CPSC Staff Statement on the

Toxicology Excellence for Risk Assessment Report,

"Exposure Assessment: Potential for the Presence of Phthalates in Selected Plastics"

September 2015

The report, *Exposure Assessment:Potential for the Presence of Phthalates in Selected Plastics*, presents the findings of research conducted by Toxicology Excellence for Risk Assessment ("TERA") under a contract with the U.S. Consumer Product Safety Commission ("CPSC"). TERA performed this research to summarize available information on the production and use of four types of plastics (i.e., polypropylene [PP, CASRN 9003-07-0], polyethylene [PE, CASRN 9002-88-4], High impact polystyrene [HIPS, CASRN 92161-65-3; 9003-55-8], and Acrylonitrile butadiene styrene [ABS, 9003-56-9]) with regards to the possibility of these plastics containing certain phthalates at concentrations greater than 0.1 percent (1000 ppm).

The 10 specified phthalates are:

- DEHP: di-(2-ethylhexyl) phthalate
- DBP: dibutyl phthalate
- BBP: benzyl butyl phthalate

- DINP: diisononyl phthalate
- DIDP: diisodecyl phthalate
- DnOP: di-n-octyl phthalate
- DIOP: diisooctyl phthalate
- DIBP: diisobutyl phthalate
- DPENP: di-n-pentyl phthalate
- DHEXP: di-n-hexyl phthalate

This research was completed in support of CPSC's work on third party testing burden reduction consistent with assuring compliance. CPSC staff will consider this information in evaluating whether staff could make a recommendation for a Commission determination that the plastics listed do not contain any of the 10 specified phthalates in concentrations above 0.1 percent, and thus, may not require third party testing to assure compliance with section 108 of the Consumer Product Safety Improvement Act of 2008.

This report will be posted on CPSC's website to keep stakeholders informed of the progress of technical research related to the agency's regulatory activities .

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Exposure Assessment: Potential for the Presence of Phthalates in Selected Plastics

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Abbreviations

ABFA	Azodicarbonamide
ABS	Acrylonitrile butadiene styrene
ACGIH	American Conference of Governmental Industrial Hygienists
AEGL	Acute Exposure Guideline Levels
ATH	Aluminum trihydrate
ATP	α-tocopherol
ATSDR	Agency for Toxic Substances and Disease Registry
BBP	Benzyl butyl phthalate
BHT	2,6-di-t-butyl-4-methylphenol
°C	degree Celsius
$CaCl_2$	Calcium chloride
CASRN	Chemical Abstracts Service Registry Number
CD	Compact disc
CDR-CDAT	Chemical Data Reporting-Chemical Data Access Tool
CEPA	Canadian Environmental Protection Act
CPSC	U.S. Consumer Product Safety Commission
CRAVE	Carcinogen Risk Assessment Verification Endeavor
CrO_3	Chromium trioxide
CRT	Cathode ray tubes monitor
DBP	Dibutyl phthalate
DCHP	Dicyclohexyl phthalate
decaBDE	Decabromodiphenyl oxide
DEHA	Di(2-ethylhexyl) adipate
DEHP	Di-(2-ethylhexyl) phthalate
DHEXP	Dihexyl phthalate
DIBP	Diisobutyl phthalate
DINP	Diisononyl phthalate
DIOP	Diisooctyl phthalate
DnOP	Di-n-octyl phthalate
DnPP	Di-n-pentyl phthalate
DOA	Di-n-octyl adipate
DOP	Dioctyl phthalate
DPB	Dibutyl phthalate
DPENP	Dipentyl phthalate
DPP	Di-n-pentyl phthalate
DVD	Digital video disc
ECHA	European Chemicals Agency
EDAP	Alkylamine acid phosphate
$FeSO_4$	Iron (II) sulfate
g/cm^3	Grams per cubic centimeter
g/cm	Grams per centimeter
HDPE	High density polyethylene
HDPP	High density polypropylene

HIPS	High impact polystyrene
HPD	Household Products Database
HSDB	Hazardous Substances Data Bank
IARC	International Agency for Research on Cancer
IFCS	Intergovernmental Forum on Chemical Safety
IPCS	International Programme on Chemical Safety
IRIS	Integrated Risk Information System
ITER	International Toxicity Estimates for Risk
km	Kilometer
KPS	Potassium persulfate
LDPE	Low density polyethylene
LLDPE	Linear low density polyethylene
MDPE	Medium density polyethylene
mg	Milligram
mg/kg	milligram(s) per kilogram(s)
Mpa	Megapascal
mPE	Metallocene polyethylene
NaPS	Sodium persulfate
NBR	Cross-linked nitrile rubber
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
NIH	National Institutes of Health
NIOSH	National Institute for Occupational Safety and Health
NSCEP	National Service Center for Environmental Publications
NTP	National Toxicology Program
OBSH	4,4'oxybis(benzenesulfonyl hydrazide
OECD	Organization for Economic Cooperation and Development
OEHHA	Office of Environmental Health Hazard Assessment
OPPT	Office of Pollution Prevention and Toxics
OSHA	Occupational Safety and Health Administration
PB	Polybutadiene
PC/ABS	Polyvinyl chloride/Acrylonitrile butadiene styrene
PC	Polyvinyl chloride
PE	Polyethylene
PET	Polyethylene terephthalate
PFR	Polyethylene foam resins
PLA/PE	Polylactic acid/polyethylene
PLA	Polylactic acid
PMMA	Polymethyl methacrylate
PP	Polypropylene
ppb	Parts per billion
ppm	Parts per million
ppt	Parts per trillion
proCAT	Pre-catalyst
PS	Polystyrene
PVC	Polyvinyl chloride

RAP	Retarded Anionic Polymerization
REL	Reference Exposure Levels
RfC	Reference concentration
RfD	Reference dose
RTECS	Registry of Toxic Effects of Chemical Substances
SAN	Styrene-acrylonitrile
SLS	Sodium lauryl sulfate
SPIN	Substances in Products in Nordic Countries
SWIR	Short wave infrared
TDDM	Tert-Dodecyl Mercaptan
TERA	Toxicology Excellence for Risk Assessment
$TiCl_4$	Titanium tetrachloride
TPO	Thermoplastic polyolefin
TRI	Toxics Release Inventory Program
TSSC	Para-toluenesulfonyl semicarbazide
µg/g	microgram(s) per gram
µg/L	microgram(s) per liter
µg/ml	microgram(s) per milliliter
U.S. EPA	U.S. Environmental Protection Agency
UHMP	Ultra High Modulus Polyethylene
UHMWPE	Ultra High Molecular Weight Polyethylene
ULDPE	Ultra Low Density Polyethylene
UV	Ultraviolet
VCR	Video cassette recorder
VLDPE	Very low density polyethylene
WEEE	Waste electrical and electronic equipment
WHO	World Health Organization
WSDE	Washington State Department of Ecology
XPE	Cross-linked polyethylene

1 Introduction

The Consumer Product Safety Act (CPSA) requires third party testing of children's products for compliance with the applicable children's product safety rules. This report summarizes available information on the production and use of four types of plastics *(i.e.*, polypropylene [PP, CASRN 9003-07-0], polyethylene [PE, CASRN 9002-88-4], High impact polystyrene [HIPS, CASRN 92161-65-3; 9003-55-8], and Acrylonitrile butadiene styrene [ABS, 9003-56-9]) with regards to the possibility of these plastics containing certain phthalates at concentrations greater than 0.1 percent (1000 ppm). Section 108 of the Consumer Product Safety Improvement Act of 2008 (CPSIA) restricts the presence of six phthalates in children's toys and child care articles: Dibutyl phthalate (DBP), Benzyl butyl phthalate (BBP), and Di-(2-ethylhexyl phthalate (DEHP) may not be present in concentrations above 0.1 percent in accessible component parts of children's toys and child care articles (CPSC, 2014). In addition, the CPSIA set an interim prohibition (in place until the Commission issues a final rule) regarding Diisononyl phthalate (DINP), Di-n-octyl phthalate (DnOP) and Diisodecyl phthalate (DIDP). In accordance with the CPSIA, the CPSC established a Chronic Hazard Advisory Panel (CHAP) to, among other things, make recommendations about the interim ban and about other children's products and other phthalates. The CHAP recommended that Diisobutyl phthalate (DIBP), Di-n-pentyl phthalate (DPENP), Di-n-hexyl phthalate (DHEXP), Diisononyl phthalate (DINP) and Dicyclohexyl phthalate (DCHP) be permanently banned for use in children's toys and child care articles at concentrations greater than 0.1 percent (CPSC, 2014). The CHAP recommended lifting the interim ban on DnOP and DIDP. The CHAP also recommended an interim ban for Diisooctyl phthalate (DIOP) until sufficient toxicity and exposure data are available to assess the potential risks. After the CHAP released its report, CPSC issued a proposed rule proposing most of the restrictions the CHAP recommended, with the exception of an interim ban on DIOP (79 Fed. Reg. 78324 (Dec. 30, 2014)).This report addresses whether the four specified plastics may contain one or more of the specific 11 phthalates at concentrations above the 0.1 percent limit (see Table 1-1).

Table 1-1. Specified Phthalates

Phthalate	**CASRN**
DEHP: di-(2-ethylhexyl) phthalate	117-81-7
DBP: dibutyl phthalate	84-74-2
BBP: benzyl butyl phthalate	85-68-7
DINP: diisononyl phthalate	28553-12-0, 68515-48-0
DIDP: diisodecyl phthalate	26761-40-0, 68515-49-1
DnOP: di-n-octyl phthalate	117-84-0
DIOP: diisooctyl phthalate	27554-26-3

DIBP: diisobutyl phthalate	84-69-5
DPENP: di-n-pentyl phthalate	131-18-0
DHEXP: di-n-hexyl phthalate	84-75-3
DCHP: dicyclohexyl phthalate	84-61-7

The CPSC is seeking information upon which to base a recommendation as to whether specific materials used for children's toys and child care articles can be determined not to contain any of the specified phthalates in concentrations above the 0.1 percent limit, and thus, would not require third party testing to assure compliance to section 108 of the CPSIA.

The CPSC requested that Toxicology Excellence for Risk Assessment (TERA) investigate the factors below:

- The raw materials used in the production of the specified plastics;
- The manufacturing processes used worldwide to produce the plastics;
- Typical applications for the specified plastics in consumer products, especially toys and child care articles, focusing on circumstances where the plastic could contain phthalates at concentrations greater than 0.1 percent;
- The potential use of recycled materials containing the specified phthalates in the production of the plastics; and
- The potential for phthalate contamination during packaging, storage, use, or other factors.

We investigated which plastics are typically used in which applications, why the phthalates might be used in the plastic, and the range of typical concentrations used for each plastic/application. Our investigation consisted of multiple tiers of researching the literature; we did not conduct experimentation. We also sought and reported information on why a specific phthalate may be unlikely to be present in each of the four plastics and explained the reasons why it would not likely be used for that plastic. Our research approach is described in Section 2. Our research was not exhaustive of the worldwide primary literature. We first screened secondary sources for information and supplemented this with information from the primary literature. Our focus was to identify relevant information on the five factors for the specified phthalates in the four plastics in order to address the question of whether PP, PE, HIPS, or ABS used in toys or child care articles may contain any of the specified phthalates in concentrations above 0.1 percent.

1.1 References

CPSC (2014). Prohibition of Children's Toys and Child Care Articles Containing Specified Phthalates. Docket No. CPSC-2014-0033, Consumer Product Safety Commission. pp. 78324-78343, https://federalregister.gov/a/2014-29967.

2 Literature Review Strategy

There are hundreds of thousands of factsheets, books, reports, and manuscripts on plastics. To research each of the four specified plastics for each of the five factors, a multi-tiered approach for collection, review and compilation of the information was undertaken. The five factors include the following:

1. raw materials used in the production of the specified plastics;
2. manufacturing processes for the specified plastics used worldwide;
3. typical applications;
4. potential use of recycled materials containing any of the 11 specified phthalates in the production of the plastics; and
5. the potential for phthalate contamination during packaging, storage, use, or other factors.

The research involved a five-tiered strategy. First (Tier 1), the "universe" of information about plastics was pared down to evaluate sources and literature search strategy for the four specified plastics (*i.e.*, a background search). The next step was to identify and evaluate the authoritative secondary sources to search and screen for each of the five factors for the four plastics (Tier 2). The third tier (Tier 3) was based on the University of Cincinnati (UC) library catalog which was used to evaluate all relevant findings for specified combined terms in Table 2-1. Literature searches for primary literature related to the five factors for the four plastics were conducted (Tier 4). Following preparation of a draft report based on the information gathered in the first four tiers, missing information or "gaps" were identified. The last tier (Tier 5) involved gap-searching of the primary literature to identify missing information not previously located with the research approach used in the earlier tiers. The overall approach for research for this project is shown in Figure 1.

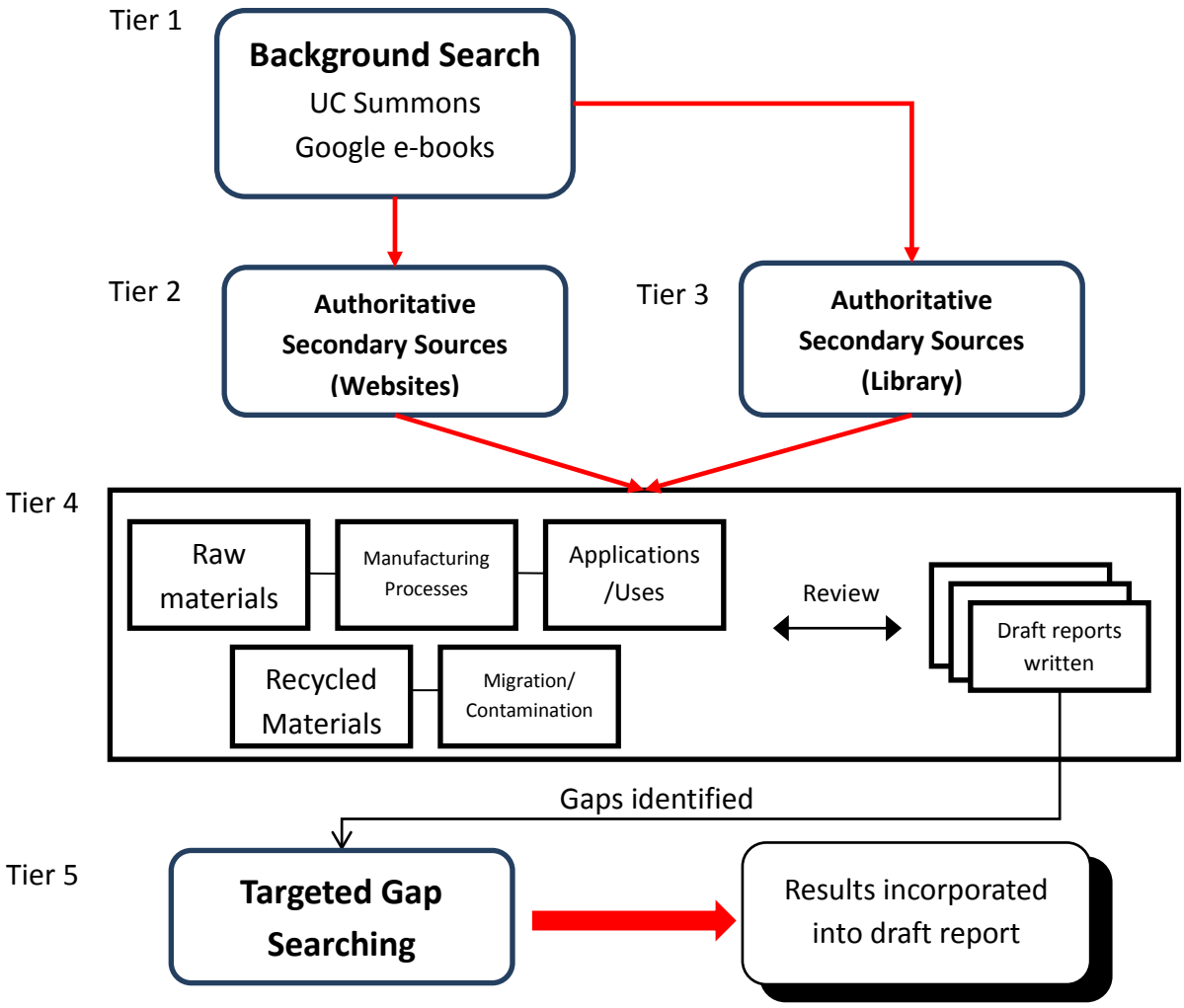

Figure 1. Research Approach for Five Factors for Four Specified Plastics

2.1 Tier 1, Universe of Literature

The purpose of Tier 1 was to gain a broad understanding of the four plastics and begin to narrow down the "universe" of literature so as to focus on information about the five factors and the potential presence of phthalates in the specified plastics.

In Tier 1, a compendia or reviews of literature on the plastics in reference books, journal articles, encyclopedias, handbooks, and dissertations were searched with the University of Cincinnati "Search Summon™" resource (provides a Google-like search). This service allows one to quickly search, discover, and access reliable and credible library content. It provides instant

access to the breadth of library holdings in one relevancy–ranked list. To supplement and identify sources that were not available within the UC library, the Google e-book search was also used.

To evaluate the universe of literature on the four plastics, we used the chemical name and/or Chemical Abstracts Service Registry Number (CASRN). This search provided a wealth of information (see Table 2-1 below). As these websites both search and provide content based on relevance to search terms, the first 100 items in Summon™ and the first two pages of Google eBooks were evaluated for content based on title, or abstract or Table of Contents.

The Summon™ search was refined by: 1) limiting to the book catalog, 2) limiting to articles from scholarly publications, including peer-review, and 3) limiting content type to journal articles, conference proceedings, and book chapter/book/ebook, and dissertations in English from 2010-2015.

Table 2-1. Evaluation of the Universe of Literature (Tier 1)

Search Strategy	**Summon™[A]**	**Google e-books[B]**
Polyethylene OR 9002-88-4	149,472	79,600,000
Polypropylene OR 9003-07-0	67,373	27,700,000
High impact polystyrene OR 9003-55-8 OR 92161-65-3	530,000	530,000
Acrylonitrile butadiene styrene OR 9003-56-9	2,200	471,000
Total for 4 plastics	749,045	108,301,000
Acrylonitrile butadiene styrene AND "phthalate*"	18	≈ 100
Polyethylene AND "phthalate*"	163	≈ 100
High impact polystyrene AND "phthalate*"	55	≈ 100
Polypropylene AND "phthalate*"	103	≈ 99
Total for 4 plastics AND phthalate	339	399
Polyethylene OR 9002-88-4 AND Manufacturing	149,472	79,600,000
Polypropylene OR 9003-07-0 AND Manufacturing	67,373	27,700,000
High impact polystyrene OR 9003-55-8 OR 92161-65-3 AND Manufacturing	530,000	530,000
Acrylonitrile butadiene styrene OR 9003-56-9 AND Manufacturing	2,200	471,000
Total for 4 plastics AND manufacturing	747,045	108,301,000

[A]Number of hits related to search terms. Summons restrictions used included: limit to articles from scholarly publications, including peer-review; journal article; polymers as subject terms; 2010-2015.

[A1] Number of hits related to search terms. Summons restrictions used included: limit to articles from scholarly publications, including books/ebook or cook chapters, any subject terms; 2010-2015.

[B]Number of hits related to search terms. Google restrictions included: 2010-2015, books

* = wildcard Boolean operator

An introduction to the plastics literature was obtained with Tier 1, and preliminary materials were obtained. As shown in Table 2-3, while the search strategy using specified key terms in Table 2-4 was very broad, it yielded useful information to initiate the report on the four specified plastics.

2.2 Tier 2, Reviewing Authoritative Secondary Sources (Websites)

The purpose of Tier 2 was to identify from secondary sources from authoritative agencies or organizations throughout the world that could have reports or other information of relevance to this project.

In a previous report for CPSC on phthalates in consumer products, useful information for raw materials, manufacturing, applications and potential contamination/migration was obtained from authoritative secondary sources based on a search of the World Wide Web. Thus, we screened 48 websites used for that task for authoritative secondary sources such as reviews, factsheets, regulatory documents or risk assessments that could provide relevant information for the specified plastics in this project.

Tier 2 searches of the Internet for authoritative secondary sources using chemical name, acronym and/or CASRN were conducted for each of the specified plastics. Searches were conducted approximately from May 2015 to August 2015. Table 2-2 shows the acronyms, chemical name and CASRN for plastics searched in Tier 2.

Many of the sources from government regulatory agencies contained information or reports of chemical agents and were familiar to TERA. When government agencies or organizations have multiple offices, a detailed examination of the different sites for the agency was conducted. While we searched only in English, we identified sources from all over the world. We formed the search strategy for potentially relevant phthalate-specific information on the five factors that would be applied in Tier 4 based, in part, on our findings in this tier.

The 48 sites were pared down to 18 sites, which were further evaluated for relevance (the sites are listed in Appendix A). From the 18 sites, a subset of nine sources was selected containing potentially relevant information for the five factors for the four specified plastics. In Tier 2, this subset of nine sources was searched using key words for the five factors for each phthalate. Table 2-3 shows the five factors stratified by the subset of nine relevant sources. No information for migration or contamination was found in the nine websites in Tier 2.

Table 2-2. Tier 2 Secondary Literature Search Terms

Chemical	CASRN	Abbreviation
Polypropylene	9003-07-0	PE
Polyethylene	9002-88-4	PP
High impact polystyrene	9003-55-8, 92161-65-3	HIPS
Acrylonitrile butadiene styrene	9003-56-9	ABS

Table 2-3. Information for Six Factors Gathered from Nine Relevant Websites in Tier 2

Database	Raw Materials	Manufacturing Process	Applications	Recycled Materials	Migration / contamination[M]
EPA[A,B,C,D] (CDR, NCCSEP, OPPTS, Science Inventory)		√	√	√	
Haz-Map[E]			√		
Health Canada[F] (HC)			√		
HSDB[G]	√	√	√		
NIOSH[H]	√	√	√		
IARC[I]	√	√	√		
OECD[J]		√	√		
Applications					
HPD[K]			√		
SPIN[L]			√		

[A]EPA NSCEP http://www.epa.gov/nscep/
[B]EPA CDR-CDAT http://java.epa.gov/oppt_chemical_search/
[C]EPA Science Inventory http://cfpub.epa.gov/si/
[D]EPA OPPT http://iaspub.epa.gov/apex/pesticides/f?p=INERTFINDER:1:1395578990735::NO:1:
[E]HazMap http://hazmap.nlm.nih.gov/index.php
[F]Health Canada http://www.hc-sc.gc.ca/index-eng.php
[G]HSDB http://toxnet.nlm.nih.gov/newtoxnet/hsdb.htm
[H]NIOSH http://www.cdc.gov/niosh/topics/
[I]IARC http://monographs.iarc.fr/ENG/Monographs/PDFs/index.php
[J]eChemPortal http://www.echemportal.org/echemportal/participant/page.action?pageID=9
[K]HPD http://householdproducts.nlm.nih.gov/cgi-bin/household/searchall
[L]SPIN http://195.215.202.234/fmi/xsl/spin/SPIN/maininfo.xsl?-db=SPINstof&-lay=SPINnavn&-view
[M] No references regarding migration or contamination were found

2.3 Tier 3, Reviewing Authoritative Secondary Sources (Library)

The purpose of Tier 3 was to identify books that could serve as authoritative secondary sources for information about the five factors for the four plastics and the presence or absence of phthalates in the specified plastics. Tier 3 utilized the extensive UC Book catalog to identify relevant books or other secondary sources from the UC Library.

The number of hits from books identified within the UC Book Catalog obtained with key words relevant to the project (such as child, toy, phthalate, recycle) and published after 2010 is shown in Table 2-4. This material was reviewed either by Title or from the Table of Contents for the key words identifying any of the specified plastics and/or five factors. These books were either checked out of the library or obtained through online UC library resources and further evaluated for utility with the subject matter. Approximately 24 books were used throughout this report and are shown in Appendix B.

Table 2-4. Tier 3 resources reviewed from UC Book Catalog

Key Words	**No. of hits**
	UC Book Catalog **2010-2015**
Polyethylene OR 9002-88-4	69
(Polyethylene OR 9002-88-4) NOT ("polyethylene glycol")	61
Polypropylene OR 9003-07-0	41
(High impact polystyrene) AND (9003-55-8) OR (92161-65-3)	5
Acrylonitrile butadiene styrene OR 9003-56-9	3
Total for 4 plastics	110
(Polyethylene) and (child*)	0
(Polypropylene) and (child*)	0
(High impact polystyrene) and (child*)	0
(Acrylonitrile butadiene styrene) and (child*)	0
ANDs	
Acrylonitrile butadiene styrene AND toy	0
Polyethylene AND toy	1
High impact polystyrene AND toy	0
Polypropylene AND toy	1
Total for 4 plastics AND toy or AND child	2

(Polypropylene) and (phthalate)	1
(Polyethylene) and (phthalate)	1
(Acrylonitrile butadiene styrene) and (phthalate)	0
(High impact polystyrene) and (phthalate)	0
Total for 4 plastics AND phthalate	2
(polyethylene) and (recycl*)	1
(Polypropylene) and (recycl*)	6
(High impact polystyrene) and (recycl*)	0
(Acrylonitrile butadiene styrene) and (phthalate)	0
recycl* AND polymer	43
Total for 4 plastics AND recycl	50

2.4 Tier 4, Literature Searching

The purpose of Tier 4 was to search the worldwide primary literature to locate required information not found in the approaches used in the earlier tiers. TERA searched the CAB Abstracts (www.cabdirect.org), Scopus (www.scopus.com), SciFinder (www.scifinder.cas.org), and Web of Science (www.webofscience.com) for primary literature for the five factors for the four specified plastics. No date limiter was placed on the searches. An example of the search table for the database results is shown in Table 2-5. The keywords searched and resultant hits for each search string are found in Appendix C. All hits for each search string were recorded, saved, and downloaded into a raw Endnote library. After an initial prescreen to remove duplicates, extraneous, and irrelevant studies, a second, more thorough screening was performed to determine relevancy and likelihood for a study to contain phthalate concentration data.

TERA first screened the literature search results for relevance (removing those studies that obviously were not relevant to this research), and then reviewed the potentially relevant studies for the information lacking for the factors(s) for each plastic. Screening of the literature search focused on English language articles in accessible and reputable journals; literature in obscure journals, or in foreign language articles were not obtained for this report. Screening of patent literature was limited to patents for application or use of the four specified plastics.

Table 2-5. Search Table using Polyethylene as an example

Name of Database	
Date Conducted	
Limits placed on search	(if any)

Search terms	Search String	Total number of hits
Polyethylene		
Polyethylene AND		
phthalates	(Polyethylene OR 9002-88-4) refined with topic “phthalate” AND “contamination”	
toys	(Polyethylene OR 9002-88-4) refined with topic “phthalate” AND “toy”	
Child care articles	(Polyethylene OR 9002-88-4) refined with topic "child care"	
Child care articles	(Polyethylene OR 9002-88-4) refined with topic "car seat" OR "crib" OR "baby bed"	
Child care articles	(Polyethylene OR 9002-88-4) refined with topic “phthalate” (“pacifier” OR "teether")	
Consumer products	(Polyethylene OR 9002-88-4) refined with topic “phthalate” "consumer product"	
packaging	(Polyethylene OR 9002-88-4) refined with topic “phthalate” AND “packaging”	
contamination	(Polyethylene OR 9002-88-4) AND (contaminat* OR leaching OR migration)	
manufacturing	(Polyethylene OR 9002-88-4) AND (manufactur*)	
Recycled materials	(Polyethylene OR 9002-88-4) AND (recycl* AND material*)	
RECYCLED POLYMER		
DEHP	(Polyethylene OR 9002-88-4) AND (DEHP OR di-2-ethylhexyl phthalate OR 117-81-7)	
DBP	(Polyethylene OR 9002-88-4) AND (DBP OR dibutyl phthalate OR 84-74-2)	
BBP	(Polyethylene OR 9002-88-4) AND (BBP OR benzyl butyl phthalate OR 85-68-7)	
DINP	(Polyethylene OR 9002-88-4) AND (DINP OR diisononyl phthalate OR 28553-12-0 OR 68515-48-0)	
DIDP	(Polyethylene OR 9002-88-4) AND (DIDP OR diisodecyl phthalate OR 26761-40-0 OR 68515-49-1)	
DnOP	(Polyethylene OR 9002-88-4) AND (DnOP OR di-n-octyl phthalate OR 117-84-0)	
DIOP	(Polyethylene OR 9002-88-4) AND (DIOP OR diisooctyl phthalate OR 27554-26-3)	
DIBP	(Polyethylene OR 9002-88-4) AND (DIBP OR diisobutyl phthalate OR 84-69-5)	
DPENP	(Polyethylene OR 9002-88-4) AND (DPENP OR di-n-pentyl phthalate OR 131-18-0)	

DHEXP	(Polyethylene OR 9002-88-4) AND (DHEXP OR di-n-hexyl phthalate OR 84-75-3)	
DCHP	(Polyethylene OR 9002-88-4) AND (DCHP OR dicyclohexyl phthalate OR 84-61-7)	

2.5 Tier 5, Gap Searching

The purpose of Tier 5 was to conduct specific, targeted searches to double check for information to fill in gaps identified as the draft sections for each plastic were being written.

Gaps included information for the four specified plastics in toys and child care articles, and for each phthalate in the specified plastic to ascertain if any data were available. TERA conducted Internet searches to fill any remaining data gaps, primarily through Google (www.google.com) and Google Scholar (www.scholar.google.com). Based on the phthalate and type of information still needed, searches were performed using CASRN, chemical names, and keywords. Results were reviewed until ten consecutive non-relevant hits were returned in the results list, at which point TERA ceased reviewing any further results.

3 Polypropylene CASRN: 9003-07-0

Polypropylene (PP) is a typical saturated linear polymer that is widely used in many applications due to its excellent properties including stiffness, heat resistance and processability. PP plastic has light weight material density and also a relatively low price (Sato and Ogawa, 2009).

3.1 Raw Materials Used in Production of Polypropylene (PP)

Several additives may be blended with PP polymer, but phthalates are not used as additives. However, Ziegler-Natta catalysts are used in the production of PP. These catalysts are prepared using magnesium- and titanium (IV) chloride, and an internal donor, which is very often a phthalate like dibutyl phthalate (DBP), diisobutyl phthalate (DIBP) or bis(2-ethylhexyl) phthalate (DEHP) (Borealis, 2014). These catalysts may survive the polymerization process and the phthalates may theoretically be present in concentrations of about 1 mg/kg in the final pellets. However, based on test results, the phthalate values do not exceed 0.15 mg/kg PP (0.15 ppm, or 0.00001 weight %), and they are often below the threshold of the analytical method of 0.01 mg/kg PP (or 0.000001 weight %) (Borealis, 2014); both values are significantly below the regulated level of 0.1% for these phthalates.

3.2 Raw Materials Used in making Virgin PP Resin

The raw materials used in making virgin PP include (Campo, 2015):

- PP monomer and ethylene and other monomers;
- Hydrocarbon solvent: hexane or heptane;
- Catalysts: for example, Ziegler-Natta catalyst, titanium-based catalyst and a second co-catalyst (triethylaluminium);
- Nucleating agents or fillers: talc, calcium carbonate or fiber glass; and

Other additives including primary and secondary antioxidants, neutralizing agents, antistatic agents, slip agents, metal deactivators, quenchers, ultraviolet (UV) stabilizers, nucleating agents, flame retardants, colorants, antiblocking agents, lubricants, and blowing or foaming agents.

3.3 Manufacturing Processes used Worldwide to Produce PP

There are three types of PP structures that differ in properties depending on the way in which the polymers can pack together (Campo, 2008; Bart, 2005):

1. Isotactic PP, whose properties may further be increased with nucleating agents or fillers, such as talc, calcium carbonate, or fiber glass;
2. Syndiotactic PP, that is produced by the monomer units inserted alternatively head-to-tail; and
3. Atactic PP, (noncrystalline polymers where the methyl groups of propylene units are arranged irregularly on the chain), a by-product of the manufacturing process (Campo, 2008).

To stabilize all forms of PP against thermal degradation, additives are used. However, none of the specified phthalates are additives in the manufacturing processes for PP. The following additives (Campo, 2008; Bart, 2005; Maier and Calafut, 1998) may be used:

- Primary antioxidants (mainly hindered phenol, such as butylated hydroxytoluene (2,6-di-t-butyl-4-methylphenol or BHT) or hindered amine light stabilizers such as α-tocopherol (ATP or Vitamin E); and
- Secondary antioxidants (most common being phosphites and thioesters) (Maier and Calafut, 1998; Equistar, 2015).

Other special additives may be added (Campo, 2008; Bart, 2005; Maier and Calafut, 1998), such as:

- Neutralizing agents: calcium and zinc stearate, zeolites, calcium and zinc oxides, and metallic salts of lactic or benzoic acid;
- Antistatic agents: cationic compounds (such as quaternary ammonium, phosphonium, or sulfonium salts); anionic compounds (usually sodium salts of sulfonates, phosphates, and carboxylic acids; nonionic compounds, such as glycerol monostearate;
- Slip agents: modified fatty acids or fatty amides, especially erucamide and oleamide;
- Metal deactivators: N,N'-dibenzaloxaldihydrazide;
- Quenchers: organic nickel complexes such as [2,2'-thiobis(4-oxtylphenolato)]-n-butalamine nickel (II), nickel salts of thiocarbamate, and nickel complexes with alkylated phenol phosphonates;
- UV stabilizers: hindered amine light stabilizers (e.g., tetramethyl piperidine – also functions as quenchers, free radical scavengers, or peroxide decomposers), carbon black, titanium dioxide, zinc oxide, derivatives of benzophenone (such as 2-hydroxy-4-octosybenzophenone), benzotriazoles (based on 2-(2'-hydroxyphenyl)benzotriazole), phenyl or aryl esters (salicylates, resorcinol monobenzoates, aryl or alkyl benzoates), formamidines, oxanilides, and acrylic esters;
- Nucleating agent: carboxylic acids, benzyl sorbitols, and salts of organic phosphates;
- Flame retardants: brominated flame retardants, such as decabromodiphenyl oxide or ether (decaBDE), octabromodiphenyl oxide, ethylenebistetrabromophthalimide,

ethylenebisdibromonorbornanedicarboximide, or cycloaliphatic chlorines. Antimony trioxide, ferric oxide, zine oxide, zinc borate, and barium metaborates have no flame retardant properties, but are generally added to halogenated flame retardants for a synergistic effect. Phosphorus flame retardants composed of ammonium polyphosphate and alkylamine acid phosphate (EDAP), as well as magnesium hydroxide and aluminum hydroxide (also called aluminum tirihydrate, ATH) are used.

- Colorants: dyes and pigments (oxides, sulfides, chromates and other complexes based on heavy metals such as cadmium, zinc, titanium, lead, and molybdenum; ultramines (sulfide-silicate complexes containing sodium and aluminum; azo pigments);
- Antiblocking agents: natural and manufactured waxes, metallic salts of fatty acids, silica compounds, or polymers such as polyvinyl alcohol, polyamides, polyethylene, polysiloxanes, and fluoroplastics;
- Lubricants: metal soaps, hydrocarbon waxes, polyethenes, amide waxes, fatty acids, fatty alcohols, and esters (calcium or zinc stearates); and
- Blowing or foaming agents: sodium bicarbonate (the most common), sodium borohydride, polycarbonic acid, citric acid, 4,4'oxybis(benzenesulfonyl hydrazide) (OBSH), azodicarbonamide (ABFA), or para-toluenesulfonyl semicarbazide (TSSC).

Three methods of PP production were described by Saravanan and Sulaiman (2014), as briefly described below.

1. Slurry Polymerization (also called solvent polymerization)- the common manufacturing process when PP production started, involves carrying out the polymerization in an inert hydrocarbon solvent such as hexane or heptane, which eliminates catalyst activity.
2. Bulk polymerization (or mass polymerization) - the common manufacturing process that followed the slurry polymerization process, unlike slurry polymerization, does not need the use of hexane or heptane solvents. Instead, it uses higher pressure and liquefied propylene as the diluent for the slurry. It eliminates unwanted products of the polymerization reaction.
3. Gas phase polymerization process- the primary current process used in which the propylene and solid catalyst (such as Ziegler-Natta catalysts) are contacted together and then polymerization takes place in either the fluidized-bed reactor or the stirred bed process at the higher pressure as used in bulk polymerization. This process is a more convenient process in production of homopolymer and copolymer and is the most common process used in modern plants among the several processes in polypropylene production.

According to Sato and Ogawa (2009), PP manufacturing primarily consists of a raw material refining process, polymerization process, after-treatment process and granulation process. The

raw material refining process eliminates minute amounts of impurities that affect the process, such as water, oxygen, carbon monoxide, carbon dioxide, and carbonyl sulfide a from the propylene and other monomers as well as the solvents and other raw materials and auxiliary materials used. The polymerization process brings the propylene and, if necessary, ethylene and other monomers into contact with a catalyst having polymerization activity. The after-treatment process eliminates catalyst residue (a process known as deashing), the solvent and atactic polymers from the PP particles obtained in the polymerization process. The granulation process involves melting and kneading additives and fillers (e.g., decaBDE, calcium carbonate, talc, mica, barite, glass spheres, carbon and glass fibers, wollastonite (calcium metasilicate, composed of calcium oxide and silicon dioxide), wood flour) (Maier and Calafut, 1998) into the PP particles that have undergone the after-processing and forming pellets.

3.3.1 Processing

PP resins can undergo a melt processing that is achieved via extrusion and molding processes (Kissel et al., 2003). The extrusion processes produce fibers (slit film or slit tape), sheet, films (cast and oriented), and yarns. Injection molding, the most common shaping technique, involves softening the polymer and pushing it through a runner system into a cavity or multiple cavities of a mold. This technique is used for consumer items (such as food storage containers and sport/exercise water bottles), which take many shapes and sizes.

3.4 Applications for Polypropylene in Consumer Products

Overall, PP is considered a “stiff” plastic (particularly as compared to PE) and has high abrasion resistance and hardness, considerations in end use applications (Strong, 2006). These properties and the higher temperature stability of polypropylene, as well as its resistance to cracking, make it useful for many applications.

3.4.1 Toys and Child Care Articles

HPD (2015) reported PP use in diapers, but the concentration was not reported. In toys, PP was reported as the most common plastic used in injection molded toys. PP-made toys represent approximately 38% of the injection molded toy market in the North America (Rosato, 2011).

Patents were found that reported PP uses, including: in a car seat (Cheng, 2010), in backpacks for carrying infants, folding baby strollers, and folding baby beds (Gunter, 1978), toy building blocks (Augenstein, 2006), in a swimming pool toy (Parucker, 2010), and in bed pads and baby changing pads (Sherrod et al., 2003). One patent reported the use of atactic PP in colored modeling clay useful for crafts and toy products that also included DBP (proportions not

provided) (Yokoyama et al., 1978). One study tested a number of PP baby bottles and because migration of phthalates (DBP and DIBP) was reported, one could assume that those specific phthalates were in the bottles (Onghena et al., 2014). However, phthalate concentrations were not provided.

3.4.2 Other Consumer Products

General use of PP in consumer products are reported from two databases, Household Products Database (HPD, 2015) and Substances in Products in Nordic Countries (SPIN, 2015), and several relevant references are summarized here. As such, this is not an exhaustive review of the consumer product uses for PP, but is a representative sample of worldwide uses or applications of PP in consumer products.

Due to its characteristics of hardness, abrasion resistance and high temperature resistance, PP is used in medical devices that would be sterilized at high heat and pressure, dishwasher safe containers, and appliance parts (Strong, 2006). PP also has a high resistance to cracking (it is bendable), and is used in carpets, rope, strapping tape, hinges, and molded items (Strong, 2006).

HPD (2015) reported PP use in a number of consumer products, including: insulation, toner, stain removers, dusting products, plastic storage bags and cooking bags, glass cleaner, plastic storage containers, and face creams and cleansers. The percentage of PP was not uniformly reported for these products; when it was, concentrations ranged from 4 to -25 percent. Phthalates were not reported in PP for these applications; it was not clear if the products were tested for phthalates.

SPIN (2015) reported PP in a number of use categories, including: as a raw material or intermediate in the production of plastic and rubber materials, plastic construction materials, in mortars (such as cement and concrete), as a binding agent or hardener (in paints, adhesives, etc.), as an additive, filler, hardener, or thinner (in paints, lacquers, and varnishes, etc.), in toner and printing inks, in flooring materials, in wall construction materials, in degreasers, as a stabilizer, in cleaning/washing agents, in dyes and pigments, in electrical insulation materials, in lubricating grease and oil, as an antistatic agent, in polishing agents, as a ‘stopping material’ (not further defined), as a corrosion inhibitor, in office products, and in sealing compounds. PP was reported as the most common plastic to use for secondary packaging (Snedeker, 2014). Snedeker (2014) reported the use of polypropylene (polyolefin thermoplastics) in food contact materials in microwavable containers, yogurt containers, bottles, and straws, including plastic water bottles. The authors report that PP (as a substituted polyolefin) has frequent use in food packaging that requires heat resistance (such as microwaveable containers and trays) (Snedeker, 2014). These authors also report PP use in textiles, carpets, and coatings, and in polyamide, thermoplastic polyolefins for use in rope and cords (Snedeker, 2014).

In another report, PP was reported as one of the plastic resins most used in packaging (including almost exclusive use in DVD packaging) (Rosato, 2011). These authors report high usage in the auto industry, and also reported uses in vacuum cleaner housings (Rosato, 2011). Other reported uses include packaging (flexible packaging films), textiles (as a filament in fabrics including tapes for textiles, carpeting, carpet backing, and medical fabrics), automotive (interior and exterior components), medical and personal care products (for use in hygiene and household goods), bottles (injection molded), and consumer products (caps, spray bottles, packaging, toys, electrical products, appliance components, outdoor furniture, luggage, and others) (Campo, 2008). PP has high use in injection molded consumer products and in injection-molded furniture (Rosato, 2011).

3.5 Potential Use of Recycled Materials Containing Phthalate in Production of Polypropylene

The use of recycled materials containing phthalates could be a potential source of phthalates in products made from PP. In addition, the recycling of PP itself with phthalates present has the potential to disseminate phthalates amongst various products. While phthalates in products is theoretically possible, no data were found in the searches conducted for this project.

Polypropylene (PP) is not often recycled because of the low cost of virgin PP and the high cost of the recycling process which requires expensive separation processes (Merrington, 2011). For example, the amount of PP in carpet recycling streams has decreased from 22% in 2006 to 8% in 2007 and 2008 (Merrington, 2011).

Damaged food contact crates made of PP are commonly reused. The end product of recycled PP crates is blended with virgin PP or used up to 100%, for new PP crates that are intended for long term storage of whole fruits and vegetables and of prepacked meat (EFSA (European Food Safety Authority), 2015). The old damaged crates are precleaned, ground into flakes from which metal parts are removed, and rewashed, before and after grinding. Flakes are further washed, centrifuged, sieved and finally dried before they are then melted and injected into a mold where it hardens. An extrusion process frequently forms the final products, where the melted plastic is forced through an orifice. The temperature of the process subjects PP to thermoxidation (Zitting, 1998).

The carpeting and battery industries use recycled PP and have played a role in developing uses of recycled PP. The PP from carpet and carpet backing are used to make recycled carpet waste pellets that can contain PP at 10 percent (Rosato, 2011). While other potential toxicants have been detected in carpet, there were no phthalates found in a study by Greenpeace Research

Laboratories et al. (2001). There was one study that detected DEHP in recycled PP (Camacho and Karlsson, 2000); however, the levels were not specified.

A reported use for recycled PP includes single-use plastic pallets (Rosato, 2011). Recycled carpet waste pellets can contain polypropylene at 10 percent (Rosato, 2011).

3.6 Potential Phthalate Contamination

While plasticizers are used in PP to improve film flexibility, clarity and gloss, facilitate molding and increase strength, phthalates are not amongst those plasticizers used in PP (Wypych, 2012). The Toy Industry Association (TIA (Toy Industry Association Inc.), 2013) reported that toys made with PP are compliant with the phthalate standard. Further, to add phthalates to this resin would cause deterioration of the physical properties for which the resins were selected; however, no data or documentation was provided as the basis for this assertion.

Information on migration or contamination of phthalates in PP was difficult to locate in the literature. Studies either reported no phthalates in PP or very low levels (in the ppb or ppt range).

Camacho and Karlsson (2000) analyzed contaminants in recycled resins of PP from mixed solid waste. Fragrances, flavorants, ethylbenzene and xylenes were constituents in the recycled materials; no phthalates were reported. Chang et al. (2015) analyzed for 22 phthalates in plastic beverage packaging (included water and milk containers, but specific type of plastic was not reported). Concentrations of DNOP, DIBP and DEHP in the ppt range were reported in one, three and one, respectively, of 11 containers.

Di Bella et al. (2014) reported phthalates (DBP and DEHP) at approximately 3-12 ppb in coffee capsules (made of PS, PE and PP) coffee pods and moka pots, suggesting phthalates could leach from these materials into coffee. When water was microwaved in a PP container for up to 10 minutes, less than 6 ppb of several phthalates were reported (Lee et al., 2011). Thomas et al. (2014) reported that DEHP in ppb concentrations can migrate from PP packaging into cosmetics. In a Japanese report with an English abstract and tables, Kawamura et al. (2000) found BBP at less than 0.01 percent (76 ppm) in a PP pouch and DINP at 0.2 percent (2000 ppm) in a PP pudding cup (no other details were provided regarding the cup or PP content).

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4 Polyethylene CASRN: 9002-88-4

Polyethylene (PE) is a thermoplastic polymer that can be produced by employing different polymerization processes. Each of these processes result in a different type of PE (Carraher, 2011). Each type is categorized according to their density and molecular structure. Although PE polymers often can be used without additives, additives may be needed for specific applications (Brydson, 1999); none of the additives contain phthalates. Ziegler-Natta catalysts are used in the production of PE. These catalysts are prepared using magnesium- and titanium (IV) chloride, and an internal donor, which is very often a phthalate like dibutyl phthalate (DBP), diisobutyl phthalate (DIBP) or bis(2-ethylhexyl) phthalate (DEHP) (Borealis, 2014). As these catalysts may survive the polymerization process, the listed phthalates may theoretically be present in concentrations of about 1 mg/kg (1 ppm, or 0.0001%) in the final pellets (Borealis, 2014). However, no actual tests were identified that estimated the phthalate levels in PE plastics. Bhunia et al. (2013) and Wypych (2012) also reported that plasticizers for PE include several of the specified phthalates of interest for this report, diisobutylphthalate (DIBP) di-n-butylphthalate (DBP), and dioctyl phthalate (DOP) (which isomer not specified).[1] However, concentrations of these phthalates were not reported in test results.

4.1 Raw Materials Used in Production of Polyethylene (PE)

There are three types of PE resins[2] (Campo, 2008; Olabisi and Adewale, 1997): high density PE (HDPE), low density PE (LDPE), and linear low density PE (LLDPE). The raw materials used in making a virgin PE resin include:

- PE monomer or copolymers of ethylene, ethylene-octene copolymers, and/or an alpha-olefin monomer such as propene (propylene), 1-butene, 1-pentene, 1-hexene, 1-heptene, 1-octene, 1-decene, 1-tetradecen, or methyl-4-pentene-1;
- Initiators: benzoyl peroxide, azodi-isobutyronitrile or oxygen;
- Promoters: sodium and calcium (as either metals or as hydrides);

[1] DOP is a common abbreviation for di-(2-ethylhexyl) phthalate (DEHP). This term may also refer to a class of phthalate esters that includes diisooctyl phthalate (DIOP), di-n-octyl phthalate (DnOP), and DEHP.

[2] Other PE resins mentioned in the literature include medium density PE (MDPE), Ultra Low-Density Polyethylene (ULDPE), Metallocene Polyethylene (mPE), Bimodal Grades, UV-Stabilized Grades, Crosslinked Polyethylene (XPE), Ultra High Molecular Weight Polyethylene (UHMWPE), Ultra High-Modulus Polyethylene, and Polyethylene Foam Resins. All of these PE materials are identified by the same CASRN.

- Catalysts: Ziegler-Natta, triethylaluminum plus a metallic salt ($TiCl_4$), chromium oxides (mainly CrO_3), silica-alumina catalyst, molybdenum oxide, metallocene catalysts (zirconium or titanium);
- Additives (Brydson, 1999)
    - Fillers: silane and titanate coupling agents;
    - Pigments: pigments based on cobalt, cadmium and manganese;
    - Flame retardants: antimony trioxide and a number of halogenated materials;
    - Anti-blocking agents: fine silicas;
    - Slip agents: fatty acids such as oleamide and erucamide;
    - Blowing agents: 4,4'-oxybisbenzenesulfonohydrazine or azocarbonamide;
    - Cross-linking agents: dicumyl peroxide or vinyl silanes;
    - Antioxidants: 4-methyl-2,6-t-butyl phenol, 1,1,3-tris-(4-hydroxy-2-methyl-5-butylphenyl)butane (Topanol CA), or bis-[2-hydroxy-5-methyl-3-(1-methylcyclohexyl)phenyl]methane (Nonox WSP), dilauryl-β,β'-thiodipropionate (DLTP);
    - Plasticizers: di-n pentyl phthalate (DPP, DPENP), bis(2-ethylhexyl) adipate (DEHA), di-n-octyl adipate (DOA), DEP, DIBP, DBP, DOP (isomer not specified), glyceryl tribenzoate, polyethylene glycol, sunflower oil, paraffin wax, paraffin oil, mineral oil, glycerin, EPDM rubber, and EVA polymer (Bhunia et al., 2013; Wypych, 2012);
    - Carbon black; and
    - Antistatic additives: polyethylene glycol alkyl esters; others are proprietary.

4.2 Manufacturing Processes used Worldwide to Produce PE

There are five distinct routes to the preparation of polymers of ethylene (Brydson, 1999), but it is not clear whether these processes are used worldwide:

1. High-pressure processes that involve production of the PE polymer, using a free-radical initiator (such as benzoyl peroxide, azodi-isobutyronitrile or oxygen), and water or inert liquid (such as benzene) to prevent a runaway reaction. Most high pressure polymers are of the lower density range for PEs (0.915 – 0.94 g/cm^3) and usually also of the lower range of molecular weights.

2. In the Ziegler processes (also referred to as co-ordination polymerization), a catalyst (e.g., TiCl4) is used. Reaction is carried out at some temperatures below 100 ºC (typically 70 ºC) in the absence of oxygen and water. The Ziegler polymers are intermediate in density (about 0.945 g/cm^3) between the high-pressure PEs and those produced by a large Indiana oil company processes.

3. The above process involves dissolving ethylene in liquid hydrocarbon (such as cyclohexane); the ethylene is polymerized by a supported metal oxide catalyst (CrO_3) at about 130-160 ºC and at about 1.4-3.5 MPa pressure. Raising the polymerization temperature from 140 ºC to just over 170 ºC can result in a lower molecular weight polymer, whereas polymerization carried out at about 90-100 ºC results in the preparation of polymers of higher molecular mass.

4. The process in #3 above has many similarities to the process in #2 above process and is based on the use of a supported transition metal oxide (molybdenum oxide) in combination with a promoter (including sodium and calcium as either metals or as hydrides). Reaction temperatures are 230 – 270 ºC and pressures are 4.05 – 8.10 MPa. The reaction is carried out in a hydrocarbon solvent (not specified). The products of the process have a density of about 0.96 g/cm^3, similar to the process #2 polymers. Another similarity between the processes is the marked effect of temperature on average molecular weight.

5. Metallocene processes. These processes are used for making LLDPE and mPE (metallocene PE). One of these processes is a gaseous phase process where gaseous monomers and a catalyst are fed to a fluid bed reactor at pressures of 0.7-2.1 MPa at temperatures of 100 ºC and below. The short branches are produced by including small amounts of propene, but-l-ene, hex-l-ene or oct-l-ene into the monomer feed. Somewhat similar products use a liquid phase process, thought to be based on a Ziegler-type catalyst system and again using higher alkenes to introduce branching. LLDPE materials are in a range of densities from around 0.900 g/cm^3 for VLDPE (very low density PE) materials to 0.935 g/cm^3 for ethylene-octene copolymers. The bulk of materials are of density approximately 0.920 g/cm^3 using butene in particular as the comonomer.

4.2.1 Additives

Some additives may be blended into PE polymer during manufacturing and/or during processing into finished parts (American Chemistry Council, 2005). According to Bhunia et al. (2013) and Wypych (2012), DIBP, DPP and DBOP (three of the eleven specified phthalates) may be used as additives in the manufacturing or processing of PE. These include fillers, pigments, flame retardants, slip agents, blowing agents, cross-linking agents, antioxidants, carbon black, and antistatic additives (see list above).

4.2.2 Processing

PE is almost exclusively processed by melt processing (Brydson, 1999). There are different types of techniques, including:

- compression molding (the polymer is heated in a mold and compressed to shape and cooled); the manufacture of large blocks and sheets;
- injection molding (the polymer is melted and injected into a mold and then allowed to harden);
- blow molding; and
- extrusion molding (molten polymer is extruded into a mold where it sets); for production of PE film.

4.3 Applications for Polyethylene (CASRN 9002-88-4) in Consumer Products

4.3.1 Toys and Child Care Articles

There are several types of PE based on the density of the manufactured material The different density PE has different end uses depending on its physical and chemical properties (Snedeker, 2014). PE was reported as the most common type of plastic. It has widely varying densities all with low moisture permeability, with high density PE (HDPE) having a lower moisture permeation rate as compared to low density PE (LDPE) (Snedeker, 2014; Strong, 2006).

HDPE was reported as the second highest plastic for use in injection molded toys (behind polypropylene) at 25 percent of the market (Rosato, 2011). HDPE is also used for injection molded furniture, including juvenile and infant furniture, and makes up about 7 percent of the market (Rosato, 2011). LDPE is used in toys due to its low density and amorphous structure (Strong, 2006; Campo, 2008). Baby products, including baby lotions, oils, powders, creams, and others were reportedly made using PE (McLain, 2007). Another use is in foil balloons made of nylon sheets sandwiched between PE and an aluminum coating (Williams, 2005). One study reported a PE car seat (Anon, 1994).

Patents were found that reported PE uses, including: in an infant seat liner (Perdelwitz et al., 1989), in car seat covers (Mielenz, 2003; Horn, 2000), in a crib/cradle sleep system for infants (Krause, 2014), in a lap shade for preventing direct heat of sunlight onto car seats (Leal and Leal, 2010), in a heating pad for pajamas (Mazon and Riehm-Constantino, 2006), in multi-purpose mats (for uses as a bedding mat, nap, and protection mat used in water-related facility, child-care facility, school, poolside, and beach) (Yogo, 2015), and in the filling material of a mattress used as a sleeping bed for an infant (Zheng, 2013). Only one patent reported a material containing PE

and dibutyl phthalate at 30-50 percent by weight used in manufacturing plastic track and plastic playgrounds (Tian, 2013).

4.3.2 Other Consumer Products

Additional uses of PE in consumer products are summarized from two databases (HPD and SPIN) and several additional references. As such, this review is not exhaustive for the use of PE in consumer products.

LDPE is commonly used in films, flexible tubing, packaging films, squeeze bottles, other household applications, extrusion coatings, food packaging items, injection molding, blow molding, rotational molding, and extruded products (principally films) (Strong, 2006; Campo, 2008). Its low density and amorphous structure make it amenable to these purposes. HDPE is commonly used in milk, water, detergent, and bleach bottles, barrels, trash carts, automotive fuel tanks, margarine tubs, high-pressure piping, packaging films, and grocery bags, due to its stiffness, strength, chemical resistance, and low permeability (Strong et al., 2006; Campo et al., 2008). Other density PE, such as ultra-low-density PE (ULDPE), has uses in food packaging, shrink wrap, heavy duty film, and heat-seal layers (Strong, 2006). Generally, PE is less stiff (as compared to polypropylene) with high resistance to stress cracking (Strong, 2006). Other properties that influence end use include resistance to solvents and high electrical resistance which lends to insulating applications (such as wires and cables) (Strong, 2006). Applications include trash bags, packaging and films, plastic containers, and houseware products due to the ease and low cost of manufacture (Strong, 2006).

PE (specific density not specified) is common in food contact materials, such as coatings to aluminum dishes and milk cartons, and ice cream and orange juice containers (Snedeker, 2014). In textiles, carpets, and coatings, PE fibers are used in drapes, carpets, and mattress ticking (Snedeker, 2014). In building insulation and construction materials, PE is used in piping and thermal insulation (Snedeker, 2014). Other uses include packaging materials (Snedeker, 2014). Additional uses include in vacuum cleaner panels, in plastic container handles, in building materials such as decking, and in piping (Rosato, 2011).

HPD (Household Products Database) (2015) reported PE use in a number of consumer products, including: foam insulation, in food plastic wrap and plastic food storage bags, in floor restoration products, in hair dyes, in toothpaste, in mouthwash, in deodorant, in body wash, in body lotion and moisturizer, in hair products, in waxing strips, in face washes, in hair removers, in cuticle gel, and in shampoo. The percentage of PE was not uniformly reported for these products; when it was, concentrations ranged from 0.5-100 percent.

In the SPIN database (2015), PE was reported with a number of use categories, including: an additive to lubricating agents, in paints, lacquers, and varnishes, as an adhesive or adhesive hardener, in aniline printing inks, as an anti-adhesive agent, as an anti-corrosive, as an anti-foaming or anti-fouling agent, as an antioxidant, as an antistatic agent, in auto shampoos, as a binder or binding agent, as a biocide, as a blowing agent, in car care products, in casting slips for plastic, in cement/concrete/mortar, in cleaning/washing agents and detergents, in coloring agents, construction materials, as a lacquer, in dye and colorants, in electrical and non-electrical insulation materials, as a filler or filling agent (in plastics, paints, etc.), in film forming agents, as a flame retardant, as a flatting agent, floor covering materials, in floor paints, in flooring materials, as a foaming agent, in glazing materials, as a hardener (for filling materials, paints, and lacquers), as an intermediate, as a lubricant, as a molding compound, as an anti-setoff agent, as a polishing agent, as a raw material for production of a number of products, as a stabilizer, as a surface treatment (for paper, cardboard, and non-metals), as a padding material, as a paper additive, in pigment pastes, in primers, in process regulators, as a releasing agent, as a resin, as a rust inhibitor or preventative, as a sealing compound, as softeners, as stabilizers, as a stopping material, in tightening materials, in underseal materials, and in wax and floor polish.

The presence of phthalates in the PE used for the above consumer product applications was not noted nor was any concentration data reported.

4.4 Recycling of Polyethylene

Two grades of PE comprise the most highly used plastics (See Appendix D). PE is made in a number of grades with a density ranging from low (0.925 g/cm) to high (>0.940 g/cm). Recovered HDPE and LDPE are usually processed separately as each has value for recycling into specific products. This difference in density of the PE raises the problem of obtaining recycled PE meeting the exact specification required for the manufacturing process (Merrington, 2011). Another problem with recycling of PE is that contamination with PP cause decreases in the mechanical properties of PE (Merrington, 2011). If the mechanical sorting is thorough and avoids mixed plastic, then recycling of HDPE and PE is useful, most notably with increasing amounts of reused food grade plastic crates (EFSA (European Food Safety Authority), 2013). Another use for recycled PE is milk bottles with low-density polyethylene (LDPE) and linear low-density polyethylene (LLDPE). Studies have shown that the recycled LDPE and LLDPE had inferior mechanical properties, but this can be overcome by using a 50/50 blend of recycled material with virgin material (Choudhury and Adhikari, 2007).

Another reported use area for recycled PE includes single use plastic pallets (Rosato, 2011). Plastic recycling of PE milk jugs (in combination with PET bottles) constitutes 26 percent of waste packaging streams, but it was reported that 57 percent of HDPE bottles are recycled (Strong, 2006).

Theoretically, there is potential of phthalate contamination in recycling of PE, if it is recycled with a mixture of plastics (such as PVC which contains phthalates). However, no reports were identified for recycled materials that contained the specific phthalates of interest in this project in the production of virgin PE.

4.5 Migration and Contamination

Amongst the plasticizers used in PE to impart more flexibility are paraffin wax and oil, and sunflower oil; none of the specified phthalates for this report are listed as being used) (Wypych, 2012). The Toy Industry Association (TIA (Toy Industry Association Inc.), 2013) reported that toys made with PE are compliant with the phthalate standard. Further, to add phthalates to this resin would cause deterioration of the physical properties for which the resins were selected; however, no data or documentation was provided as the basis for this assertion.

While fragrances, flavorants, ethylbenzene and xylenes were constituents in the recycled materials when Camacho and Karlsson (2000) analyzed contaminants in recycled resins of HDPE from mixed solid waste, no phthalates were reported. However, phthalates (DEHP, DBP) were present in physically recycled HDPE regranules from household waste at low concentrations (up to 200 ppm or 0.02%) (Huber and Franz, 1997).

Detectable levels of DEHP (<0.5 µg/mL, or 0.5 ppm) did not leach from PE infusion tubing (Bagel-Boithias et al., 2005).

Di Bella et al., 2014) reported phthalates (DBP and DEHP) at approximately 3-12 ppb in coffee capsules (made of PS, PE and PP) coffee pods and moka pots, suggesting phthalates could leach from these materials into coffee. Al-Saleh et al. (2011) reported BBP, DEHP and in bottled water at concentrations less than 0.002 ppm. The source of phthalates was thought to be either the plastic water bottle or contamination of the water. Casajuana and Lacorte (2003) found no phthalates in water from PE bottles; however, after 10 weeks of storage, DBP, BBP and DEHP were present up to 0.2 µg/L (0.2 ppb). Thomas et al. (2014) reported that phthalates were not present in 79 cosmetics packaged in PE or HDPE packaging.

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5 High impact polystyrene (HIPS) CASRN: 9003-55-8

High impact polystyrene (HIPS) is a polymer blend that consists of many tiny polybutadiene rubber particles (discrete phase, impacting high-impact resistance to the plastic). These particles are then dispersed in a polystyrene matrix (continuous phase). The polymerization of butadiene to produce polybutadiene, a potential starting material for manufacturing HIPS, involves the use of Ziegler-Natta catalysts. These catalysts "are prepared starting from a pre-catalyst (proCAT) mixture, containing, besides magnesium- and titanium (IV) chloride, an internal donor, which is very often a phthalate like dibutyl phthalate (DBP), diisobutyl phthalate (DIBP) or di-(2-ethylhexyl) phthalate (DEHP)" (Borealis, 2014) There is, therefore, the potential of the HIPS plastic to contain some of these phthalates. Although no actual testes were identified that estimated the phthalate levels in HIPS, it is unlikely that these phthalates will constitute more than 0.1% of the HIPS plastic as the phthalates are used solely as internal donors. These donors and the activated catalyst are consumed or rapidly decomposed or the residual traces of the phthalates are either removed in the process or end up as catalyst residues in the plastic (Borealis, 2014).

5.1 Raw Materials Used in Production of High impact polystyrene (HIPS)

The raw materials for making HIPS include:

- Styrene, polybutadiene rubber, benzene;
- Internal lubricant: zinc stearate;
- Chain transfer/transition agent: tertdocecylmercaptan or liquid paraffin;
- Diluent: ethylbenzene or toluene;
- Aluminum chloride and ethyl chloride or hydrochloric acid;
- Iron oxide, potassium oxide, chromium oxide;
- Bifunctional peroxide such as Luperox;
- Stabilizer: tert-butylcatechol;
- Ziegler-Natta catalysts

5.2 Manufacturing Processes used Worldwide to Produce HIPS

Several processes have been described in the literature for the manufacturing of HIPS.

1. HIPS production involves a free radical polymerization of styrene in the presence of various elastomers (natural or synthetic polymers having elastic properties), most commonly, polybutadiene (Wunsch, 2000; Choi et al., 2000; Jahanzad et al., 2008; Robertson, 2013; Cunha et al., 2013; Lithner, 2011). The first step involves dissolving polybutadiene rubber in styrene (stabilized with, for example, tert-butyl catechol)

containing a diluent (e.g., ethylbenzene or toluene) (Wunsch, 2000). Lubricants (not identified), regulators or chain transfer agents (e.g. tertdodecyl mercaptan), or peroxide or hydroperoxide initiators (such as a bifunctional peroxide such as Luperox 331) may be added. This solution is then filtered, followed by a prepolymerization step. Next, polymerization is continued, predominantly by a continuous bulk process in solution. A bulk suspension process may also be used where the polymer solution is dispersed in water with suspension aids (e.g. polyvinyl alcohol or polyvinyl pyrrolidone). The polybutadiene is made by solution polymerization of butadiene with the aid of Ziegler-Natta catalysts (Chanda and Roy, 2008).

2. HIPS is also reportedly manufactured from raw materials consisting of styrene, zinc stearate (as an internal lubricant**)** and liquid paraffin (as a chain transition agent) (Inclusive Science and Engineering, 2012). The authors claimed that "all current styrene manufacturing starts with ethyl benzene, followed by a conversion to crude styrene, which then requires finishing to produce pure product." The process involves:

    - Alkylation of benzene to ethyl benzene using Friedel-Craft's process (a set of reactions to attach substituents to an aromatic ring) (Organic Chemistry Portal, 2015) in the presence of aluminum chloride and ethyl chloride or hydrochloric acid.
    - Dehydrogenation of ethyl benzene (endothermic) to styrene in presence of iron oxide promoted with potassium or chromium oxides.

3. A leading chemical company (Phillippe et al., 2006) has also described a new process for the manufacturing of HIPS via an anionic route, referred to as A-HIPS. In the company's system, the production of A-HIPS includes the synthesis of the rubber, a styrene-butadiene block polymer. This process involves a proprietary technology, referred to as Retarded Anionic Polymerization (RAP) (Phillippe et al., 2006; Carlotti et al., 2009). The RAP process allows styrene polymerization to 100% conversion under similar reaction conditions as the radical polymerization (mass/suspension polymerization). In this system, "the polybutadiene used for the radical HIPS is replaced by a styrene-butadiene block copolymer to allow cohesion between the polystyrene and the polybutadiene phases. The polymerization reaction is initiated by trialkylaluminum with metal hydride, particularly sodium hydride. The chemical company also states that they have succeeded in operating a continuous retarded anionic HIPS polymerization and have developed an A-HIPS injection molding and extrusion grade whose property profile is comparable to that of the radical HIPS.

5.2.1 Processing

HIPS polymers are processed using injection molding or extrusion processes. The melted polymer can be shaped in injection-molding operations into various products (for example, injection-molded eating utensils). The melted polymer can also be subjected to flat-film extrusion (the most common processing for styrene-butadiene block copolymers to make thermoformed drinking cups, for example); blown film extrusion for the production of thin films; or coextrusion by combining different thermoplastics to customize films with special properties (Wunsch, 2000).

None of the 11 specified phthalates are used as additives in manufacturing or processing according to the literature consulted for this report.

5.3 Applications for High impact polystyrene (HIPS) (CASRN 9003-55-8) in Consumer Products

HIPS is a type of polystyrene polymer, and these materials are widely used (Chanda and Roy, 2008; NIIR Board of Consultants & Engineers, 2006).

5.3.1 Toys and Child Care Articles

Polystyrene copolymers are used in hard plastic toys; however, the specific polymers and specific toys were not identified (Snedeker, 2014). Rosato (2011) reported polystyrene (specific type not specified) as used in injection molded toys comprises less than 10 percent of the market. There were no data specific for HIPS in toys and child care articles reported in the literature sources searched for this project.

Patents were identified for specific products using HIPS or novel HIPS copolymers, such as a decorative faucet assembly with handles of a plastic figurine in the form of a toy (Giagni and Weinstein, 2006), toy bricks (RTM: Colorful interlocking plastic brick) (Knoeppel, 2010), and in a plastic coloring sheet or book for children (Jones-Fenleigh, 1998). However, there was no mention of phthalates being used in HIPS in these patents.

5.3.2 Other Consumer Products

General use of HIPS in consumer products reported from two databases (HPD, 2015 and SPIN, 2015) and several relevant references are summarized here. As such, this is not an exhaustive review of the consumer uses (other than toys and child care articles) for HIP.

In SPIN (2015), HIPS was reported for a wide variety of use categories, including: adhesives, adhesion promoters, anti-corrosives, asphalt (including bitumen, tar, etc.), binders and binding agents, car care products, cement (concrete, mortar), cleaning/washing agents, construction

materials, drilling chemicals, dyestuffs and pigments, filling agents, intermediates or raw materials (in plastic and rubber manufacture), lubricants, surface treatments, and in paints, lacquers, and varnishes, and padding. It is also used in plastic additives, primers, printing inks, rubberizing materials, rust inhibitors or preventatives, sealing compounds, tightening materials, and underseal materials . Detailed information as to the purpose or amount of HIPS in these products was not provided.

When searching HPD (Household Products Database, 2015) using the HIPS CASRNs the results shown were for styrene/butadiene copolymers. Uses of these copolymers include: liquid nails, floor, carpet, and other adhesives; cements and mortar mixes; and in latex, crack filler, and driveway and roof sealer. The percentage of HIPS was not uniformly reported for these products; when it was, concentrations ranged from 1-40 percent. No information as to specific phthalates in these products was found in the literature sources for this project. Other reports include the use of HIPS in housings of electrical and electronic equipment (such as TVs and PCs), in cathode-ray tube and liquid-crystal displays (monitors, TVs), and in small appliances and their circuit boards (such as TVs, VCRs, computers, radios, and phones) (Snedeker, 2014). HIPS was also reportedly used in food contact materials (such as food trays), and in the manufacturing of foam furniture, electronics, food packaging, and building materials, and in waste materials from electrical and electronic equipment (Snedeker, 2014). HIPS is also one of the more common plastics used in packaging (Rosato, 2011), including for food packaging and containers (Robertson, 2013). No information regarding phthalates in the HIPS used for these products was reported.

5.4 Recycling of HIPS

HIPS are low-cost and versatile materials commonly used in a wide range of applications. Mechanical recycling is the preferred route for the recovery of HIPS waste in packaging applications. Heat generated during the mechanical recycling process can cause degradation of the recovered plastic and impact the potential reuse of HIPS (Domingo, 2008; Vilaplana et al., 2006, Vilaplana et al., 2007). However, in general HIPS appears to highly suitable for mechanical recycling (Domingo, 2008).

The HIPS present in electronic waste (WEEE) causes additional recycling problems because of the integrated nature of HIPS in these products, the difficulties for dismantling and separating the HIPS, and the presence of potential hazardous substances (for example, brominated flame retardants) (Domingo, 2008). Electrical and electronic equipment contain approximately 18% in weight of plastic materials and styrene polymers constitute an important fraction in WEEE plastics (HIPS approximately 19%) (Domingo, 2008). Other investigators studied the recycling

of HIPS in plastic casting in waste computer equipment with 21% HIPS. The waste plastics were mechanically recycled and then examined to determine if the recycling process altered the mechanical properties of the plastics. HIPS was not altered except for reduction of impact strengths (Brennan et al., 2002). Analytical strategies have been developed to assess the quality of recycled HIPS including a determination of the presences of chemical impurities (phthalates were not mentioned) (Vilaplana et al., 2007).

HIPS is mainly being used in rigid materials where it would be unlikely to find plasticizers that soften materials. It cannot be discerned from the literature searched for this report with what other materials (such as plastics) recycled HIPS may be mixed. There is no indication in the literature searched for this report that phthalates were measured in HIPS.

5.5 Migration and Contamination

No data regarding migration of phthalates from HIPS or contamination of HIPS by phthalate-containing materials were found in the sources searched for this report.

One report noted that styrene migration from HIPS cups was dependent on the temperature of the drink (Khaksar and Ghazi-Khansari, 2009 as cited in Bhunia et al., 2013).

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6 Acrylonitrile butadiene styrene CASRN: 9003-56-9

Acrylonitrile butadiene styrene (ABS) plastic is a thermoplastic polymer – a polymer that becomes pliable or moldable above a specific temperature and solidifies upon cooling – that contains three monomers, acrylonitrile, butadiene, and styrene. It is made by polymerizing acrylonitrile and styrene in the presence of polybutadiene. The resulting product contains long butadiene chains captured by shorter chains of poly(acrylonitrile-co-styrene). ABS resins are materials of choice for many medical, pharmaceutical, and consumer products because of their durability, stability (against heat and light), and high-quality surface finish (Bennett et al., 2011). Additives including non-phthalate plasticizers are used in ABS polymers.

ABS is used to make rigid-molded products such as piping and fittings, fuel tanks, automotive body parts, toys, wheel covers, enclosures, and where good shock absorbance is needed, such as golf club heads and protective head gear. For example, some toy building blocks are currently made from ABS plastic (Carraher, 2011).

6.1 Raw Materials Used in Production of ABS

The raw materials used in making ABS (Cha et al., 2006; Whelan, 1994) are:

- Monomers: acrylonitrile, butadiene, and styrene, trans-1,4-butadiene, cis-1,4-butadiene, 1,2-butadiene
- Hydrocarbon solvent; hexane, heptane, ethyl benzene
- Additives:
    - stabilizers (against heat or light): phenolic antioxidants, thiol-containing antioxidants, phosphites, thioesters, substituted benzophenones and benzotriazoles, and hindered amines (Adams et al., 1993)
    - plasticizers: hydrocarbon processing oil, phosphate esters (e.g., triphenyl phosphate, resorcinol bis(diphenyl phosphate), or oligomeric phosphate), long chain fatty acid esters, and aromatic sulfonamide (Wypych, 2012)
    - lubricants (not specified)
    - colorants (not specified)
- Molecular weight regulator: *tert*-dodecyl mercaptan (TDDM)

- Initiator/catalysts: water-soluble initiator such as potassium persulfate (KPS) or sodium persulfate (NaPS), or oil-soluble initiators using a redox system (cumene hydroperoxide, sodium pyrophosphate, dextrose, and iron (II) sulfate ($FeSO_4$)

- Activator: not specified

- Emulsifier: salt of rosin, fatty sodium lauryl sulfate (SLS), oleate

- Antioxidant: phenolic-based or phosphate-based (examples not provided)

6.2 Manufacturing Processes used Worldwide to Produce ABS

ABS thermoplastic materials were originally made by blending a lightly cross-linked nitrile rubber (NBR) into a styrene-acrilonitrile (SAN) copolymer (Whelan, 1994). ABS materials are now commonly made by polymerizing styrene and acrylonitrile onto polybutadiene (contained in a polybutadiene (PB) latex); the resultant grafted polybutadiene phase (the rubbery phase) is then melt compounded with SAN, which is the plastics phase. Additives such as stabilizers, lubricants, and colorants are added at this stage (Whelan, 1994) (see Section 1.1 above for specific chemical information). The manufacturing processes are briefly described below.

ABS resins are manufactured using either the graft-type or blended-type processes. The graft-type process, where a polymer chain is formed by one monomer and then a chain of the other monomer is attached as a branch to the main backbone, is largely classified into three types: emulsion polymerization, mass polymerization, and mass suspension methods. Combinations of processes are widely used in the ABS industry to achieve a good balance of polymer properties, cost, and environmental susceptibility (Olabisi and Adewale, 1997). Of these methods, the emulsion polymerization process is the method mainly used currently in the manufacture of ABS resins. The ABS resins are generally prepared in the compositional ratio of 21 to 27% acrylonitrile, 12 to 25% butadiene, and 54 to 63% styrene on average (Cha et al., 2006). The final ABS resin is completed by compounding grafted ABS and SAN copolymer, with the SAN copolymer prepared by either the emulsion polymerization or bulk polymerization. None of the 11 phthalates that are subject of this project are found to be used in the manufacturing or processing of ABS.

6.2.1 Emulsion Polymerization Process

In this process, ABS resins are obtained by addition of an initiator (oil-soluble initiators such as cumene hydroperoxide), a molecular weight regulator (typically, the chain transfer reagent, *tert*-dodecyl mercaptan (TDDM)), and an emulsifier (e.g., rosin, fatty SLS, oleate) to PB rubber latex, followed by graft polymerization of the SAN copolymer (Cha et al., 2006). Water is present in the continuous phase, while the reactants are present in the discontinuous phase. Particles of ABS resins are produced in water as the reaction proceeds.

Upon completion of the polymerization, polymer particles are obtained by adding acids or salts to remove the stability of emulsion and then are washed and dried to obtain the final ABS resin.

6.2.2 Preparation of Polybutadiene Rubber Latex

This latex is prepared according to *trans*-1,4, *cis*-1,4 addition free-radical emulsion polymerization of butadiene, using an initiator (water-soluble initiator such as KPS or NaPS, or oil-soluble initiators using a redox system) (Cha et al., 2006). Carraher (2011) also notes that a PB composition of about 60% trans-1,4; 20% cis-1,2; and 20% 1,2 configuration is generally employed in the production of ABS. The butadiene monomer, emulsifier (a salt of rosin or fatty soap), and chain reaction agent (TDDM) are introduced into the reaction mixture. After completion of the reaction, unused butadiene is recovered and reused in the polymerization reaction. While direct polymerization ensures preparation of butadiene latex of desired particle size, the more advantageous, chemical agglomeration method, where the particles with the desired size are prepared by polymerization of small-size particles followed by latex agglomeration, is also being used.

6.2.3 Preparation of ABS Latex

ABS polymers are generally produced as a bimodal resin type that comprises two particles sizes for better surface and impact resistance properties Cha et al., 2006). This is accomplished either by:

1. The graft polymerization taking place in the concurrent presence of two kinds of PB latex having different particle sizes, or
2. Respective PB latexes, after the graft polymerization is accomplished, may be mixed in a certain ratio to prepare the product.

In the preparation of the ABS latex, PB latex is introduced in a graft polymerization reactor, followed by addition of styrene and acrylonitrile monomers in a certain quantity to the reactor, and then the molecular weight regulator, initiator, activator (not identified by authors), and emulsifier also as required. Once the reaction is complete, the resulting product is transported to the coagulation and drying steps.

In the coagulation step, a phenolic-based or phosphate-based antioxidant may be used (to curtail ageing), followed by addition of a coagulator (a dilution of acids or dilution of calcium chloride ($CaCl_2$)). The coagulated ABS slurry is centrifuged to remove water and then washed to remove the impurities.

6.2.4 Preparation of Mass Polymerization ABS

In this process, the polymerization reaction is initiated by dissolving ground PB rubber in a mixed solution of styrene and acrylonitrile monomers with a small amount of ethyl benzene (Cha et al., 2006). As the reaction proceeds, the styrene and acrylonitrile copolymer is produced, a phase inversion occurs, after which the SAN copolymer is present in the continuous (matrix) phase. When the reaction is complete, the resulting product undergoes a devolatilization step or film evaporation where residues are removed.

6.2.5 Processing

Different processing methods are used to convert ABS polymer into finished products (American Chemistry Council, 2005). Examples of these include:

- injection molding where the molten ABS plastic is injected into a mold under pressure, and
- extruding the molten ABS polymer through a die in which there are small holes to make fibers or through a slit to make sheet or film.

Each of the injection molding grades and the extrusion grades can further be sub-divided into medium, high, and very high impact grades. Other grades include high heat, plating and flame retardant grades.

6.3 Applications for ABS in Consumer Products

ABS has high impact toughness, high solvent resistance, high weatherability, and high processability, lending its use to numerous applications (Strong, 2006).

6.3.1 Toys and Child Care Articles

ABS was reported as having use in injection molded toys and in gaming joysticks (Rosato, 2011). ABS injection molded toys comprise less than 10% of the injection molded toy market. In a study looking at testing of phthalates in plastic products, an acrylonitrile butadiene styrene copolymer children's toy car had DBP at 22 mg/kg (22 ± 3 ppm), BBP was not detected, and DEHP at 40 mg/kg (40 ppm ± 5 ppm) (Song et al., 2012, a Korean article wherein the data were

provided in a table in English). Other authors reported toys such as three rattles, an animal toy, three toy bugles, and a teether made from ABS (Campo, 2008; Ohno and Kawamura, 2010). A popular toy block was also reported as made from ABS (Defosse, 2006). The latter studies did not include information as to the presence of phthalates in these materials.

Patents were identified for specific products using ABS or novel ABS copolymers, such as a decorative faucet assembly with handles of a plastic figurine in the form of a toy (Giagni and Weinstein, 2006), a toy figure fashion doll (Kroskrity et al., 2011), a domino chip for use in domino toy (Lee, 2009), a toy ball (bowling ball) for children (Mao, 2015), in vertical support tubes in play accessory for infants, new toddlers, and toddlers (such as a toy baseball bat, a toy hockey stick, a soft small basketball, a soft soccer ball, a soft football, a soft baseball, and a soft hockey puck) (Monaghan, 2011), a toy water pistol (Nagel, 1999), a submersible bouncing toy for use in swimming pool (Nimmo et al., 2008), a water cannon toy made from ABS (Barker, 2011), components of a children's playhouse (Deblanco and Deblanco, 2014), a hula hoop (Sang Jin, 2009), a base for toy figurine used by children (Stucke et al., 2014), in the shell for an electronic water spraying toy (Wu, 2011), and a bicycle helmet (Yen, 2008). No specific phthalates researched for this project were reported in these patents.

6.3.1 Other Consumer Products

Additional uses of ABS in consumer products are summarized from two databases (HPD and SPIN) and several relevant references. As such, this review is not exhaustive for the use of ABS in consumer products (other than toys and child care articles).

ABS is used in applications such as engineering plastics applications, injection molded products (such as telephones, helmets, steering wheels, and small appliance cases), pipes (drain, waste, and vent), and extruded specialty shapes is attributable to its high impact toughness, high solvent resistance, high weatherability, and high processibility (Strong, 2006). Thermoformed ABS products include snowmobile covers, luggage, and refrigerator liners, while electroplated ABS has uses in metallized knobs, handles for radios, televisions, and automobiles (Strong, 2006). ABS is foamable and used in wall panels, picture frames, handles, ice buckets, and injection molded furniture (Strong, 2006). ABS is used in alloys and blends, and applications include: refrigerators (interior and exterior), small appliance housings, power tool applications, automotive components (interior and exterior), drainage materials (such as waste and vent pipes), telecommunications components (such as portable phones and phone housings), consumer electronics, household items (such as countertops and sink surrounds), recreational products (such as picnic cooler liners and hard sided luggage), and other (such as household packaging and cosmetics) (Campo, 2008).

HPD (Household Products Database) (2015) reported ABS use in only one consumer product: cement, at 20 to 45 percent.

In the SPIN database (2015), ABS was reported in the following use categories: adhesives, intermediates or raw materials in plastic manufacture, in plastic construction materials, and in printing inks.

Snedeker (2014) reported ABS as a hard polymer plastic that is commonly used for TV and computer housings and casings and in the cathode-ray tube or liquid crystal displays in monitors and TVs. Other uses include small appliances and their circuit boards such as TVs, VCRs, computers, radios, and phones, and waste electrical and electronic equipment (Snedeker et al., 2014). It is used extensively in food contact materials, but the specific uses were not reported (Snedeker, 2014). Other reported uses were in air conditioner drain pans and in vacuum cleaner housings (but mentioned that ABS was being replaced by polypropylene), vacuum cleaner casings, CD disc-holding booklet sheets, and in the heat controller in thermal fabrics (Rosato, 2011).

ABS was reported as one of the plastics used in a 3D printer (RepRap) available to consumers, meaning that a number of products could be made with ABS, however, there was no additional data on the types of products that can be made using these printers (Kreiger and Pearce, 2013). ABS resin was also reported as used in yoga mats (Sun and Tang, 2011).

The product uses described by the various sources did not discuss phthalates in the reported products.

6.4 Recycling of ABS

Electrical and electronic equipment contain approximately 18% in weight of plastic materials. Styrene polymers constitute an important fraction in WEEE plastics, with ABS as an Acrylonitrile butadiene styrene tri-polymer (33%) (Domingo, 2008). Other investigators studied the recycling of ABS in plastic casting in waste computer equipment that contained ABS ~45 % by weight. Not only is ABS used frequently in computer CRT (cathode ray tube) monitor and appliances, ABS is mechanically recycled. In recycling, ABS is first shredded, and then separated from other plastic and contaminated materials by floatation. After the composition of the separated plastics has been analyzed, the recovered ABS can be blended with virgin ABS to produce a desirable recycled plastic. ABS mechanical properties, for example the impact strength, can be degraded during the mechanical recycling process. Because ABS is mainly being used in rigid type materials, it is not likely that plasticizers will be found (Strong, 2006). There is no indication in the literature of phthalates measured in during recycling of ABS.

Recycled ABS waste material from an ABS edge banding operation was reported as used in furniture manufacturing (Cosereanu and Lica, 2014).

6.5 Migration and Contamination

There is a paucity of information regarding migration or contamination of phthalates from/to ABS, despite the extensive searching in this project. The Toy Industry Association (TIA (Toy Industry Association Inc.), 2013) reported that toys made with ABS are compliant with the phthalate standard. Further, to add phthalates to this resin would cause deterioration of the physical properties for which the resins were selected; however, no data or documentation was provided as the basis for this assertion.

Phosphate esters, long chain fatty acid esters and aromatic sulfonamide are used as plasticizers in ABS to improve mold release, flame retardation, and decrease melt and viscosity processing temperature (Wypych, 2012). There was no mention of phthalates in ABS by Wypych (2012). Thomas et al. (2014) reported that phthalates were not present in 79 cosmetics packaged in ABS packaging.

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7 Summary

The tiered approach used to research the five factors for four plastics for the presence of the 11 specified phthalates is an effective and efficient way to identify relevant information (or data) sources.

In Tiers 1, 2 and 3, secondary sources were used to narrow the field of possible information for further investigation of the primary literature in Tier 4. The tiered approach also assisted us in identifying what information was *not* available and what gaps existed to better focus further efforts on specific phthalates, specific plastics, and specific factor in Tier 5. The "universe" of over 109,000,000 sources in Tier 1 for the four specified plastics and plastic manufacturing, and the 738 sources for phthalates and the four plastics formed the "universe" of information from which we pared secondary authoritative websites (from 48 to 9) and secondary authoritative library sources (from over 110 to 24) in Tiers 2 and 3. Tier 4 involved using a search strategy developed for this project and searched four online databases, yielding more than 119,800 articles (8672 for PP; 106,200 for PE; 2,535 for HIPS; 2,400 for ABS), which were then screened by scientists for relevance to the phthalates, factors and plastics (Appendix C). Gap searching was conducted using Google and Google Scholar. We searched by a variety of strategies, numerous sources and yielded what we considered to be a nonbiased and representative sample of the "universe" of information on the specified phthalates in the four specified plastics for the five factors. Our assertion of nonbiased and representative is supported by the more than 109,000,000 sources found in Tier 1, the 48 websites and 110 library sources in Tiers 2 and 3, the 109,800 articles in Tier 5 located using several different search approaches, terms and strategies to identify the "universe" of information on the specified plastics, phthalates and factors relevant to this project.

Our search techniques for this task and a previous task have identified significant information on the phthalates, a lot of information on their uses, a lot of information on the plastics, and information on manufacturing and additives used in the specified plastics. However, very little information on the phthalate content of these specific plastics has been found using our tiered search techniques (as described in Section 2 of this report). As TERA learned on a previous project (Task 11), the 11 specified phthalates are produced in large quantities, making them High Production Volume (HPV) chemicals. The phthalates, both as a class and individually, are widely researched. In addition, the four specified plastics are widely used for toys, childcare products and other consumer products. Given the search strategy and its success at getting the other information, we can be confident that if there had been information on the phthalate content of the four plastics we would have found it. In fact, the consistent lack of information amongst the many places we searched, both secondary authoritative web and library sources and

primary literature sources made us highly confident that there was very little information on the specified phthalates in the four plastics.

While the volume of information available for the four plastics varied, as did the volume of information on the five factors for each plastic, and the volume of literature for the 11 phthalates, there was relatively little information for any of the phthalates in the four plastics. The largest information gaps were for the potential use of recycled materials containing the specified phthalates in the production of the four plastics as well as for the potential for phthalate contamination during packaging, storage, use or other factors.

In PP, the specified phthalates are not raw materials, additives or solvents. Three of the specified phthalates (DBP, DIBP, and DEHP) are used as Ziegler-Natta catalysts in production of PP. In the final pellets, their concentrations are very low and generally do not exceed 0.0001% (1 ppm).

Polypropylene is used for toys and child care articles; and while DBP and DIBP were reported in baby bottles (presumed in the bottles themselves), no phthalate concentrations were reported. PP is used in a wide variety of consumer products, but the presence or concentration of the specified phthalates was not reported. While PP is not often recycled, it is recycled for food crates and carpet. Very limited data as to the presence of phthalates in recycled PP were available and indicate that phthalates were not found or that concentrations were not reported. Information as to whether phthalates present in other recycled materials could be used for production of PP was not found in the literature searched for this project. Studies on migration or contamination of phthalates in PP reported either no phthalates or very low levels in the ppb or ppt range.

The raw materials for PE production may include phthalates (DIBP, DBP) as plasticizers and as Zeigler-Natta catalysts. These phthalates could theoretically be present at concentrations of 0.0001%, although no test data are reported in the literature searched for this project. PE (HDPE) is used in injection molded toys and molded furniture (including juvenile and infant furniture), as well as baby products and applications related to car seats. The presence of phthalates in these products was not reported, with the exception of one study finding 30-50 percent by weight of DBP in plastic tracks and playgrounds. PE is used in food containers, films and a wide variety of household and other products. Rarely is the presence or concentration of phthalates reported. DEHP and DBP have been found in recycled PE at concentrations up to 0.02%. Phthalates (DBP, BBP and DEHP) have been reported to leach from some materials (coffee pods and water bottles), but not other materials (cosmetic packaging and infusion tubing). In cases where phthalates were reported, concentrations were in ppb range. There were no reports for phthalate contamination of PP during packaging, storage or use in the literature searched for this report.

The raw materials for HIPS production do not include phthalates but may include Ziegler-Natta catalysts; phthalates may function in this role. These phthalates could theoretically be present at concentrations of 0.0001%, although no test data are reported in the literature searched for this project. Polystyrene copolymers may be used for hard plastic toys, although the literature searched for this report did not present data specific for HIPS in toys or child care articles, nor was information available on the presence of phthalates in these products. HIPS is used in a variety of household products and building materials. No information on the purpose or presence of phthalates is reported. HIPS in electronic waste can be mechanically recycled. The presence of phthalates was not mentioned in the literature for recycled HIPS. No data regarding migration of phthalates from HIPS or contamination of HIPS by phthalate-containing materials were found in the sources searched for this report.

The raw materials for ABS production or processing do not include phthalates. ABS may be used for hard plastic toys, including teethers. Available data from one study on the presence of phthalates in an ABS copolymer showed DBP, BBP and DEHP at less than 40 ppm, although it was not clear if the phthalates were associated with the ABS in the copolymer. Other studies and patents for toys and child care products did not include information on the presence of phthalates in ABS. ABS has wide usage in engineering plastics applications and household products (e.g., appliances). No information on the purpose or presence of phthalates in these products is reported. ABS present in electronic waste can be mechanically recycled. The presence of phthalates was not mentioned in the literature for recycled HIPS. One study reported phthalates were not present in cosmetics packaged in ABS; no other data regarding migration of phthalates from ABS or contamination of ABS by phthalate-containing materials were found in the sources searched for this report.

An overview of the plastics that may contain one of the 11 specified phthalates is presented in Table 7-1. The phthalates are used in the production of PP and PE as Ziegler-Natta catalyst.

Despite the research limitations, some generalizations can be derived from the research conducted for this report on the four plastics and the potential for the presence of phthalates in the selected plastics. The four plastics are used in toys as well as household products, building materials and other products. All but HIPS are used in personal care products, while ABS is used in teethers and rattles, PP is used in medical devices, and PP and PE are used in child care articles.

Table 7-1. Overview of plastics found in certain materials

Plastic	Toys & Modeling Material	Teethers &Rattles	Child Care Articles	Household	Personal Care Products	Medical Care Products & Devices	Building Materials	Other Products
PP	√		√	√	√	√	√	√
PE	√		√	√	√		√	√
HIPS	√			√			√	√
ABS	√	√		√	√		√	√

Child Care Article: other than teethers and rattles
Household: flooring, curtains, table clothes, wall coverings
Personal Care Products: nail polish, perfumes, hair products
Building materials: insulation, "construction materials"
Other Products: aerosol propellants, flame retardant, pesticide, explosives, electronics

The paucity of information and data on the presence of phthalates in the four specified phthalates does not reflect the lack of searching for data. There simply is very little information available. Of the 11 specified phthalates, at most, three phthalates were found (DEHP, DBP, and DIBP) in three of the specified plastics (PP, PE, ABS). The concentration of phthalates in all of the cases reported (save one with incomplete information) were less than 200 ppm (or 0.02%), less than the 0.1% limit specified in section 108 of the CPSIA.

Table 7-2. Overview of phthalates found in plastics

Phthalate	Polypropylene[a]	Polyethylene[a,b]	High impact polystyrene (HIPS)[a]	Acrylonitrile butadiene styrene (ABS)[c]
DEHP	√			√
DBP	√	√		√
BBP				
DINP				
DIDP				
DnOP				
DIOP				
DIBP	√	√		
DPENP		√		
DHEXP				
DCHP				

[a] phthalates used as Ziegler-Natta catalysts, concentrations likely less than 0.0001%

[b] may be used as a plasticizer in PE

[c] may be used as a plasticizer reported in a ABS copolymer

8 Appendix A. Authoritative Secondary Sources (Websites)

Appendix A lists the 48 websites identified as authoritative secondary sources searched in Tier 2. Shaded sites indicate the 18 sites pared down from the 48 for further research.

Secondary Authoritative References--Background Check of 48 websites searched[1]		
Country	Office	Website (n = 48)
Australia	Dept. of Health	http://www.nicnas.gov.au/home
	NICNAS	http://www.nicnas.gov.au/industry/aics/search.asp
Canada	Canadian Centre for Occupational Health & Safety - RTECS	http://www.ccohs.ca/search.html
	Draft Assessments	http://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&xml=6892C255-5597-C162-95FC-4B905320F8C9
	Environment Canada	http://www.ec.gc.ca/default.asp?lang=En&n=ECD35C36
	Health Canada	http://www.hc-sc.gc.ca/index-eng.php
	Health Canada First Priority List Assessments	http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/psl1-lsp1/index-eng.php
	Health Canada Second Priority List Assessments	http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/psl2-lsp2/index-eng.php
	Risk Management reports - Final Assessments	http://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&xml=09F567A7-B1EE-1FEE-73DB-8AE6C1EB7658
	Toxic Substances Managed under CEPA	http://www.ec.gc.ca/toxiques-toxics/Default.asp?lang=En&n=98E80CC6-1
Europe	ECHA	http://echa.europa.eu/
	ECHA	http://echa.europa.eu/en/search?p_p_id=echasearch_WAR_echaportlet&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view&p_p_col_id=column-
	European Commission	http://ec.europa.eu/consumers/consumers_safety/safety_products/rapex/index_en.htm
Internatio	eChemPortal	http://www.echemportal.org/echemportal/participant/pag

Secondary Authoritative References--Background Check of 48 websites searched[1]		
Country	Office	Website (n = 48)
nal		e.action?pageID=9
	ITER TERA Database	https://iter.ctc.com/publicURL/pub_search_list.cfm
	OECD	http://www.echemportal.org/echemportal/substancesearch/page.action?pageID=9
Norway, Sweden, Denmark and Finland	SPIN	http://195.215.202.233/DotNetNuke/
USA	ACGIH	http://www.acgih.org/home.htm
	CPSC	http://www.cpsc.gov/
	Federal Docket	http://www.regulations.gov/#!home
	OSHA	https://www.osha.gov/dts/chemicalsampling/toc/toc_chemsamp.html
USA - NIH	ChemIDPlus	http://chem.sis.nlm.nih.gov/chemidplus/rn/117-81-7
	HPD	http://householdproducts.nlm.nih.gov/cgi-bin/household/searchall
	HSDB	http://toxnet.nlm.nih.gov/newtoxnet/hsdb.htm
	NTP	http://ntp.niehs.nih.gov/index.cfm
	PubChem	https://pubchem.ncbi.nlm.nih.gov/search/
	Haz-Map	http://hazmap.nlm.nih.gov/index.php
USA - CA	Biomonitoring - Priority Chemicals California	http://www.oehha.ca.gov/multimedia/biomon/pdf/PriorityChemsCurrent.pdf
	Biomonitoring California-Designated Chemicals	http://www.oehha.ca.gov/multimedia/biomon/pdf/DesignatedChemCurrent.pdf
	Cal/Ecotox database	http://www.oehha.ca.gov/scripts/cal_ecotox/CHEMLIST.ASP
	Non-cancer health effects Table (RELs) and Cancer Potency Factors	http://www.oehha.ca.gov/air/hot_spots/index.html

Secondary Authoritative References--Background Check of 48 websites searched[1]		
Country	Office	Website (n = 48)
	(Appendix A & B)	
	OEHHA	http://www.oehha.ca.gov/
	OEHHA Toxicity Criteria Database	http://www.oehha.ca.gov/tcdb/index.asp
	Office of Environmental Health Hazard Assessment	http://www.oehha.ca.gov/risk.html
USA - CDC	ATSDR	http://www.atsdr.cdc.gov/substances/index.asp
	NIOSH	http://www.cdc.gov/niosh/topics/
USA - EPA	AEGLs	http://www.epa.gov/oppt/aegl/pubs/chemlist.htm
	CDR-CDAT	http://java.epa.gov/oppt_chemical_search/
	EPA Science Inventory	http://cfpub.epa.gov/si/
	IRIS Track/New Assessments & Reviews / NSCEP	http://www.epa.gov/ncepihom/
	National Service Center for Environmental Publications (NSCEP)	http://www.epa.gov/nscep/
	OPPT	http://iaspub.epa.gov/apex/pesticides/f?p=INERTFINDER:1:1395578990735::NO:1::
	RfD/RfC & CRAVE meeting notes	http://cfpub.epa.gov/si/
	TRI	http://www.epa.gov/enviro/facts/tri/search.html
USA - WA	ECY	http://www.ecy.wa.gov/programs/swfa/cspa/
WHO	IARC	http://monographs.iarc.fr/ENG/Monographs/PDFs/index.php

Secondary Authoritative References--Background Check of 48 websites searched[1]		
Country	Office	Website (n = 48)
	IFCS	http://www.who.int/ifcs/en/
	IPCS - INCHEM	http://www.inchem.org/

[1]NICNAS - National Industrial Chemicals Notification and Assessment Scheme; RTECS - Registry of Toxic Effects of Chemical Substances; ECHA - European Chemicals Agency; SPIN - Substances in Products in Nordic Countries; ACGIH - American Conference of Governmental Industrial Hygienists; CPSC - Consumer Product Safety Commission; ITER – International Toxicity Estimates for Risk; TERA – Toxicology Excellence for Risk Assessment; OECD – Organisation for Economic Cooperation and Development; NSCEP – National Service Center for Environmental Publications; OSHA – Occupational Safety and Health Administration; HPD – Household Products Database; HSDB – Hazardous Substances Data Bank; NIH – National Institutes of Health; NTP – National Toxicology Program; OEHHA – Office of Environmental Health Hazard Assessment; REL – Reference Exposure Levels; CEPA – Canadian Environmental Protection Act; U.S. CDC – U.S. Center for Disease Control; ATSDR – Agency for Toxic Substances and Disease Registry; NIOSH – National Institute for Occupational Safety and Health; U.S. EPA – U.S. Environmental Protection Agency; AEGL – Acute Exposure Guideline Levels; CDR-CDAT – Chemical Data Reporting-Chemical Data Access Tool; IRIS – Integrated Risk Information System; OPPT – Office of Pollution Prevention and Toxics; RfD/RfC – reference dose/reference concentration; CRAVE - Carcinogen Risk Assessment Verification Endeavor; TRI – Toxics Release Inventory Program; WSDE – Washington State Department of Ecology; WHO – World Health Organization; IARC – International Agency for Research on Cancer; IFCS – Intergovernmental Forum on Chemical Safety; IPCS – International Programme on Chemical Safety

9 Appendix B. Authoritative Secondary Sources (Library)

Appendix B lists the 24 books identified from the broader Tier 3 search of the UC Book Catalog. These books were used to research various factors throughout the project.

- Additives in polymers: industrial analysis and applications (Bart, 2005)
- Advances in polymer processing: From macro- to nano-scales (Thomas and Yang, 2009)
- Applied Plastics Engineering Handbook: Processing and Materials (Kutz, 2011)
- Compositional and failure analysis of polymers: a practical approach (Scheirs, 2000)
- Condensed Encyclopedia of Polymer Engineering Terms (Cheremisinoff, 2001)
- Disposal and Recycling of Fisheries Plastic Wastes: Fishing Net and Expanded Polystyrene in More Efficient Utilization of Fish and Fisheries Products (Kanehiro, 2001)
- Engineering Materials (Jones and Ashby, 2012)
- Engineering Plastics Handbook (Margolis, 2005)
- Handbook of Polymer Synthesis, Characterization, and Processing (Saldivar-Guerra and Vivaldo-Lima, 2013)
- Industrial polymers (Campo, 2008)
- Industrial polymers handbook: products, processes, applications (Wilks, 2001)
- Introduction to industrial polypropylene: properties, catalysts, processes (Malpass and Band, 2012)
- Plastic end use applications (Rosato, 2011)
- Plastics Additives and Testing (Subramanian, 2013)
- Plastics and the Environment (Andrady, 2003)
- Plastics Materials (Seventh Edition) (Brydson, 1999)
- Polymer analysis, degradation, and stabilization (Zaikov and Jimenez, 2005)
- Polymer recycling: science, technology, and applications (Scheirs, 1998)
- Practical Guide to Polyethylene (Vasile and Pascu, 2005)
- Principle Nine: Properly Recycle Used Computer Equipment. In: Socially Responsible IT Management (Erbschloe, 2003)
- Principles of Polymer Processing (Tadmor and Gogos, 2006)
- Recycling of plastic waste, rubber waste and end-of-life cars in Germany (Dreher et al., 2004)
- Recycling of Plastics. In: Kutz, M., (Ed.), Applied Plastics Engineering Handbook: Processing and Materials (Merrington, 2011)

- Toxicants in food packaging and household plastics exposure and health: exposure and health risks to consumers (Snedeker, 2014)

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Kutz, M. (2011). Applied Plastics Engineering Handbook: Processing and Materials. Oxford, UK, William Andrew.

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Margolis, J. M. (2005). Engineering Plastics Handbook. New York, NY, McGraw-Hill Professional.

Merrington, A. (2011). Recycling of Plastics. Applied Plastics Engineering Handbook: Processing and Materials. M. Kutz. Amsterdam, Boston, William Andrew.

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Thomas, S. and W. Yang (2009). Advances in Polymer Processing: From Macro- to Nano- Scales, Woodhead Publishing.

Vasile, C. and M. Pascu (2005). Practical Guide to Polyethylene Shropshire, UK, Rapra Technology Limited.

Wilks, E. S. (2001). Industrial Polymers Handbook - Products, Processes, and Applications, Wiley-VCH.

Zaikov, G. E. and A. Jimenez (2005). Polymer Analysis, Degradation, and Stabilization. Hauppauge, NY, Nova Publishers.

10 Appendix C

Appendix C shows the results for literature searches of four databases (CAB Abstracts, SciFinder, Scopus, and Web of Science) for each of the four plastics.

Name of Database:	CAB Abstracts http://www.cabdirect.org/	
Date Conducted	7/15/15	
Limits placed on search	None	
Search terms	**Search String**	**Total number of hits**
Polypropylene AND		
phthalates	(Polypropylene OR 9003-07-0) AND (phthalate*)	2
toys	(Polypropylene OR 9003-07-0) AND (toy*)	0
Child care articles	(Polypropylene OR 9003-07-0) AND ("child care")	0
Child care articles	(Polypropylene OR 9003-07-0) AND ("car seat" OR "crib" OR "baby bed")	0
Child care articles	(Polypropylene OR 9003-07-0) AND ("pacifier" OR "teether")	0
Consumer products	(Polypropylene OR 9003-07-0) AND ("consumer product")	0
packaging	(Polypropylene OR 9003-07-0) AND (packaging)	84
contamination	(Polypropylene OR 9003-07-0) AND (contaminat* OR leaching OR migration)	62
manufacturing	(Polypropylene OR 9003-07-0) AND (manufactur*)	16
Recycled materials	(Polypropylene OR 9003-07-0) AND (recycl* AND material*)	12
DEHP	(Polypropylene OR 9003-07-0) AND (DEHP OR di-2-ethylhexyl phthalate OR 117-81-7)	2
DBP	(Polypropylene OR 9003-07-0) AND (DBP OR dibutyl phthalate OR 84-74-2)	4
BBP	(Polypropylene OR 9003-07-0) AND (BBP OR benzyl butyl phthalate OR 85-68-7)	2
DINP	(Polypropylene OR 9003-07-0) AND (DINP OR diisononyl phthalate OR 28553-12-0 OR 68515-48-0)	2
DIDP	(Polypropylene OR 9003-07-0) AND (DIDP OR diisodecyl phthalate OR 26761-40-0 OR 68515-49-1)	2
DnOP	(Polypropylene OR 9003-07-0) AND (DnOP OR di-n-octyl phthalate OR 117-84-0)	2
DIOP	(Polypropylene OR 9003-07-0) AND (DIOP OR diisooctyl phthalate OR 27554-26-3)	2
DIBP	(Polypropylene OR 9003-07-0) AND (DIBP OR diisobutyl phthalate OR 84-69-5)	4

DPENP	(Polypropylene OR 9003-07-0) AND (DPENP OR di-n-pentyl phthalate OR 131-18-0)	3
DHEXP	(Polypropylene OR 9003-07-0) AND (DHEXP OR di-n-hexyl phthalate OR 84-75-3)	4
DCHP	(Polypropylene OR 9003-07-0) AND (DCHP OR dicyclohexyl phthalate OR 84-61-7)	3
	TOTAL HITS	196

Name of Database:	SciFinder https://scifinder.cas.org/	
Date Conducted	7/15/15	
Limits placed on search	None	
Search terms	**Search String**	**Total number of hits**
Polypropylene AND		
phthalates	(Polypropylene OR 9003-07-0) refined with topic “phthalate* AND contamination”	74
toys	(Polypropylene OR 9003-07-0) refined with topic “toy*”	23
Child care articles	(Polypropylene OR 9003-07-0) refined with topic "child care"	7
Child care articles	(Polypropylene OR 9003-07-0) refined with topic "car seat" OR "crib" OR "baby bed"	56
Child care articles	(Polypropylene OR 9003-07-0) refined with topic "pacifier" OR "teether"	6
Consumer products	(Polypropylene OR 9003-07-0) refined with topic “phthalate” AND "consumer product"	11
packaging	(Polypropylene OR 9003-07-0) refined with topic “phthalate” and “packaging”	248
contamination	(Polypropylene OR 9003-07-0) refined with topic “phthalate” AND (“contaminat* OR leaching OR migration)	144
manufacturing	(Polypropylene OR 9003-07-0) refined with topic (manufactur*)	1811
Recycled materials	(Polypropylene OR 9003-07-0) refined with topic (recycl* AND material*)	42
DEHP	(Polypropylene OR 9003-07-0) refined with topic (DEHP OR di-2-ethylhexyl phthalate OR 117-81-7)	1212
DBP	(Polypropylene OR 9003-07-0) AND (DBP OR dibutyl phthalate OR 84-74-2)	2014
BBP	(Polypropylene OR 9003-07-0) AND (BBP OR benzyl butyl phthalate OR 85-68-7)	134
DINP	(Polypropylene OR 9003-07-0) AND (DINP OR diisononyl phthalate OR 28553-12-0 OR 68515-48-0)	165
DIDP	(Polypropylene OR 9003-07-0) AND (DIDP OR diisodecyl phthalate OR 26761-40-0 OR 68515-49-1)	182
DnOP	(Polypropylene OR 9003-07-0) AND (DnOP OR di-n-octyl phthalate OR 117-84-0)	181
DIOP	(Polypropylene OR 9003-07-0) AND (DIOP OR diisooctyl phthalate OR 27554-26-3)	5
DIBP	(Polypropylene OR 9003-07-0) AND (DIBP OR diisobutyl phthalate OR 84-69-5)	24
DPENP	(Polypropylene OR 9003-07-0) AND (DPENP OR di-n-pentyl phthalate OR 131-18-0)	0

DHEXP	(Polypropylene OR 9003-07-0) AND (DHEXP OR di-n-hexyl phthalate OR 84-75-3)	0
DCHP	(Polypropylene OR 9003-07-0) AND (DCHP OR dicyclohexyl phthalate OR 84-61-7)	83
	TOTAL HITS	6422

Name of Database:	Scopus http://www.scopus.com/home.url	
Date Conducted	7/15/15	
Limits placed on search	None	
Search terms	**Search String**	**Total number of hits**
Polypropylene AND		
phthalates	(Polypropylene OR 9003-07-0) AND (phthalate*)	201
toys	(Polypropylene OR 9003-07-0) AND (toy*)	50
Child care articles	(Polypropylene OR 9003-07-0) AND ("child care")	0
Child care articles	(Polypropylene OR 9003-07-0) AND ("car seat" OR "crib" OR "baby bed")	19
Child care articles	(Polypropylene OR 9003-07-0) AND ("pacifier" OR "teether")	0
Consumer products	(Polypropylene OR 9003-07-0) AND ("consumer product")	76
packaging	(Polypropylene OR 9003-07-0) AND (packaging)	9
contamination	(Polypropylene OR 9003-07-0) AND (contaminat* OR leaching OR migration)	17
manufacturing	(Polypropylene OR 9003-07-0) AND (manufactur*)	14
Recycled materials	(Polypropylene OR 9003-07-0) AND (recycl* AND material*)	4
DEHP	(Polypropylene OR 9003-07-0) AND (DEHP OR di-2-ethylhexyl phthalate OR 117-81-7)	14
DBP	(Polypropylene OR 9003-07-0) AND (DBP OR dibutyl phthalate OR 84-74-2)	55
BBP	(Polypropylene OR 9003-07-0) AND (BBP OR benzyl butyl phthalate OR 85-68-7)	2
DINP	(Polypropylene OR 9003-07-0) AND (DINP OR diisononyl phthalate OR 28553-12-0 OR 68515-48-0)	1
DIDP	(Polypropylene OR 9003-07-0) AND (DIDP OR diisodecyl phthalate OR 26761-40-0 OR 68515-49-1)	0
DnOP	(Polypropylene OR 9003-07-0) AND (DnOP OR di-n-octyl phthalate OR 117-84-0)	2
DIOP	(Polypropylene OR 9003-07-0) AND (DIOP OR diisooctyl phthalate OR 27554-26-3)	3
DIBP	(Polypropylene OR 9003-07-0) AND (DIBP OR diisobutyl phthalate OR 84-69-5)	24
DPENP	(Polypropylene OR 9003-07-0) AND (DPENP OR di-n-pentyl phthalate OR 131-18-0)	0
DHEXP	(Polypropylene OR 9003-07-0) AND (DHEXP OR di-n-hexyl phthalate OR 84-75-3)	0
DCHP	(Polypropylene OR 9003-07-0) AND (DCHP OR dicyclohexyl phthalate OR 84-61-7)	2
	TOTAL HITS	493

Name of Database:	Web of Science http://thomsonreuters.com/en/products-services/scholarly-scientific-research/scholarly-search-and-discovery/web-of-science.html	
Date Conducted	7/15/15	
Limits placed on search	None	
Search terms	**Search String**	**Total number of hits**
Polypropylene AND		
phthalates	(Polypropylene OR 9003-07-0) AND (phthalate*)	22
toys	(Polypropylene OR 9003-07-0) AND (toy*)	586
Child care articles	(Polypropylene OR 9003-07-0) AND ("child care")	7
Child care articles	(Polypropylene OR 9003-07-0) AND ("car seat" OR "crib" OR "baby bed")	51
Child care articles	(Polypropylene OR 9003-07-0) AND ("pacifier" OR "teether")	8
Consumer products	(Polypropylene OR 9003-07-0) AND ("consumer product")	40
packaging	(Polypropylene OR 9003-07-0) AND (packaging)	52
contamination	(Polypropylene OR 9003-07-0) AND (contaminat* OR leaching OR migration)	39
manufacturing	(Polypropylene OR 9003-07-0) AND (manufactur*)	136
Recycled materials	(Polypropylene OR 9003-07-0) AND (recycl* AND material*)	11
DEHP	(Polypropylene OR 9003-07-0) AND (DEHP OR di-2-ethylhexyl phthalate OR 117-81-7)	61
DBP	(Polypropylene OR 9003-07-0) AND (DBP OR dibutyl phthalate OR 84-74-2)	343
BBP	(Polypropylene OR 9003-07-0) AND (BBP OR benzyl butyl phthalate OR 85-68-7)	25
DINP	(Polypropylene OR 9003-07-0) AND (DINP OR diisononyl phthalate OR 28553-12-0 OR 68515-48-0)	20
DIDP	(Polypropylene OR 9003-07-0) AND (DIDP OR diisodecyl phthalate OR 26761-40-0 OR 68515-49-1)	38
DnOP	(Polypropylene OR 9003-07-0) AND (DnOP OR di-n-octyl phthalate OR 117-84-0)	21
DIOP	(Polypropylene OR 9003-07-0) AND (DIOP OR diisooctyl phthalate OR 27554-26-3)	14
DIBP	(Polypropylene OR 9003-07-0) AND (DIBP OR diisobutyl phthalate OR 84-69-5)	64
DPENP	(Polypropylene OR 9003-07-0) AND (DPENP OR di-n-pentyl phthalate OR 131-18-0)	0
DHEXP	(Polypropylene OR 9003-07-0) AND (DHEXP OR di-n-hexyl phthalate OR 84-75-3)	2

DCHP	(Polypropylene OR 9003-07-0) AND (DCHP OR dicyclohexyl phthalate OR 84-61-7)	21
	TOTAL HITS	1561

Name of Database:	CAB Abstracts http://www.cabdirect.org/	
Date Conducted	7/15/15	
Limits placed on search	None	
Search terms	**Search String**	**Total number of hits**
Polyethylene AND		
phthalates	(Polyethylene OR 9002-88-4) AND (phthalate*)	6
toys	(Polyethylene OR 9002-88-4) AND (toy*)	1
Child care articles	(Polyethylene OR 9002-88-4) AND ("child care")	0
Child care articles	(Polyethylene OR 9002-88-4) AND ("car seat" OR "crib" OR "baby bed")	0
Child care articles	(Polyethylene OR 9002-88-4) AND ("pacifier" OR "teether")	0
Consumer products	(Polyethylene OR 9002-88-4) AND ("consumer product")	0
packaging	(Polyethylene OR 9002-88-4) AND (packaging)	265
contamination	(Polyethylene OR 9002-88-4) AND (contaminat* OR leaching OR migration)	198
manufacturing	(Polyethylene OR 9002-88-4) AND (manufactur*)	50
Recycled materials	(Polyethylene OR 9002-88-4) AND (recycl* AND material*)	31
DEHP	(Polyethylene OR 9002-88-4) AND (DEHP OR di-2-ethylhexyl phthalate OR 117-81-7)	7
DBP	(Polyethylene OR 9002-88-4) AND (DBP OR dibutyl phthalate OR 84-74-2)	13
BBP	(Polyethylene OR 9002-88-4) AND (BBP OR benzyl butyl phthalate OR 85-68-7)	1
DINP	(Polyethylene OR 9002-88-4) AND (DINP OR diisononyl phthalate OR 28553-12-0 OR 68515-48-0)	6
DIDP	(Polyethylene OR 9002-88-4) AND (DIDP OR diisodecyl phthalate OR 26761-40-0 OR 68515-49-1)	6
DnOP	(Polyethylene OR 9002-88-4) AND (DnOP OR di-n-octyl phthalate OR 117-84-0)	6
DIOP	(Polyethylene OR 9002-88-4) AND (DIOP OR diisooctyl phthalate OR 27554-26-3)	7
DIBP	(Polyethylene OR 9002-88-4) AND (DIBP OR diisobutyl phthalate OR 84-69-5)	10
DPENP	(Polyethylene OR 9002-88-4) AND (DPENP OR di-n-pentyl phthalate OR 131-18-0)	7
DHEXP	(Polyethylene OR 9002-88-4) AND (DHEXP OR di-n-hexyl phthalate OR 84-75-3)	14
DCHP	(Polyethylene OR 9002-88-4) AND (DCHP OR dicyclohexyl phthalate OR 84-61-7)	9
	TOTAL HITS	637

Name of Database:	SciFinder https://scifinder.cas.org/	
Date Conducted	7/15/15	
Limits placed on search	None	
Search terms	**Search String**	**Total number of hits**
Polyethylene AND		
phthalates	(Polyethylene OR 9002-88-4) refined with topic “phthalate” AND “contamination”	153
toys	(Polyethylene OR 9002-88-4) refined with topic “phthalate” AND “toy”	20
Child care articles	(Polyethylene OR 9002-88-4) refined with topic "child care"	0
Child care articles	(Polyethylene OR 9002-88-4) refined with topic "car seat" OR "crib" OR "baby bed"	72
Child care articles	(Polyethylene OR 9002-88-4) refined with topic “phthalate” (“pacifier” OR "teether")	24
Consumer products	(Polyethylene OR 9002-88-4) refined with topic “phthalate” "consumer product"	24
packaging	(Polyethylene OR 9002-88-4) refined with topic “phthalate” AND “packaging”	502
contamination	(Polyethylene OR 9002-88-4) refined with topic “contaminat* OR leaching OR migration”	24
manufacturing	(Polyethylene OR 9002-88-4)) refined with topic “manufactur*”	93716
Recycled materials	(Polyethylene OR 9002-88-4) refined with topic “recycl* AND material*”	0
DEHP	(Polyethylene OR 9002-88-4) refined with topic “DEHP OR di-2-ethylhexyl phthalate OR 117-81-7”	3144
DBP	(Polyethylene OR 9002-88-4) refined with topic “DBP OR dibutyl phthalate OR 84-74-2”	3173
BBP	(Polyethylene OR 9002-88-4) refined with topic “BBP OR benzyl butyl phthalate OR 85-68-7”	328
DINP	(Polyethylene OR 9002-88-4) refined with topic “DINP OR diisononyl phthalate OR 28553-12-0 OR 68515-48-0”	274
DIDP	(Polyethylene OR 9002-88-4) refined with topic “DIDP OR diisodecyl phthalate OR 26761-40-0 OR 68515-49-1”	334
DnOP	(Polyethylene OR 9002-88-4) refined with topic “DnOP OR di-n-octyl phthalate OR 117-84-0”	289
DIOP	(Polyethylene OR 9002-88-4) refined with topic “DIOP OR diisooctyl phthalate OR 27554-26-3”	10
DIBP	(Polyethylene OR 9002-88-4) refined with topic “DIBP OR diisobutyl phthalate OR 84-69-5”	16

DPENP	(Polyethylene OR 9002-88-4) refined with topic “DPENP OR di-n-pentyl phthalate OR 131-18-0”	0
DHEXP	(Polyethylene OR 9002-88-4) refined with topic “DHEXP OR di-n-hexyl phthalate OR 84-75-3”	0
DCHP	(Polyethylene OR 9002-88-4) refined with topic “DCHP OR dicyclohexyl phthalate OR 84-61-7”	153
	TOTAL HITS	102256

Name of Database:	Scopus http://www.scopus.com/home.url	
Date Conducted	7/15/15	
Limits placed on search	None	
Search terms	**Search String**	**Total number of hits**
Polyethylene AND		
phthalates	(Polyethylene OR 9002-88-4) AND (phthalate*)	268
toys	(Polyethylene OR 9002-88-4) AND (toy*)	132
Child care articles	(Polyethylene OR 9002-88-4) AND ("child care")	21
Child care articles	(Polyethylene OR 9002-88-4) AND ("car seat" OR "crib" OR "baby bed")	12
Child care articles	(Polyethylene OR 9002-88-4) AND ("pacifier" OR "teether")	2
Consumer products	(Polyethylene OR 9002-88-4) AND ("consumer product")	180
packaging	(Polyethylene OR 9002-88-4) AND (packaging) AND (phthalate*)	52
contamination	(Polyethylene OR 9002-88-4) AND (contaminat* OR leaching OR migration)	86
manufacturing	(Polyethylene OR 9002-88-4) AND (manufactur*)	26
Recycled materials	(Polyethylene OR 9002-88-4) AND (recycl* AND material*)	10
DEHP	(Polyethylene OR 9002-88-4) AND (DEHP OR di-2-ethylhexyl phthalate OR 117-81-7)	75
DBP	(Polyethylene OR 9002-88-4) AND (DBP OR dibutyl phthalate OR 84-74-2)	95
BBP	(Polyethylene OR 9002-88-4) AND (BBP OR benzyl butyl phthalate OR 85-68-7)	15
DINP	(Polyethylene OR 9002-88-4) AND (DINP OR diisononyl phthalate OR 28553-12-0 OR 68515-48-0)	4
DIDP	(Polyethylene OR 9002-88-4) AND (DIDP OR diisodecyl phthalate OR 26761-40-0 OR 68515-49-1)	6
DnOP	(Polyethylene OR 9002-88-4) AND (DnOP OR di-n-octyl phthalate OR 117-84-0)	4
DIOP	(Polyethylene OR 9002-88-4) AND (DIOP OR diisooctyl phthalate OR 27554-26-3)	1
DIBP	(Polyethylene OR 9002-88-4) AND (DIBP OR diisobutyl phthalate OR 84-69-5)	12
DPENP	(Polyethylene OR 9002-88-4) AND (DPENP OR di-n-pentyl phthalate OR 131-18-0)	0
DHEXP	(Polyethylene OR 9002-88-4) AND (DHEXP OR di-n-hexyl phthalate OR 84-75-3)	1
DCHP	(Polyethylene OR 9002-88-4) AND (DCHP OR dicyclohexyl phthalate OR 84-61-7)	1
	TOTAL HITS	1003

Name of Database:	Web of Science http://thomsonreuters.com/en/products-services/scholarly-scientific-research/scholarly-search-and-discovery/web-of-science.html	
Date Conducted	7/15/15	
Limits placed on search	None	
Search terms	**Search String**	**Total number of hits**
Polyethylene AND		
phthalates	(Polyethylene OR 9002-88-4) AND (phthalate*)	49
toys	(Polyethylene OR 9002-88-4) AND (toy*)	7
Child care articles	(Polyethylene OR 9002-88-4) AND ("child care")	8
Child care articles	(Polyethylene OR 9002-88-4) AND ("car seat" OR "crib" OR "baby bed")	87
Child care articles	(Polyethylene OR 9002-88-4) AND ("pacifier" OR "teether")	6
Consumer products	(Polyethylene OR 9002-88-4) AND ("consumer product")	113
packaging	(Polyethylene OR 9002-88-4) AND (packaging)	164
contamination	(Polyethylene OR 9002-88-4) AND (contaminat* OR leaching OR migration)	123
manufacturing	(Polyethylene OR 9002-88-4) AND (manufactur*)	326
Recycled materials	(Polyethylene OR 9002-88-4) AND (recycl* AND material*)	31
DEHP	(Polyethylene OR 9002-88-4) AND (DEHP OR di-2-ethylhexyl phthalate OR 117-81-7)	144
DBP	(Polyethylene OR 9002-88-4) AND (DBP OR dibutyl phthalate OR 84-74-2)	885
BBP	(Polyethylene OR 9002-88-4) AND (BBP OR benzyl butyl phthalate OR 85-68-7)	66
DINP	(Polyethylene OR 9002-88-4) AND (DINP OR diisononyl phthalate OR 28553-12-0 OR 68515-48-0)	56
DIDP	(Polyethylene OR 9002-88-4) AND (DIDP OR diisodecyl phthalate OR 26761-40-0 OR 68515-49-1)	65
DnOP	(Polyethylene OR 9002-88-4) AND (DnOP OR di-n-octyl phthalate OR 117-84-0)	42
DIOP	(Polyethylene OR 9002-88-4) AND (DIOP OR diisooctyl phthalate OR 27554-26-3)	38
DIBP	(Polyethylene OR 9002-88-4) AND (DIBP OR diisobutyl phthalate OR 84-69-5)	52
DPENP	(Polyethylene OR 9002-88-4) AND (DPENP OR di-n-pentyl phthalate OR 131-18-0)	0
DHEXP	(Polyethylene OR 9002-88-4) AND (DHEXP OR di-n-hexyl phthalate OR 84-75-3)	3

DCHP	(Polyethylene OR 9002-88-4) AND (DCHP OR dicyclohexyl phthalate OR 84-61-7)	39
	TOTAL HITS	2304

Name of Database:	CAB Abstracts http://www.cabdirect.org/	
Date Conducted	7/16/15	
Limits placed on search	None	
Search terms	**Search String**	**Total number of hits**
High impact polystyrene AND		
phthalates	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (phthalate*)	6
toys	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (toy*)	4
Child care articles	(High impact polystyrene OR “HIP” OR 9003-55-8) AND ("child care")	29
Child care articles	(High impact polystyrene OR “HIP” OR 9003-55-8) AND ("car seat" OR "crib" OR "baby bed")	0
Child care articles	(High impact polystyrene OR “HIP” OR 9003-55-8) AND ("pacifier" OR "teether")	0
Consumer products	(High impact polystyrene OR “HIP” OR 9003-55-8) AND ("consumer product")	2
packaging	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (packaging)	22
contamination	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (contaminat* OR leaching OR migration)	11
manufacturing	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (manufactur*)	118
Recycled materials	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (recycl* AND material*)	11
DEHP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DEHP OR di-2-ethylhexyl phthalate OR 117-81-7)	10
DBP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DBP OR dibutyl phthalate OR 84-74-2)	64
BBP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (BBP OR benzyl butyl phthalate OR 85-68-7)	5
DINP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DINP OR diisononyl phthalate OR 28553-12-0 OR 68515-48-0)	7
DIDP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DIDP OR diisodecyl phthalate OR 26761-40-0 OR 68515-49-1)	7
DnOP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DnOP OR di-n-octyl phthalate OR 117-84-0)	17
DIOP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DIOP OR diisooctyl phthalate OR 27554-26-3)	16
DIBP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DIBP OR diisobutyl phthalate OR 84-69-5)	31

DPENP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DPENP OR di-n-pentyl phthalate OR 131-18-0)	21
DHEXP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DHEXP OR di-n-hexyl phthalate OR 84-75-3)	31
DCHP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DCHP OR dicyclohexyl phthalate OR 84-61-7)	31
	TOTAL HITS	443

Name of Database:	SciFinder https://scifinder.cas.org/	
Date Conducted	7/16/15	
Limits placed on search	None	
Search terms	**Search String**	**Total number of hits**
High impact polystyrene AND		
phthalates	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic “phthalate”	105
toys	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic “toy”	146
Child care articles	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic "child"	2
Child care articles	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic ("car seat" OR "crib" OR "baby bed")	0
Child care articles	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic ("pacifier" OR "teether")	1
Consumer products	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic "consumer product"	31
packaging	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic “packaging” AND “phthalate”	7
contamination	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic (contaminate OR leaching OR migration)	115
manufacturing	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic “manufacture” AND “phthalate”	17
Recycled materials	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic “recycle” AND “material”	352
DEHP	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic “DEHP”	38
DBP	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic “DBP”	30
BBP	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic “BBP”	3
DINP	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic “DINP”	1
DIDP	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic “DIDP”	3
DnOP	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic “DnOP”	4
DIOP	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic “DIOP”	0
DIBP	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic “DIBP”	0

DPENP	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic “DPENP”	0
DHEXP	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic “DHEXP”	0
DCHP	(High impact polystyrene OR “HIP” OR 9003-55-8) then refined with topic “DCHP”	0
	TOTAL HITS	855

Name of Database:	Scopus http://www.scopus.com/home.url	
Date Conducted	7/16/15	
Limits placed on search	None	
Search terms	**Search String**	**Total number of hits**
High impact polystyrene AND		
phthalates	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (phthalate*)	1
toys	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (toy*)	3
Child care articles	(High impact polystyrene OR “HIP” OR 9003-55-8) AND ("child care")	0
Child care articles	(High impact polystyrene OR “HIP” OR 9003-55-8) AND ("car seat" OR "crib" OR "baby bed")	0
Child care articles	(High impact polystyrene OR “HIP” OR 9003-55-8) AND ("pacifier" OR "teether")	0
Consumer products	(High impact polystyrene OR “HIP” OR 9003-55-8) AND ("consumer product")	10
packaging	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (packaging)	91
contamination	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (contaminat* OR leaching OR migration)	91
manufacturing	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (manufactur*)	159
Recycled materials	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (recycl* AND material*)	117
DEHP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DEHP OR di-2-ethylhexyl phthalate OR 117-81-7)	0
DBP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DBP OR dibutyl phthalate OR 84-74-2)	0
BBP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (BBP OR benzyl butyl phthalate OR 85-68-7)	0
DINP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DINP OR diisononyl phthalate OR 28553-12-0 OR 68515-48-0)	0
DIDP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DIDP OR diisodecyl phthalate OR 26761-40-0 OR 68515-49-1)	0
DnOP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DnOP OR di-n-octyl phthalate OR 117-84-0)	0
DIOP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DIOP OR diisooctyl phthalate OR 27554-26-3)	0
DIBP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DIBP OR diisobutyl phthalate OR 84-69-5)	0

DPENP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DPENP OR di-n-pentyl phthalate OR 131-18-0)	0
DHEXP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DHEXP OR di-n-hexyl phthalate OR 84-75-3)	0
DCHP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DCHP OR dicyclohexyl phthalate OR 84-61-7)	0
	TOTAL HITS	472

Name of Database:	Web of Science http://thomsonreuters.com/en/products-services/scholarly-scientific-research/scholarly-search-and-discovery/web-of-science.html	
Date Conducted	7/16/15	
Limits placed on search	None	
Search terms	**Search String**	**Total number of hits**
High impact polystyrene AND		
phthalates	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (phthalate*)	48
toys	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (toy*)	202
Child care articles	(High impact polystyrene OR “HIP” OR 9003-55-8) AND ("child care")	31
Child care articles	(High impact polystyrene OR “HIP” OR 9003-55-8) AND ("car seat" OR "crib" OR "baby bed")	71
Child care articles	(High impact polystyrene OR “HIP” OR 9003-55-8) AND ("pacifier" OR "teether")	7
Consumer products	(High impact polystyrene OR “HIP” OR 9003-55-8) AND ("consumer product")	14
packaging	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (packaging)	4
contamination	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (contaminat* OR leaching OR migration)	0
manufacturing	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (manufactur*)	7
Recycled materials	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (recycl* AND material*)	1
DEHP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DEHP OR di-2-ethylhexyl phthalate OR 117-81-7)	4
DBP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DBP OR dibutyl phthalate OR 84-74-2)	368
BBP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (BBP OR benzyl butyl phthalate OR 85-68-7)	3
DINP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DINP OR diisononyl phthalate OR 28553-12-0 OR 68515-48-0)	2
DIDP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DIDP OR diisodecyl phthalate OR 26761-40-0 OR 68515-49-1)	0
DnOP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DnOP OR di-n-octyl phthalate OR 117-84-0)	0
DIOP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DIOP OR diisooctyl phthalate OR 27554-26-3)	0

DIBP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DIBP OR diisobutyl phthalate OR 84-69-5)	3
DPENP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DPENP OR di-n-pentyl phthalate OR 131-18-0)	0
DHEXP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DHEXP OR di-n-hexyl phthalate OR 84-75-3)	0
DCHP	(High impact polystyrene OR “HIP” OR 9003-55-8) AND (DCHP OR dicyclohexyl phthalate OR 84-61-7)	0
	TOTAL HITS	765

Name of Database:	CAB Abstracts http://www.cabdirect.org/	
Date Conducted	7/16/15	
Limits placed on search	None	
Search terms	**Search String**	**Total number of hits**
Acrylonitrile butadiene styrene AND		
phthalates	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (phthalate*)	0
toys	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (toy*)	0
Child care articles	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND ("child care")	0
Child care articles	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND ("car seat" OR "crib" OR "baby bed")	0
Child care articles	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND ("pacifier" OR "teether")	0
Consumer products	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND ("consumer product")	0
packaging	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (packaging)	1
contamination	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (contaminat* OR leaching OR migration)	2
manufacturing	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (manufactur*)	2
Recycled materials	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (recycl* AND material*)	0
DEHP	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (DEHP OR di-2-ethylhexyl phthalate OR 117-81-7)	0
DBP	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (DBP OR dibutyl phthalate OR 84-74-2)	0
BBP	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (BBP OR benzyl butyl phthalate OR 85-68-7)	0
DINP	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (DINP OR diisononyl phthalate OR 28553-12-0 OR 68515-48-0)	0
DIDP	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (DIDP OR diisodecyl phthalate OR 26761-40-0 OR 68515-49-1)	0
DnOP	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (DnOP OR di-n-octyl phthalate OR 117-84-0)	0
DIOP	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (DIOP OR diisooctyl phthalate OR 27554-26-3)	0
DIBP	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (DIBP OR diisobutyl phthalate OR 84-69-5)	0

DPENP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DPENP OR di-n-pentyl phthalate OR 131-18-0)	0
DHEXP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DHEXP OR di-n-hexyl phthalate OR 84-75-3)	0
DCHP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DCHP OR dicyclohexyl phthalate OR 84-61-7)	0
	TOTAL HITS	5

Name of Database:	SciFinder https://scifinder.cas.org/	
Date Conducted	7/16/15	
Limits placed on search	None	
Search terms	**Search String**	**Total number of hits**
Acrylonitrile butadiene styrene AND		
phthalates	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) refined with topic “phthalate” AND “contamination”	7
toys	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) refined with topic “phthalate” AND “toy*”	10
Child care articles	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND ("child care")	0
Child care articles	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) refined with topic "car seat" OR "crib" OR "baby bed"	13
Child care articles	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) refined with topic "pacifier" OR "teether"	40
Consumer products	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) refined with topic “consumer product”	135
packaging	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) refined with topic “phthalate” AND “packaging”	29
contamination	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) refined with topic “contaminat* OR leaching OR migration”	17
manufacturing	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) refined with topic “manufactur*” AND “phthalate”	177
Recycled materials	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (recycl* AND material*)	10
DEHP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) refined with topic (DEHP OR di-2-ethylhexyl phthalate OR 117-81-7)	247
DBP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) refined with topic (DBP OR dibutyl phthalate OR 84-74-2)	170
BBP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) refined with topic (BBP OR benzyl butyl phthalate OR 85-68-7)	20
DINP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) refined with topic (DINP OR diisononyl phthalate OR 28553-12-0 OR 68515-48-0)	30
DIDP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) refined with topic (DIDP OR diisodecyl phthalate OR 26761-40-0 OR 68515-49-1)	39
DnOP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) refined with topic (DnOP OR di-n-octyl phthalate OR 117-84-0)	28
DIOP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DIOP OR diisooctyl phthalate OR 27554-26-3)	0

DIBP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DIBP OR diisobutyl phthalate OR 84-69-5)	1
DPENP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DPENP OR di-n-pentyl phthalate OR 131-18-0)	0
DHEXP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DHEXP OR di-n-hexyl phthalate OR 84-75-3)	0
DCHP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DCHP OR dicyclohexyl phthalate OR 84-61-7)	19
	TOTAL HITS	992

Name of Database:	Scopus http://www.scopus.com/home.url	
Date Conducted	7/16/15	
Limits placed on search	None	
Search terms	**Search String**	**Total number of hits**
Acrylonitrile butadiene styrene AND		
phthalates	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (phthalate*)	11
toys	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (toy*)	7
Child care articles	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND ("child care")	0
Child care articles	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND ("car seat" OR "crib" OR "baby bed")	0
Child care articles	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND ("pacifier" OR "teether")	0
Consumer products	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND ("consumer product")	9
packaging	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (packaging)	40
contamination	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (contaminat* OR leaching OR migration)	55
manufacturing	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (manufactur*)	279
Recycled materials	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (recycl* AND material*)	117
DEHP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DEHP OR di-2-ethylhexyl phthalate OR 117-81-7)	0
DBP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DBP OR dibutyl phthalate OR 84-74-2)	1
BBP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (BBP OR benzyl butyl phthalate OR 85-68-7)	0
DINP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DINP OR diisononyl phthalate OR 28553-12-0 OR 68515-48-0)	2
DIDP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DIDP OR diisodecyl phthalate OR 26761-40-0 OR 68515-49-1)	0
DnOP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DnOP OR di-n-octyl phthalate OR 117-84-0)	0
DIOP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DIOP OR diisooctyl phthalate OR 27554-26-3)	0
DIBP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DIBP OR diisobutyl phthalate OR 84-69-5)	0

DPENP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DPENP OR di-n-pentyl phthalate OR 131-18-0)	0
DHEXP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DHEXP OR di-n-hexyl phthalate OR 84-75-3)	0
DCHP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DCHP OR dicyclohexyl phthalate OR 84-61-7)	0
	TOTAL HITS	521

Name of Database:	Web of Science http://thomsonreuters.com/en/products-services/scholarly-scientific-research/scholarly-search-and-discovery/web-of-science.html	
Date Conducted	7/16/15	
Limits placed on search	None	
Search terms	**Search String**	**Total number of hits**
Acrylonitrile butadiene styrene AND		
phthalates	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (phthalate*)	363
toys	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (toy*)	250
Child care articles	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND ("child care")	2
Child care articles	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND ("car seat" OR "crib" OR "baby bed")	4
Child care articles	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND ("pacifier" OR "teether")	0
Consumer products	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND ("consumer product")	9
packaging	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (packaging)	11
contamination	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (contaminat* OR leaching OR migration)	7
manufacturing	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (manufactur*)	36
Recycled materials	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (recycl* AND material*)	4
DEHP	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (DEHP OR di-2-ethylhexyl phthalate OR 117-81-7)	16
DBP	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (DBP OR dibutyl phthalate OR 84-74-2)	116
BBP	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (BBP OR benzyl butyl phthalate OR 85-68-7)	7
DINP	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (DINP OR diisononyl phthalate OR 28553-12-0 OR 68515-48-0)	8
DIDP	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (DIDP OR diisodecyl phthalate OR 26761-40-0 OR 68515-49-1)	14
DnOP	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (DnOP OR di-n-octyl phthalate OR 117-84-0)	10
DIOP	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-9) AND (DIOP OR diisooctyl phthalate OR 27554-26-3)	10
DIBP	(Acrylonitrile butadiene styrene OR "ABS" OR 9003-56-	9

	9) AND (DIBP OR diisobutyl phthalate OR 84-69-5)	
DPENP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DPENP OR di-n-pentyl phthalate OR 131-18-0)	0
DHEXP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DHEXP OR di-n-hexyl phthalate OR 84-75-3)	0
DCHP	(Acrylonitrile butadiene styrene OR “ABS” OR 9003-56-9) AND (DCHP OR dicyclohexyl phthalate OR 84-61-7)	6
	TOTAL HITS	882

11 Appendix D. Overview of Plastics Recycling

This Appendix provides an overview of the various processes used for recycling of the plastics of interest to this project.

11.1 Recycling of Plastics

Plastic recycling is the process of recovering scrap or waste plastics and reprocessing material into useful products, sometimes completely different in form from their original state (Merrington, 2011). Recycling of plastic presents difficulties that explain, in part, the low percentage of plastics recycled. There are many different kinds of plastics with different physical and chemical properties, and plastic waste can contain many different metals, glasses, rubbers, or plastics. Mixtures of plastics that can be made during the recycling process results in a heterogeneous plastic with mechanical properties that are inferior to the virgin plastic. This causes a need to separate or sort waste plastics. Furthermore, during usage and the recycling process, the plastic is degraded. Thus, products made from recycled plastics can have reduced or inferior properties (Fisher, 2005). In some cases, additives are included to meet application needs or rejuvenate the properties diminished by use or the recycling process (Merrington, 2011).

In general, recycling efforts can be divided into four major types or processes: 1) mechanical recycling, 2) thermal reprocessing, 3) chemical recycling, and 4) energy recovery. Other processes include dissolution based recycling that uses acetone as a solvent (Arostegui et al., 2006), and reuse where beverage plastic bottles are returned, cleaned and reused (Hamad et al., 2013). The following is a description of these processes.

11.2 Mechanical recycling

Mechanical recycling or secondary recycling is a process of recovering solid waste by mechanical means for reuse in manufacturing (Al-Salem et al., 2009). Mechanical (or physical) means start by sorting; shortwave infrared (SWIR) hyperspectral imaging has been successfully used to sort PP, PE, PVC, PET and PS (Karaca et al., 2013). The recovered plastic is melted and molded into a new product. This recycling process is limited to thermoplastics (plastics that can melt); the recycled plastic should be exclusively of one kind of plastic in order to yield a reusable pure product (Dreher et al., 2004). An example of this is damaged crates made from PP or HDPE for packaging of fruits and vegetables or meat products. These damaged crates are separated based on type of plastic and then ground into flakes. The regrind is washed and dried to remove potential adhering contamination. This provides recycled PP or HDPE material for the

production of new crates by injection molding with or without blending with virgin material (EFSA (European Food Safety Authority), 2013). The following is an illustration of the various steps in the mechanical recycling process. The first step is to cut the large plastics into small pieces or flakes, removal of paper and dust and then floating the plastic flakes is done to remove any different type of plastic (plastics are separated by density). The recycling starts by milling or grinding the plastic followed by washing. The product is gathered together (agglutination), melted, and then forced through a die (extrusion) into strands or pellets. The product is cooled and then granulated into the final product.

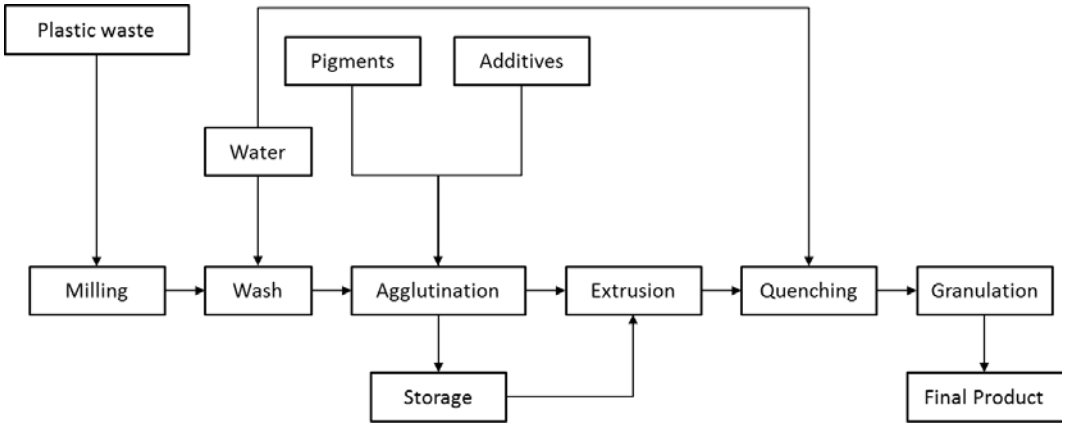


Figure 2. Mechanical recycling steps as described in Al-Salem et al., 2009.

Recycled plastics (LDPE, PET, and PVC) are frequently mixed with the specific virgin plastic in the manufacture of a new product. The amount of the recycled material in relation to the new or virgin plastic is variable and has an effect on the impact strength, hardness and tensile strength of the final product. In general, the mechanical properties of the recycle/virgin blend depends on the characteristic of the recycled plastic (Marulanda et al., 2014).

11.3 Thermal Reprocessing

Thermal Reprocessing (also called thermal pyrolysis) consists of heating a thermoplastic to high temperatures converting the solid plastic to a liquid (Siddique, 2008 p102/3). The plastic can be converted or remolded into a new product. This method does not involve the modification of the chemical composition of the plastics. For example, CDs made of HIPS can be heated and styrene monomer can be recovered (Antonakou et al., 2014). An initial mechanical sorting is most likely required since separation of liquids with similar densities can be difficult.

11.4 Chemical Recycling

Chemical recycling or tertiary or “feed stock” (Dreher et al., 2004) recycling is an advanced technology process resulting in depolymerization of the plastic converting the plastic materials into smaller molecules suitable for use as a feedstock or starting material for the production of new petrochemicals and plastics (Al-Salem et al., 2009). An example of tertiary recycling is using a polymer blend of polylactic acid/polyethylene (PLA/PE) (Hamad et al., 2013). Two methods for PLA/PE chemical recycling are direct separation and by the selective degradation of PLA in the PLA/PE blend. The end product PE remains unchanged and can be recovered by a reprecipitation method for material recycling.

The advantage of chemical recycling is that waste plastic can be a heterogeneous mixture of plastics and can be used if they contain possible contaminates or toxicants. Chemical recycling provides a high yield of product with minimum waste and can be profitable (Al-Salem et al., 2009).

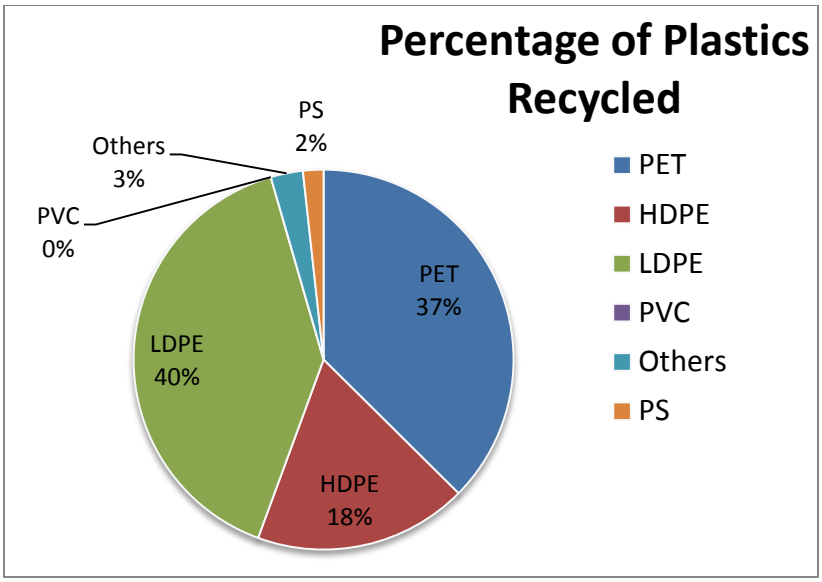
11.5 Energy Recovery

Energy Recovery is the burning of plastic waste to produce energy. All types and mixture of thermogenic plastic or plastics that can be melted can be used as a substitute for traditional fuel (Dreher et al., 2004). Plastic materials have a very high calorific value comparable to oil (see Table 11 in Al-Salem et al., 2009). Plastics solid waste is derived from petroleum and thus has recoverable energy comparable to other energy sources.

Most single resins or single plastic types undergo a similar basic recycling process. The plastics are collected, transported to a recycling facility, separated by resin/type, washed and dried to remove debris, then ground into flake or pelletized.

11.6 Volumes of Recycled Plastics

The most widely recyled thermoplastic for the year 2007 was PE (as reported in Merrington, 2011.)



Other thermoplastics included, polyamides (nylon 6, nylon 6,6, etc.), polycarbonates (PC), acrylics (polymethyl methacrylate (PMMA), styrenics (acrylonitrile butadiene styrene ABS), and blends (thermoplastic polyolefin TPO, PC/ABS, etc.).

11.7 Problems associated with the use of recycled plastics.

The recycling process yields a recovered plastic that can be useful but it can also cause a degradation of the recovered product (Zitting, 1998). The degradation is a complex process related to the forces of mechanical processing, melting temperature (thermo-oxidation) or mechanical-thermo degradation (an increase in temperature created by the mechanical force) (Najafi, 2013). This can result in the following changes in the recovered plastic (Takatori, 2014):

1. Irreversible changes in the molecular structure or higher order structure during the recycling process
2. Deformation caused by heat used in the process
3. Chemical reactions occur during the process can result in changes in the chemical structure
4. Accumulation of metal catalysis residues

Recently, Marulanda et al. (2014) examined the effects of how variation in the ratio of recycled to virgin plastic with LDPE, PET and PVC impact the properties of these plastics. Variation in the content of recycled plastics altered the impact strength,

hardness, and tensile strength; pointing to the critical importance of a careful characterization of the recycled material before reuse.

In addition to problems of degraded properties the recycled plastics can be contaminated or have higher levels of potential toxic chemicals. Analysis of WEEE recycled plastics showed 200 ppm of lead and 70 ppm of cadmium (Stenvall et al., 2013). Major constituents of WEEE were styrene-based plastics (84 wt %) and consisted mainly of ABS (including ABS + acrylate, ABS + ester and styrene–acrylonitrile copolymer) and HIPS (including PS + acrylate and poly (vinyl cyclohexane) (Stenvall et al., 2013).

The main drawback that obstructs material recovery of HIPS and ABS from WEEE is the wide variety of polymers that are being used, which result in elaborate sorting and recycling processes.

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