Renskers, Takasago International Corporation
Heather Trim, Zero Waste Washington

Appendix V

Stakeholder interview questions

Interviews were conducted over the phone and supplemented by additional follow-up questions and information via email, if necessary. After a brief project description and introduction to the five phthalates of concern, the following questions were asked of all stakeholders:

- What uses/functions of these five phthalates should we consider and why?
- If you currently use phthalates, which phthalates do you currently use? For which functions/products?
    - Have you explored alternatives? If so, what alternatives did you find?
    - Have you substituted any phthalates for alternatives? If so, which phthalate and which alternatives? Can you describe you experience with substitution?
- If you currently manufacturer phthalates, which phthalates do you currently manufacturer? What functions/products are they used in?
- We are looking for alternatives to these five phthalates. What alternatives are you aware of?
    - Are these currently being used on the market?
    - What attributes make these more or less preferable as alternatives?
    - What opportunities/barriers do you see in substitution?
- Are there any uses/functions of these phthalates for which there are no alternatives? Why are none of the other alternatives suitable for these uses/functions?
- If the interviewee was willing, we provided our list of potential alternatives requested that they review the list and let us know which:
    - Are functional alternatives to the five phthalates, and any caveats in their use?
    - Are currently used as substitutes to the five phthalates?
    - Are not functional alternatives, and why?
- Is there anyone else you recommend we talk to about this?
- Is there anything else we should know about phthalates and phthalate substitution that we have not already addressed?

Appendix VI[1]

Chemical hazard assessments for full list of plasticizers and fast fusers

CAS #	Common name	Abbreviation	CHA Date	CHA Profiler	CHA type	CHA score	C	M	R	D	E	AT	ST	ST*	N	N*	SnS*	SnR*	IrS	IrE	AA	CA	P	B	Rx	F	US EPA SCIL	CORAP
117-81-7	**Bis (2-ethylhexyl) phthalate**	DEHP	9/17/2018	Data Commons	GS LT	1	H		H	H	H					vH-L		M		M	vH	H	pC	pC			unlisted	
117-81-7	**Bis (2-ethylhexyl) phthalate**	DEHP	Harmon 2017	BASF	Mod. GS BM	1	M	L	H	H	H	L	M		L	L	L	L	L	L	L	L	vL	L	L	L	unlisted	
84-74-2	**Di-n-butyl phthalate**	DBP	9/17/2018	Data Commons	GS LT	1	M		H	H	H	L				vH-M	H	M		H	vH	H	pC	pC			unlisted	
85-68-7	**Butylbenzyl phthalate**	BBP	9/17/2018	Data Commons	GS LT	1	M		H-M	H	H	L						M	M		vH	H	pC	vH			unlisted	
6422-86-2	Bis (2-ethylhexyl) terephthalate	DEHT	9/20/2016	ToxServices	GS BM	3dg	L	L	L	L	DG	L	L	L	L	DG	L	L	L	L	L	L	vL	L	L	L	unlisted	
166412-78-8	Diisononyl cyclohexanedicarboxylate	DINCH	9/22/2016	ToxServices	GS BM	2	L	L	L	L	M	L	L	L	L	L	L	L	M	L	L	L	M	L	L	L	unlisted	
474919-59-0	Diisononyl cyclohexanedicarboxylate	DINCH	9/22/2016	ToxServices	GS BM	2	L	L	L	L	M	L	L	L	L	L	L	L	M	L	L	L	M	L	L	L	unlisted	
1962-75-0	Dibutylterephthalate	DBT	9/17/2018	Data Commons	GS NoGS													M			pC						unlisted	
3319-31-1	Tris (2-ethylhexyl) trimellitate	TOTM	5/1/2013	ToxServices	Expired GS BM	U	DG	L	M	L	DG	L	M	L	L	DG	L	DG	L	L	L	L	M	vL	L	L	unlisted	X
3319-31-1	Tris (2-ethylhexyl) trimellitate	TOTM	9/18/2018	Data Commons	GS LT	UNK																	M	vL	L	L	unlisted	X
103-23-1	2-ethylhexyl adipate	DEHA	9/17/2018	Data Commons	GS LT	P1	M	pC	M		H-M								M	pC	pC		pC	pC			unlisted	X
77-90-7	Acetyl tributyl citrate	ATBC	9/17/2018	Data Commons	GS LT	P1															pC						unlisted	
33703-08-1	Diisononyl adipate	DINA	9/17/2018	Data Commons	GS LT	UNK																					unlisted	
8013-07-8	Epoxidized soybean oil	ESBO	9/17/2018	Data Commons	GS LT	UNK													M								unlisted	
15834-04-5	Pentaerythritol tetravalerate	-	9/17/2018	Data Commons	GS LT	UNK															pC						unlisted	
91082-17-6	Alkylsuphonic phenyl ester	ASE	9/17/2018	Data Commons	GS LT	UNK																					unlisted	
736150-63-3	Acetylated monoglycerides derived from fully hydrogenated castor oil	COMGHA	9/17/2018	Data Commons	GS NoGS																						Green [Circle] - Surfactants	
68082-35-9	Methyl esters of epoxidized soybean oil fatty acids	-	9/17/2018	Data Commons	GS LT	UNK																		vH			unlisted	
120-55-8	Diethylene glycol dibenzoate	-	9/17/2018	Data Commons	GS LT	P1						L															unlisted	X
27138-31-4	Dipropylene glycol dibenzoate	-	9/17/2018	Data Commons	GS LT	P1														pC							Green [Circle] - Emollients	X
102-76-1	Triacetin	-	9/17/2018	Data Commons	GS LT	UNK						M															Green [Circle] - Fragrances	
53306-54-0	Di(2-propylheptyl) phthalate	DPHP	5/9/2012	ToxServices	Expired GS BM	U	DG	L	L	L	M	L	DG	L	DG	DG	L	DG	L	L	L	L	L	vL	L	L	unlisted	**X**
53306-54-0	Di(2-propylheptyl) phthalate	DPHP	9/18/2018	Data Commons	GS LT	UNK	M																				unlisted	**x**
68515-48-0	Diisononyl phthalate	DINP (DINP-1)	9/17/2018	Data Commons	GS LT	1	H		M-L	H-M	H-M							M	H	H	pC						unlisted	
28553-12-0	Diisononyl phthalate	DINP (DINP-2 and DINP-3)	2/10/2012	ToxServices	Expired GS BM	1	DG	L	H	H	H	L	DG	M	DG	DG	L	L	L	M	L	L	vL	vL	L	L	unlisted	
28553-12-0	Diisononyl phthalate	DINP (DINP-2 and DINP-3)	9/18/2018	Data Commons	GS LT	UNK	M											M									unlisted	
26761-40-0	Diisodecyl phthalate	DIDP	9/17/2018	Data Commons	GS LT	1	M		M-L	H	H-M							M	pC	pC			pC	pC			unlisted	
84-69-5	Diisobutyl Phthalate	DIBP	9/17/2018	Data Commons	GS LT	1			M	H-M	H	pC						M			vH		pC	pC			unlisted	
71888-89-6	Diisoheptyl phthalate	DIHP	9/17/2018	Data Commons	GS LT	1				H								M									unlisted	
117-84-0	Diocty Phthalate	DNOP	9/17/2018	Data Commons	GS LT	P1			M-L	H-M	H-M							M					pC	pC			unlisted	
68515-49-1	Diisodecyl phthalate	DIDP	9/17/2018	Data Commons	GS LT	1	M		M-L	H	H-M							M	pC	pC			pC	pC			unlisted	
3648-20-2	Diundecyl phthalate	DUP	9/17/2018	Data Commons	GS LT	P1					H-M							M				M					unlisted	
77-89-4	Acetyl triethyl citrate		9/17/2018	Data Commons	GS LT	UNK											pC										unlisted	
103-24-2	Di-2-ethylhexyl azelate	DOZ	10/9/2012	ToxServices	Expired GS BM	U	DG	L	L	L	DG	L	DG	L	DG	DG	L	DG	M	L	L	L	vL	vL	L	L	unlisted	
103-24-2	Di-2-ethylhexyl azelate	DOZ	9/18/2018	Data Commons	GS LT	UNK																					unlisted	
105-99-7	Di-butyl adipate	DBA	9/17/2018	Data Commons	GS LT	P1			M		H-M										H						unlisted	
109-43-3	Di-butyl sebacate	DBS	9/17/2018	Data Commons	GS LT	UNK			M				pC						pC	pC	pC						unlisted	
120-56-9	Triethylene glycol dibenzoate		9/17/2018	Data Commons	GS LT	P1																					unlisted	
1215036-04-6	Isosorbide Diesters		9/17/2018	Data Commons	GS NoGS																						unlisted	
128-37-0	Butylated Hydroxytoluene	BHT	9/17/2018	Data Commons	GS LT	P1	M	pC	M	M-L	H-M	M	pC	pC			H		pC	M	vH						unlisted	X

[1] See Supplement Excel worksheet for improve image clarity

CAS #	Common name	Abbreviation	CHA Date	CHA Profiler	CHA type	CHA score	C	M	R	D	E	AT	ST	ST*	N	N*	SnS*	SnR*	IrS	IrE	AA	CA	P	B	Rx	F	US EPA SCIL	CORAP
1330-78-5	Tricresyl Phosphate or Tritolyl Phosphate	TCP	9/17/2018	Data Commons	GS LT	P1	pC	pC	H			M							M	H	vH						unlisted	X
122-62-3	Dioctyl sebacate	DOS	9/17/2018	Data Commons	GS LT	UNK						M															unlisted	
24817-92-3	Acetyltri-n-hexyl citrate	ATHC	9/17/2018	Data Commons	GS NoGS																						unlisted	
28473-19-0	Di-isodecyl sebacate	DIDS	9/17/2018	Data Commons	GS NoGS																						unlisted	
298-07-7	Di(2-ethylhexyl) phosphate	DEHPA	9/17/2018	Data Commons	GS LT	P1		pC	pC			M							vH	vH	M		vH-H				unlisted	
131298-44-7	Isodecyl benzoate		9/17/2018	Data Commons	GS NoGS																						unlisted	
670241-72-2	Isononyl Benzoate		9/17/2018	Data Commons	GS LT	P1																					unlisted	
19224-26-1	Propylene glycol dibenzoate		9/17/2018	Data Commons	GS LT	UNK													pC	pC							unlisted	
64742-53-6	Naphthenic Hydrocarbon		9/17/2018	Data Commons	GS LT	1	H			M		H-M		pC					H	H-M				vH			unlisted	
65520-42-5	Di (butoxyethoxyethoxyethtyl) glutarate		9/17/2018	Data Commons	GS NoGS	0															pC						unlisted	
68082-34-8	Epoxidized soybean fatty acid		9/17/2018	Data Commons	GS NoGS	0																					unlisted	
6846-50-0	2,2,4-trimethyl-1,3 pentanediol diisobutyrate	TXIB	9/17/2018	Data Commons	GS LT	P1					H-M			pC			pC		pC	pC	H			vH			unlisted	
68515-60-6	1,2,4-Benzenetricarboxylic acid, tri-C7-9-branched and linear alkyl esters		9/17/2018	Data Commons	GS LT	UNK																	vH-H				unlisted	
68609-92-7	Epoxidized propylene glycol dioleate		9/17/2018	Data Commons	GS NoGS	0																					unlisted	
1726-23-4	Tributyl Trimellitate		9/17/2018	Data Commons	GS NoGS	0															pC						unlisted	
77-94-1	Tributyl Citrate		9/17/2018	Data Commons	GS LT	UNK																					unlisted	
78-42-2	Tri(2-ethylhexyl) phosphate	TEHPA	9/17/2018	Data Commons	GS LT	P1		pC	pC		H-M								H	H	vH		vH-H				unlisted	
8016-11-3	Epoxidized linseed oil		9/17/2018	Data Commons	GS NoGS	0																					unlisted	
82469-79-2	n-Butyryltri-n-hexyl Citrate		9/17/2018	Data Commons	GS NoGS	0																					unlisted	
88-19-7	O-toluene sulfonamide	OTSA	9/17/2018	Data Commons	GS LT	P1																	vH-H				unlisted	
89-04-3	Trioctyl trimellitate		9/17/2018	Data Commons	GS LT	UNK																					unlisted	
68130-50-7	1,2,4-Benzenetricarboxylic acid, mixed decyl and hexyl and octyl esters		9/17/2018	Data Commons	GS LT	UNK																					unlisted	
208945-13-5	Hexanedioic acid, polymer with 2,2-dimethyl-1,3-propanediol and 1,2-propanediol, isononyl ester		9/17/2018	Data Commons	GS LT	NoGS																					unlisted	
208945-12-4	Adipic acid and polyhydric alcohols		9/17/2018	Data Commons	GS NoGS	0																					unlisted	

Appendix VII[2]

Chemical hazard assessments for full list of fragrance fixatives and solvents

CAS #	Common name	Abbreviation	CHA Date	CHA Profiler	CHA type	CHA score	C	M	R	D	E	AT	ST	ST*	N	N*	SnS*	SnR*	IrS	IrE	AA	CA	P	B	Rx	F	US EPA SCIL	EU allergen	CORAP LIST
84-66-2	**Diethyl phthalate**	**DEP**	9/17/2018	Data Commons	GS LT	P1	H-L				H-M	M		pC			H	M	H	M	H		vH-H				unlisted	unlisted	X
131-11-3	**Dimethyl phthalate**	**DMP**	9/17/2018	Data Commons	GS LT	P1	H-L				H-M	H						M		H	M		vH-H				unlisted	unlisted	
84-74-2	**Di-n-butyl phthalate**	**DBP**	9/17/2018	Data Commons	GS LT	1	M		H	H	H	L				vH-M	H	M		H	vH	H	pC	pC			unlisted	unlisted	
25265-71-8	Dipropylene glycol		9/17/2018	Data Commons	GS LT	UNK				M-L		pC							M	H							Green [Circle] - Solvents	unlisted	
77-93-0	Triethyl citrate		9/17/2018	Data Commons	GS LT	UNK															pC						Yellow [Triangle] - Fragrances	unlisted	
102-76-1	Triacetin		9/17/2018	Data Commons	GS LT	UNK						M															Green [Circle] - Fragrances	unlisted	
110-27-0	Isopropyl myristate		9/17/2018	Data Commons	GS NoGS			pC				pC							pC		pC						Half Green [Circle] - Solvents	unlisted	
100-51-6	Benzyl alcohol		2/1/2016	ToxServices	GS BM	2	L	L	L	M	DG	M	DG	H	M	L	H	DG	L	H	L	L	vL	vL	L	L	unlisted	Chemical of concern	X
120-51-4	Benzyl benzoate		9/17/2018	Data Commons	GS LT	P1						M					pC				H						unlisted	Chemical of concern	
7732-18-5	Water		8/27/2012	SciVera	Expired GS BM	4	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	H	L	L	L	Green [Circle] - Solvents	unlisted	
64-17-5	Ethanol		4/22/2014	NSF	Expired GS BM	2	L	L	L	M	DG	L	M	L	M	M	L	DG	L	H	L	L	L	vL	L	H	Green [Circle] - Antimicrobial Additives	unlisted	
6790-58-5	(3aR-(3aalpha,5abeta,9aalpha,9bbeta))-Dodecahydro-3a,6,6,9a-tetramethylnaphtho(2,1-b)furan (Ambermor)		9/17/2018	Data Commons	GS LT	UNK															pC			vH			unlisted	unlisted	
6790-58-5	Ambroxide (1/2 CASRN) (unspecified stereochemistry)		9/17/2018	Data Commons	GS LT	UNK															pC			vH			unlisted	unlisted	
13215-88-8	(4E)-4-[(2Z)-But-2-en-1-ylidene]-3,5,5-trimethylcyclohex-2-en-1-one		9/17/2018	Data Commons	GS LT	P1			pC			pC									pC						unlisted	unlisted	
29806-73-3	2-ethylhexyl palmitate		9/17/2018	Data Commons	GS NoGS																						unlisted	unlisted	
3738-00-9	Ambroxide (1/2 CASRN) (unspecified stereochemistry)		9/17/2018	Data Commons	GS LT	P1															pC			vH			unlisted	unlisted	
122-40-7	Amyl cinnamic aldehyde	ACA	9/17/2018	Data Commons	GS LT	P1											H		H		vH						unlisted	Chemical of concern	
119-53-9	Benzoin		9/17/2018	Data Commons	GS LT	P1																					unlisted	unlisted	
140-11-4	Benzyl acetate		9/17/2018	Data Commons	GS LT	UNK	H-L	pC				M	pC						H	H	H					M	unlisted	unlisted	
118-58-1	Benzyl salicylate		9/17/2018	Data Commons	GS LT	P1					H-M	L	pC				H		pC	H							Yellow [Triangle] - Fragrances	Chemical of concern	X
8007-75-8	Bergamot oil (furocoumarin free)(Citrus bergamia Risso et Poiteau)		9/17/2018	Data Commons	GS NoGS												pC		pC	pC	pC					pC	unlisted	unlisted	
68411-27-8	C12-15 Alkyl benzoate		9/17/2018	Data Commons	GS LT	UNK																					unlisted	unlisted	
104-54-1	Cinnamic alcohol		9/17/2018	Data Commons	GS LT	P1						M					H		pC	pC							unlisted	Chemical of concern	
84929-26-0	Commiphora myrrha resin extract		9/17/2018	Data Commons	GS NoGS							pC															unlisted	unlisted	
106-02-5	Cyclopentadecanolide		9/17/2018	Data Commons	GS LT	UNK											pC				pC			vH			Half Green [Circle] - Fragrances	unlisted	
141-04-8	Diisobutyl adipate		9/17/2018	Data Commons	GS LT	P1					H-M																unlisted	unlisted	
105-95-3	Ethylene brassylate		9/17/2018	Data Commons	GS LT	P1													pC		pC			vH			Half Green [Circle] - Fragrances	unlisted	
8016-36-2	Frankincense oil		9/17/2018	Data Commons	GS LT	UNK																					unlisted	unlisted	
8050-07-5	Frankincense resin		9/17/2018	Data Commons	GS NoGS																						unlisted	unlisted	
1222-05-5	Galaxolide		4/20/2015	ToxServices	GS BM	1	L	L	DG	L	M	L	L	L	L	DG	L	DG	M	L	vH	vH	H	H	L	L	unlisted	Chemical of concern	
8023-91-4	Galbanum essential oil		9/17/2018	Data Commons	GS NoGS																						unlisted	unlisted	
65997-13-9	Glyceryl hydrogenated rosinate		9/17/2018	Data Commons	GS LT	P1																	vH-H	vH			unlisted	unlisted	X
142-62-1	Hexanoic acid		9/17/2018	Data Commons	GS LT	UNK						H							vH	vH	M						Green [Circle] - Surfactants	unlisted	
101-86-0	Hexyl cinnamal / α-n-Hexyl-β-Phenylacrolein		9/17/2018	Data Commons	GS LT	P1											H		H								unlisted	Chemical of concern	
85186-93-2	hydrolyzed jojoba		9/17/2018	Data Commons	GS NoGS																						unlisted	unlisted	
107-74-4	Hydroxyciol		9/17/2018	Data Commons	GS LT	UNK														pC	pC						unlisted	unlisted	
646-13-9	Isobutyl stearate		9/17/2018	Data Commons	GS NoGS																						unlisted	unlisted	
8016-26-0	Labdanum oil		9/17/2018	Data Commons	GS NoGS																						unlisted	unlisted	
84775-64-4	Labdanum resin		9/17/2018	Data Commons	GS LT	P1																					unlisted	unlisted	

[2] See Supplement Excel worksheet for improve image clarity

CAS #	Common name	Abbreviation	CHA Date	CHA Profiler	CHA type	CHA score	C	M	R	D	E	AT	ST	ST*	N	N*	SnS*	SnR*	IrS	IrE	AA	CA	P	B	Rx	F	US EPA SCIL	EU allergen	CORAP LIST
129811-19-4	Macadamia integrifolia seed oil		9/17/2018	Data Commons	GS NoGS																						unlisted	unlisted	
67634-12-2	Methyl 2-[[(4-(4-hydroxy-4-methylpentyl)-1-cyclohexenyl)methylene]amino]benzoate		9/17/2018	Data Commons	GS LT	P1																		vH			unlisted	unlisted	
8050-15-5	methyl hydrogenated rosin		9/17/2018	Data Commons	GS LT	P1											pC						vH-H	vH			unlisted	unlisted	
68186-14-1	Methyl rosinate		9/17/2018	Data Commons	GS LT	UNK																		vH			unlisted	unlisted	
3391-83-1	Musk lactone		9/17/2018	Data Commons	GS LT	P1															pC			vH			unlisted	unlisted	
81-15-2	Musk xylol (2,4,6-trinitro-5-tert-butyl-m-xylene)		9/17/2018	Data Commons	GS LT	1	M		pC	H-L	H-M									M	vH		vH-H		H	M	unlisted	unlisted	
9000-45-7	Myrrh		9/17/2018	Data Commons	GS NoGS																						unlisted	unlisted	
93686-00-1	Opopanax (1 of 3 CASRN)		9/17/2018	Data Commons	GS NoGS																						unlisted	unlisted	
9000-78-6	Opopanax (gum) (1 of 3 CASRN)		9/17/2018	Data Commons	GS LT	P1																					unlisted	unlisted	
93384-32-8	Opopanax (resin) (1 of 3 CASRN)		9/17/2018	Data Commons	GS NoGS																						unlisted	unlisted	
8007-00-9	Peru Balsam		9/17/2018	Data Commons	GS LT	P1						L					H		H	H							unlisted	unlisted	
122-99-6	Phenoxyethanol		2/1/2016	ToxServices	GS BM	2	L	L	L	M	DG	M	DG	L	M	L	L	DG	L	H	L	L	vL	vL	L	L	Yellow [Triangle] - Preservatives-Antioxidants	unlisted	
25322-68-3	Polyethylene glycol		9/17/2018	Data Commons	GS LT	UNK							pC		pC					pC			vH-H				Green [Circle] - Polymers	unlisted	
61849-72-7	PPG-10 Methyl glucose ether		9/17/2018	Data Commons	GS LT	UNK																	vH-H				unlisted	unlisted	
97488-91-0	shea butter glycerides		9/17/2018	Data Commons	GS NoGS																						unlisted	unlisted	
126-13-6	Sucrose acetate isobutyrate (1 of 3 CASRN)		9/17/2018	Data Commons	GS LT	UNK																		vH			unlisted	unlisted	
137204-24-1	Sucrose acetate isobutyrate (1 of 3 CASRN)		9/17/2018	Data Commons	GS NoGS																						unlisted	unlisted	
27216-37-1	Sucrose acetate isobutyrate (1 of 3 CASRN)		9/17/2018	Data Commons	GS NoGS																						unlisted	unlisted	
1406-66-2	Tocopherol		9/17/2018	Data Commons	GS LT	UNK																					unlisted	unlisted	
9000-64-0	Tolu balsam		9/17/2018	Data Commons	GS LT	UNK													M	H							unlisted	unlisted	
1506-02-1	Tonalide		9/17/2018	Data Commons	GS LT	P1			pC		H-M	pC									pC						unlisted	Chemical of concern	X
61789-91-1	Waxes and waxy substances, jojoba		9/17/2018	Data Commons	GS NoGS																						unlisted	unlisted	
159518-81-7	Waxes and waxy substances, jojoba ethoxylated		9/17/2018	Data Commons	GS NoGS																						unlisted	unlisted	
84-69-5	Diisobutyl Phthalate	DIBP	9/17/2018	Data Commons	GS LT	1			M	H-M	H	pC						M			vH		pC	pC			unlisted	unlisted	
77-89-4	Acetyl triethyl citrate		9/17/2018	Data Commons	GS LT	UNK											pC										unlisted	unlisted	

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