Plastics Scorecard

Evaluating the Chemical Footprint of Plastics

CLEAN PRODUCTION ACTION

THE PLASTICS SCORECARD

Evaluating the Chemical Footprint of Plastics

VERSION 1.0

Mark S. Rossi, Ph.D. and Ann Blake, Ph.D.

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CLEAN PRODUCTION ACTION

Clean Production Action designs and delivers strategic solutions for
green chemicals, sustainable materials and environmentally preferable products

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Acknowledgements

The Plastics Scorecard v1.0 is the result of years of discussions, debates, pilots, and drafts on how best to integrate concerns with human health and the environment as well as desires for safer chemicals across the life cycle of plastics into a robust, replicable, and transparent method that will ideally shape how manufacturers and markets develop and select plastic products.

On the path to *v1.0* many individuals shaped its development. In the early years, Tim Greiner, Alexandra McPherson, and Beverley Thorpe helped to birth the *beta version*. Pilots with Mike Belliveau and Shari Franjevic revealed fatal flaws in the *beta version*. Monica Becker and Mikhail Davis, former and current co-chairs of the BizNGO Sustainable Materials Work Group were critical to resurrecting, re-directing, and re-energizing development of *v1.0*. Without their guidance and thoughtfulness the Plastics Scorecard would be a much different resource.

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On behalf of all us interested in making plastics the truly sustainable polymers they should be, your humblest of chroniclers,

Ann Blake & Mark Rossi

DESIGN
David Gerratt
NonprofitDesign.com

COVER PHOTO

Glossary of Terms

Additive
Material added to a polymer to enhance processability, performance, or aesthetics. The major types of plastic additives include: antioxidants, antistatic agents, blowing agents, colorants, flame retardants, impact modifiers, lubricants, plasticizers, and heat and ultraviolet (UV) light stabilizers. Article 3.1 of REACH includes the definition of additive within the definition of *substance* as "a chemical element and its compounds in the natural state or obtained by any manufacturing process, including any additive necessary to preserve its stability and any impurity deriving from the process used, but excluding any solvent which may be separated without affecting the stability of the substance or changing its composition" (REACH, 2006).

Catalyst
Chemical substance that causes or accelerates a chemical reaction without itself being affected.

Chemical Feedstock
For plastic production, chemical feedstocks can be derived from fossil fuels (crude oil, natural gas, and coal) or bio-based resources. Crude oil feedstocks are derived from the "cracking" and distillation (separation) of the feedstock. Feedstocks from natural gas are derived from the processing or separation of that raw material. These processes yield the feedstocks ethane, propane, butane, methane and others. Sources of biobased chemicals include algae, corn, sugarcane, sugar beets, potatoes, and other biological feedstocks.

Chemical Footprint
The measure by number and mass of chemicals of high concern, as determined by hazard level, in products and supply chains (CPA, 2014).

Chemical of High Concern (CoHC)
Substance that has any of the following properties: 1) persistent, bioaccumulative and toxic (PBT); 2) very persistent and very bioaccumulative (vPvB); 3) very persistent and toxic (vPT); 4) very bioaccumulative and toxic (vBT); 5) carcinogenic; 6) mutagenic; 7) reproductive or developmental toxicant; 8) endocrine disruptor; or 9) neurotoxicant. "Toxic" (T) includes both human toxicity and ecotoxicity (BizNGO, 2008).

Compounded Plastic Product
A product or material consisting of a polymer and a package of additives (for example, colorants, softeners, and flame retardants).

Homogeneous Material
As defined by the European Union, Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS), a "homogeneous material is either: 1) A material with a uniform composition throughout; or 2) A material that consists of a combination of materials, that cannot be disjointed or separated into different materials by mechanical actions such as unscrewing, cutting, crushing, grinding or abrasive processes. Examples of homogeneous materials include a plastic cover to a computer screen, a copper wire inside a cable, and the solder part of a solder joint" (European Commission, 2012a).

Intermediate Chemical
Chemical produced by the chemical conversion of primary chemicals to more complicated derivative products such as ethylbenzene, ethylene dichloride, and lactic acid.

Monomer
The molecular unit from which polymers are prepared. REACH Article 3(6) defines a monomer as "a substance which is capable of forming covalent bonds with a sequence of additional like or unlike molecules under the conditions of the relevant polymer-forming reaction used for that particular process" (REACH, 2006).

Mixture
A formulated mixture of single chemicals and impurities (e.g., liquid cleaning product, fragrances, lotions, printing ink). With respect to polymers, European Commission (2012b) states that "when a polymeric material contains such substances [e.g., stabilisers and impurities] it should be considered as a mixture or an article."

Plastic
Generically, a polymer and/or the product made from the polymer through its entire life cycle. The European Commission Review of REACH with Regard to the Registration Requirements on Polymers, (2012b), p. 34, states that "The term 'plastics' is used to describe plastic polymers with additives to enable processing and/or give the properties needed for a desired application . . . [including] . . . polymer substances, . . . polymer substances in mixtures and final articles."

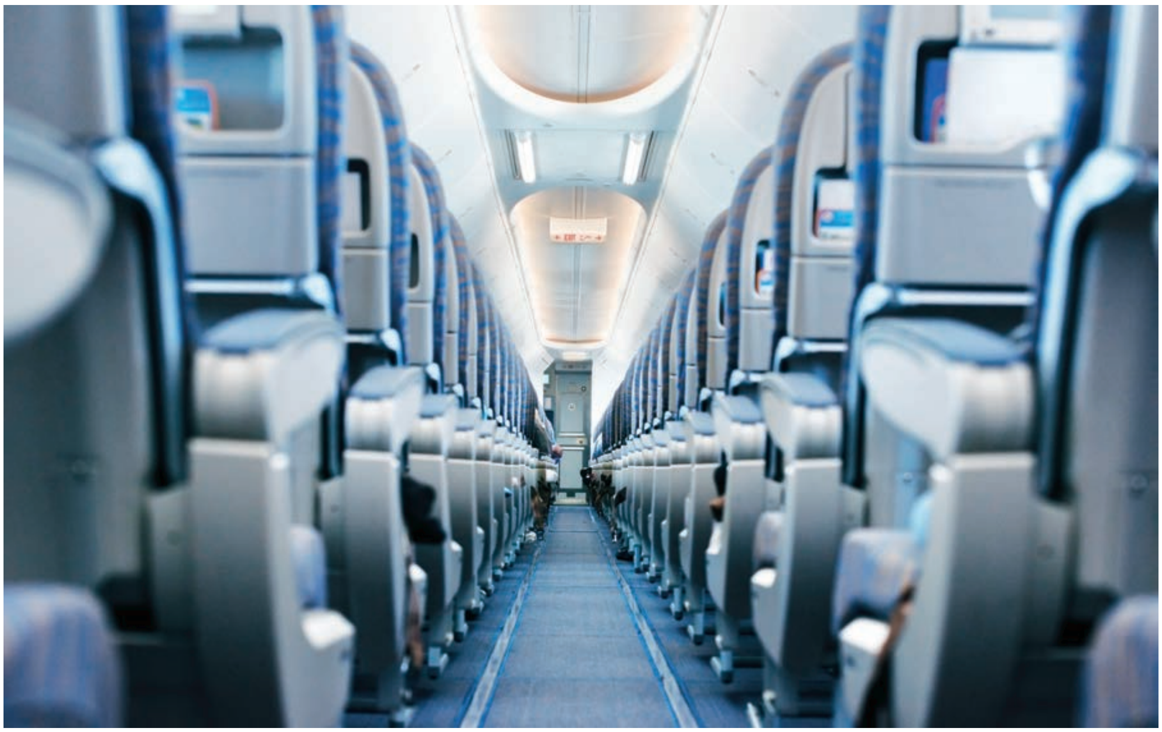
Plastic Compounding
The process of preparing plastic materials with desired properties by mixing or blending polymers and additives in a molten state.

Polymer
Long chain of molecules made from repeating parts, called monomers, which are a product of a polymerization reaction. A polymer can be natural or synthetic. In relation to a "compounded plastic product", "polymer" is the stage prior to the addition of performance additives. REACH Article 3(5) defines "polymer substance" as "a substance consisting of molecules characterized by the sequence of one or more types of monomer units" (REACH, 2006).

Polymeric materials
A special kind of formulated mixture made of polymers and typically containing additives to improve performance (e.g., compounded plastics, adhesives, foams, and resins). Polymeric Material is a broad term used to describe plastics, resins, adhesives, foams, etc. The European Commission (2012b) Review of REACH with Regard to the Registration Requirements of Polymers defines *Polymer materials/products* as "mixtures of polymer substances and other additive substances, such as plasticisers."

Primary chemicals
The building block chemicals that the vast majority of other chemicals and plastics are manufactured from. Fossil fuel-based primary chemicals derived from petroleum include: ethylene, propylene and butadiene (olefins); benzene, toluene, and xylene (aromatics); and methanol. Biobased primary chemicals include sugars (glucose) and ethanol from corn.

Executive Summary



Plastics are ubiquitous in our modern lives and provide benefits to people across the globe. Lightweight, durable, flexible and easy to form, their use continues to grow rapidly. Cell phones, baby car seats, blood bags, backpacks, chairs, cars, and clothing are among the many products made with plastics and reflect their beneficial properties. Yet plastic litter, gyres of plastics in the oceans, and toxic additives in plastic products are raising public awareness, consumer demand, retail pressure, and regulations for a more sustainable material.

Businesses, hospitals, and individuals are increasingly seeking plastics that are more sustainable across their life cycle—from raw material extraction to manufacturing to use to end of life. They want to know the sources of the plastic's raw materials, if a plastic contains chemicals of high concern (CoHCs)[1] to human health or the environment, the plastic's carbon footprint, its recycled content and whether it is recyclable, compostable, or biodegradable in the environment. Existing tools cover aspects of these life cycle areas of interest, however, they do not focus on the inherent hazards of

1 BizNGO (2008) defines "chemical of high concern" as having the following properties: 1) persistent, bioaccumulative and toxic (PBT); 2) very persistent and very bioaccumulative (vPvB); 3) very persistent and toxic (vPT); 4) very bioaccumulative and toxic (vBT); 5) carcinogenic; 6) mutagenic; 7) reproductive or developmental toxicant; 8) endocrine disruptor; or 9) neurotoxicant. Toxic, or T, includes both human toxicity and ecotoxicity.

the chemicals used to manufacture polymers and contained within plastic products.

The Plastics Scorecard is a method for evaluating the chemical footprint of plastics and a guide for selecting safer alternatives. Version 1.0 (v1.0) addresses the progress to safer chemicals in plastics manufacturing and the chemical footprint of plastic products. Chemical footprinting is the process of assessing progress toward the use of safer chemicals and away from CoHCs. Clean Production Action defines chemical footprint as the number and mass of CoHCs used in manufacturing and supply chains, and contained in the final product.

The use of inherently safer chemicals in manufacturing will greatly reduce the costs of hazardous chemicals all along the plastics life cycle, from manufacturing to usage to end of life management.

The goals of the Plastics Scorecard are to inform the selection of safer plastics by businesses and catalyze manufacturers to reduce the number and volume of CoHCs in manufacturing processes and products. If successful the Plastics Scorecard will advance the development and use of plastics that use inherently safer chemicals in all steps of polymer production as well as in the selection of additives. The use of inherently safer chemicals in manufacturing will greatly reduce the costs of hazardous chemicals all along the plastics life cycle, from manufacturing to usage to end of life management. The Plastics Scorecard is for anyone interested in identifying and selecting plastics based on inherently less hazardous chemicals. Product designers, material specifiers, and purchasers will all find value in both the criteria for evaluating plastics as well as the assessments of individual plastics.

The Plastics Scorecard v1.0 report addresses:

- Why Plastics? The deep and impactful connections between plastics, chemicals, human health, and the environment.
- Method for Measuring the Chemical Footprint of Plastics:
  - evaluating progress to safer chemicals in polymer manufacturing and
  - evaluating the chemical footprint of plastic products.
- Key Findings
  - Benchmarking polymer progress to safer chemicals.
  - Chemical footprints of plastic intravenous (IV) bags and electronic enclosures.
- Strategies for Reducing the Chemical Footprint of Plastics

Why Plastics

Synthetic plastics are a newcomer to the family of materials manufactured and used by humans. Over the past 70 years, plastics have grown from a bit player in the material economy—with less than a million pounds produced globally in 1944—to a material behemoth, with global production at 288 million metric tons in 2012. Producing those 634 billion pounds of plastics requires a huge input of chemicals, many of which are CoHCs. The chemical inputs into plastics manufacturing are, in turn, manufactured largely from fossil fuels—millions of barrels of crude oil and cubic feet of natural gas are the raw materials for chemicals used to manufacture plastics, with plastics manufacturing and its associated energy consumption accounting for 7–8% of total oil and gas consumption globally.

Reducing the chemical footprint of plastics is a significant challenge. Starting from their feedstock base of fossil fuels, plastics rely on chemicals of high concern to human health or the environment that result from the refining of crude oil and the processing of natural gas. The plastic pathway from feedstock to polymer to final plastic is littered with CoHCs. Of the CoHCs consumed in polymer manufacturing, plastics represent approximately 244 million metric tons or 90% of the markets for those chemicals. Among those CoHCs are well known, highly hazardous chemicals, including benzene, Bisphenol A (BPA), styrene, and vinyl chloride monomer (VCM).

Exposure to a wide array and high volume of CoHCs during manufacturing, usage, and disposal poses a significant risk to the health of workers, communities, and the global environment. Reducing CoHCs in manufacturing will help to improve the health and safety of workers and communities, both by reducing the number of potentially hazardous chemicals and their overall volume. For example, recent studies find that "workers carry a body burden of plastics-related contaminants that far exceeds those documented in the general public . . . existing epidemiologic and biological evidence indicates that women in the plastics industry are developing breast cancer and experiencing reproductive problems at elevated rates as a result of these workplace exposures" (DeMatteo, et al., 2011). In addition, safer chemicals and materials can generate innovative new markets for companies, workers, and communities alike.

Current initiatives in the health care, apparel and footwear, and building products sectors highlight the drivers for incorporating safer chemistry in decisions on plastics and other materials, the attributes considered, and the methods that these sectors use to assess and select safer plastics. These practices are driven by a range of motivations, including: regulatory compliance, marketplace advantage, environmental certifications and standards, government procurement specifications, and corporate commitments to actively avoid CoHCs.

Method

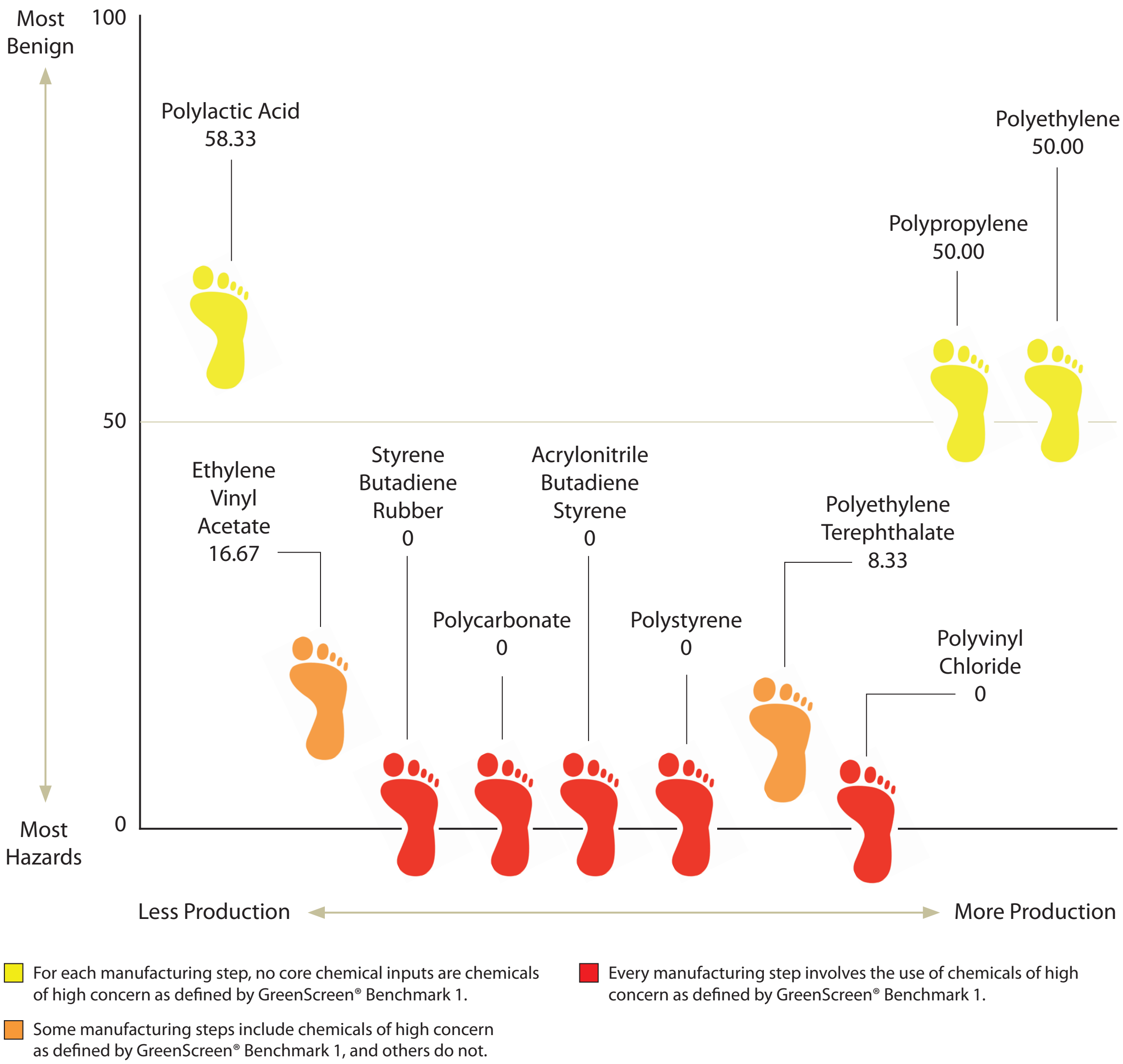
The Plastics Scorecard v1.0 differentiates between chemicals used in polymer manufacturing and contained in the final plastic product, creating methods that score:

1. polymers on their progress to safer chemicals in the core steps of polymer manufacturing; and
2. plastic products on their chemical footprint.

The Progress to Safer Chemicals in Polymer Manufacturing Score assesses the hazards associated with polymer manufacturing by evaluating the core chemical inputs of the manufacturing process: primary chemicals, intermediate chemicals, and monomers. For example, in evaluating the manufacture of the polymer, polystyrene, v1.0 scores each stage of manufacturing based on the hazards of the primary input chemicals and then aggregates them into a single score that ranks polymers from 0 (most hazards) to 100 (most benign). Polystyrene, for example, was scored based on its primary chemicals of ethylene and benzene, its intermediate chemical of ethylbenzene, and its monomer of styrene.

Photo: © iStockphoto/Utkucavuskizil

FIGURE ES-1 **Progress to Safer Chemicals in Polymer Manufacturing**



The Chemical Footprint of Plastic Products scores products on both the number and percent by weight of CoHCs in a final, plastic product.

Key Findings—Progress to Safer Chemicals in Polymer Manufacturing

Given the number of CoHCs associated with plastics, it is not surprising that five out of the ten polymers—ABS, PC, PS, PVC, SBR[2]—evaluated for their progress to safer chemicals in manufacturing scored 0 out of 100 in the Plastics Scorecard—scoring a "0" overall means that for each manufacturing stage the polymer uses a CoHC as a primary input. An ideal polymer based on low hazard chemicals would score 100. Three polymers—polyethylene, polypropylene, and polylactic acid (PLA)—scored 50 or above and are making the greatest progress to safer chemicals in manufacturing, while EVA and PET are making some progress beyond chemicals of high concern (see Figure ES-1).

It is clear that manufacturers can make significant progress towards producing polymers from

2 ABS=Acrylonitrile Butadiene Styrene; PC=Polycarbonate; PS=Polystyrene; PVC=Polyvinyl Chloride; and SBR=Styrene Butadiene Rubber.

inherently safer chemicals. PLA is a significant example of that. A newcomer to the commodity market of polymers, PLA had the best score in terms of progress to safer chemicals in manufacturing. Yet its score of 58 out of 100 illustrates the challenges of producing plastics from low hazard chemicals. PLA is not a green polymer by any means, but it is the greenest in terms of progress to safer chemicals in manufacturing of the ten polymers evaluated in v1.0 of the Plastics Scorecard.

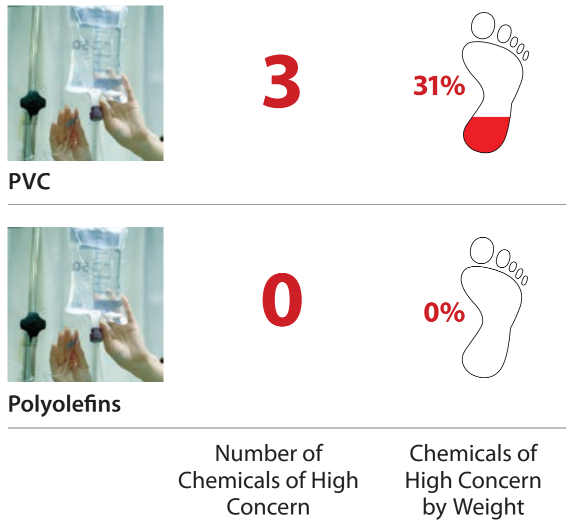
Figure ES-1 graphically illustrates the scoring of 10 polymers on their progress to safer chemicals. On the y-axis is progress to safer chemicals and on the x-axis is volume of production. Thus the polymers that are most widely produced and making the greatest progress to safer chemicals are polyethylene and polypropylene, while PLA is an emerging polymer that has made significant progress to safer chemicals but is produced in significantly smaller volumes than the other polymers.

Key Findings—Chemical Footprint of Plastic IV Bags

The chemical footprint of a plastic product measures the number and weight (or percent weight) of CoHCs in a homogeneous plastic product, be it a component such as a plastic case around a computer monitor or a plastic "rubber" duck. The homogeneous plastic product is a "compounded plastic product" because it includes both the polymer and the additives. The Plastics Scorecard v1.0 scored two plastic products for two categories of products—intravenous (IV) bags and electronic enclosures—on their chemical footprints.

Polyolefin IV bags have a much lower chemical footprint than the PVC/DEHP (di(2-ethylhexyl) phthalate) IV bags. Figure ES-2 illustrates the benefits of using polyolefins versus PVC/DEHP: they reduce the number of estimated CoHCs from three to zero and reduce the percent of estimated CoHCs by weight from 30% to 0%. PVC/DEHP IV bags contain a significant percentage of CoHCs: 30% DEHP and 0.5% BPA —in comparison to the estimated 0% for polyolefins. In addition, the polyolefin polymers (polyethylene and polypropylene) score much higher, 50.0,

FIGURE ES-2 **Estimated Chemical Footprint of IV Bags Made from PVC/DEHP and Polyolefins**



PVC = Polyvinyl chloride; DEHP = di(2-ethylhexyl) phthalate

on the Plastics Scorecard's Progress to Safer Chemicals in Polymer Manufacturing Score than PVC, which scores 0.0 (see Figure ES-1).

In switching from PVC/DEHP to polyolefin-based IV bags Dignity Health reduced its chemical footprint by over 700,000 pounds over a six year period. Dignity Health eliminated the use of 673,023 pounds of DEHP (a reproductive, developmental toxicant) and 33,651 pounds of BPA (an endocrine disruptor) from 2008–2013. This example demonstrates how chemical footprinting provides a clear metric for measuring of progress to safer chemicals.

Key Findings—Chemical Footprint of Plastic Electronic Enclosures

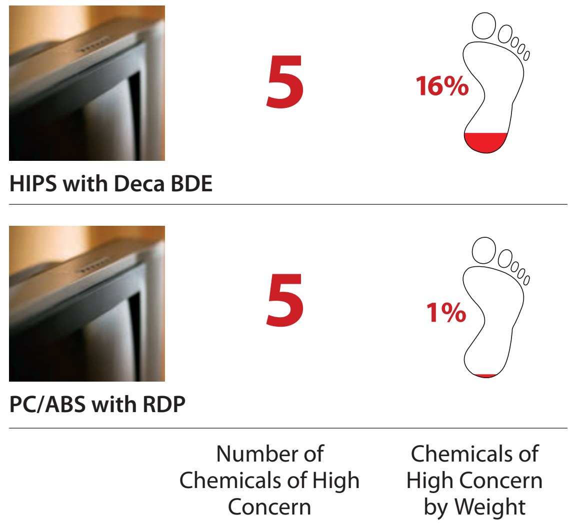
The electronic enclosures example compared products made from High Impact Polystyrene (HIPS) flame retarded with decabromodiphenyl ether (decaBDE) to products made from Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS) flame retarded with Resorcinol bis(diphenyl phosphate) (RDP). Figure ES-3 illustrates how PC/ABS with RDP reduces the percent weight of CoHCs in comparison to HIPS/decaBDE electronic enclosures by 15%. The key actor in the beneficial result is the elimination of the CoHC, decaBDE, and its replacement with

Photo: © Thinkstockphoto/whitetag

RDP. While RDP is by no means a green flame retardant, its ingredients overall are less hazardous than decaBDE. The electronic enclosures story is one where the opportunities for greening are fairly limited. Given price and performance needs, PC/ABS is the most effective solution. While the volume of CoHCs decline with RDP, the number of CoHCs in the product remains unchanged. And similarly the Progress to Safer Chemicals in Polymer Manufacturing remains grounded at 0.0 for both PC/ABS and Polystyrene (see Figure ES-1, and compare the polymers: PS, PC, and ABS).

Is PC/ABS with RDP a regrettable substitution? The above data indicate it is not, and at the

FIGURE ES-3 **Estimated Chemical Footprint of Electronic Enclosures Made from HIPS with DecaBDE & PC/ABS with RDP**



ABS = Acrylonitrile Butadiene Styrene; DecaBDE = Decabromodiphenyl Ether; PC = Polycarbonate; RDP = Resorcinol Diphenylphosphate

aggregate level it results in a significant reduction in CoHCs by percent weight. Yet there are many unknowns. The science on the health effects of phosphorous-based chemistry continues to develop and to date unknown health hazards may arise with this chemistry. At the same time, the small amounts of unknown additives as well as the residual monomers (like BPA in polycarbonate) may prove to be problematic in the future. It is clear PC/ABS with RDP is a less bad solution, but it is hardly an optimal solution.

The chemical footprints of IV bags and electronic enclosures clearly demonstrate that material designers and purchasers can select alternative products based on safer chemistries and can document that progress. Yet it is important to note that knowledge gaps were an issue for both the electronic enclosures and IV bag comparisons. Gaining a comprehensive list of all additives by Chemical Abstracts Services Registry Number (CAS #), along with levels of residual monomers and catalysts, was not possible for any product. This lack of information makes it impossible to ascertain whether significant, but unknown CoHCs lurk in the plastic formulations. The knowledge gap in chemical inventories for plastic products is a barrier to accuracy with chemical footprints that will require persistence

Photo: (top) © Thinkstockphoto/agencyby; (bottom) © Thinkstockphoto/UltraONEs in terms of asking for the data from all companies in a supply chain to resolve.

Strategies for Reducing the Chemical Footprint of Plastics

The Plastics Scorecard provides value to both those that want to demonstrate the lowered chemical footprint of their polymer or product, as well as for those designers, specifiers, and purchasers who want to select products with a lesser chemical footprint. Reducing the chemical footprint of plastics is a challenging endeavor; these potential approaches provide a path forward:

- First ask, is it necessary?
- Use safer additives.
- Use safer polymers.
- Close the loop and use post-consumer recycled (PCR) content (but beware of legacy CoHCs).
- Redesign the product.

Plastics markets are shifting more quickly to safer additive packages because that is often the easiest route to reducing the chemical footprint of a plastic product. Witness the PVC industry's recent plans to eliminate the use of lead and cadmium stabilizers, certain phthalates like DEHP, and BPA. Reducing the use of CoHCs in plastics is good news, but as the Progress to Safer Chemicals in Polymer Manufacturing component of the Plastics Scorecard illustrates, safer additive packages on their own do not reduce the hazards of polymer manufacturing.

Among the challenges of effectively evaluating the hazards of additives include the absence of relevant publically available data for the various additive chemistries, as well as the total number of classes of additives utilized. This is another area ripe for research and potentially an opportunity for green chemistry solutions. As the movement to safer additive packages grows what will become increasingly significant is the small amounts of CoHCs and residual monomers and catalysts in plastic products. The knowledge gaps on chemicals in additive packages will become increasingly significant along with the necessity for full hazard assessments of the substitutes.

As companies move away from well-known CoHCs it will drive down the percentage of CoHCs in products. What will remain are questions around the hazard profiles of the alternatives as well as the small amounts of CoHCs in products, like residual BPA monomer.

Manufacturers and purchasers are making significant progress on the pathway to safer chemicals in plastics. From polymer manufacturing to final products, safer chemicals use is growing. That said, much progress is still to be achieved. The plastics economy, from cradle to grave, remains one based on CoHCs. The Plastics Scorecard v1.0 presents a novel method for evaluating the chemical footprint of plastics, selecting safer alternatives, and measuring progress away from CoHCs. Version 1.0 will support the design, production, and selection of safer plastics.

The Plastics Scorecard provides value to both those that want to demonstrate the lowered chemical footprint of their product, as well as for those who want to select products with a lesser chemical footprint.

The overarching philosophy that underpins v1.0 is that the optimum route to addressing the life cycle concerns of chemicals in plastics is to use inherently safer chemicals in manufacturing and in products, thereby eliminating concerns surrounding CoHCs in manufacturing, usage, and end of life management of plastics. Hazardous chemicals in plastics create legacy issues that block closed loop systems. To effectively close the loop plastics need safer chemical inputs. Polymers are a bedrock of nature and the human economy—now the challenge is making plastics that are safer for humanity and the environment.

CHAPTER 1

Introduction

Plastics are ubiquitous in our modern lives and provide benefits to people across the globe. Lightweight, durable, flexible, and easy to form, their use continues to grow rapidly. Cell phones, baby car seats, blood bags, backpacks, chairs, cars, and clothing are among the many products made with plastics and reflect their beneficial properties. Yet plastic litter, gyres of plastics in the oceans, and toxic additives in plastic products are raising public awareness, consumer demand, retail pressure, and regulations for a more sustainable material.

Businesses, hospitals and individuals are increasingly seeking plastics that are more sustainable across their life cycle—from raw material extraction to manufacturing to use to end of life. They want to know the sources of a plastic's raw materials, whether it contains chemicals of high concern to human health or the environment, the plastic's carbon footprint, its recycled content and whether it is recyclable, compostable, or biodegradable in the environment at the end of its useful life. Existing tools cover aspects of these life cycle areas of interest, however, they do not focus on the inherent hazards of the chemicals used to manufacture and contained within plastics.

The Plastics Scorecard is a method for evaluating the chemical footprint of plastics and a guide for selecting safer alternatives. Version 1.0 (v1.0) addresses the progress to safer chemicals in plastics manufacturing and in the chemical footprint of plastic products. Chemical footprinting is the process of assessing progress toward the use of safer chemicals and away from chemicals of high concern (CoHCs).[3] Clean Production Action defines chemical footprint as the number and volume of CoHCs used in manufacturing and supply chains, and contained in the final product (CPA, 2014).

The goals of the Plastics Scorecard are to inform the selection of safer plastics by businesses and catalyze manufacturers to reduce the number and volume of CoHCs in manufacturing processes and products. If successful the Plastics Scorecard will advance the development and use of plastics that use inherently safer chemicals in all steps of polymer production as well as in the selection of additives. The Plastics Scorecard is for anyone interested in identifying and selecting plastics based on inherently less hazardous chemicals. Product designers, material specifiers and purchasers will all find value in the both the criteria for evaluating plastics as well as the assessments of individual plastics. The Plastics Scorecard reveals the human and environmental health problems associated with plastics and sets criteria for identifying more environmentally preferable plastics.

Plastics Scorecard v.1.0 *beta*

In 2009, Clean Production Action released the *Plastics Scorecard v1.0 beta*. The intent of *Plastics Scorecard v.1.0 beta* was to create a transparent, robust, replicable method for benchmarking plastics against each other based in life cycle thinking, accounting for feedstock production, chemical and plastics manufacturing, use, and end of life factors. Guided by principles of sustainable resources, green chemistry, and closed loop systems, the *beta* version created a scoring system for three core stages of a plastic product's life cycle: feedstock production/raw material extraction, manufacturing, and end of life management. At the core of the *beta* version of the Plastics Scorecard were the goals of reducing the chemical footprint of plastics across their life cycle and creating a method that would drive meaningful change in material selection.

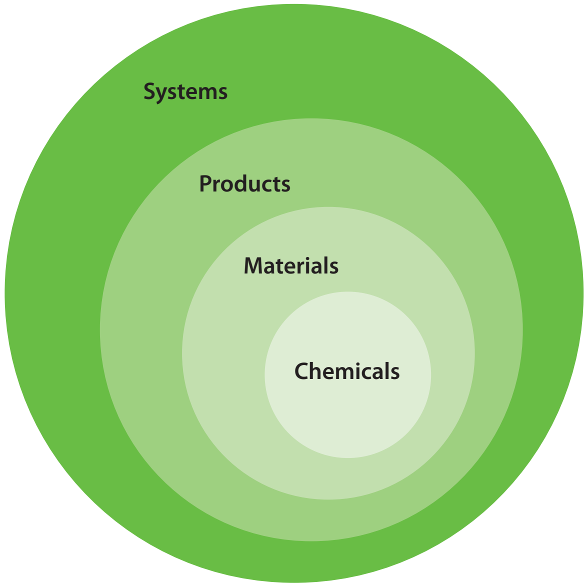
For the feedstock stage the *beta* version of the Plastics Scorecard focused on reducing the impacts of biobased feedstocks or increasing the use of post-consumer recycled (PCR) content. Including PCR content in the feedstock was seen as the means for lowering the environmental impacts of fossil fuel extraction. The manufacturing stage covered the inputs into plastics after feedstock production—primary and intermediate chemicals, monomers, additives, catalysts, with a special focus on nanomaterials. The end of life stage considered pollution from recycling and incineration, and compostability or biodegradability in the marine environment.

The Plastics Scorecard will advance the development and use of plastics that use inherently safer chemicals in all steps of polymer production as well as in the selection of additives.

Pilots of the *beta* version revealed an inconsistent treatment of plastics made from biobased as opposed to fossil fuel feedstocks. This orientation of the Plastics Scorecard was intentional because the opportunity to green biobased plastics, especially in the feedstock stage, are huge, whereas the only alternative for greening up feedstocks for fossil fuels is to use recycled content. For plastics made from biobased materials the source of the feedstock is usually known, e.g., corn from the Midwestern U.S. For fossil fuel-based plastics, the geographical source and the type of fossil fuels used—coal, natural gas, or crude oil—is known only generically—as an average of all production. Thus the *beta* version struggled with specifying metrics that are both actionable for designers, material specifiers, and purchasers while remaining useful for assessing different plastics and their feedstocks.

3 BizNGO (2008) defines "chemical of high concern" as having the following properties: 1) persistent, bioaccumulative and toxic (PBT); 2) very persistent and very bioaccumulative (vPvB); 3) very persistent and toxic (vPT); 4) very bioaccumulative and toxic (vBT); 5) carcinogenic; 6) mutagenic; 7) reproductive or developmental toxicant; 8) endocrine disruptor; or 9) neurotoxicant. Toxic, or T, includes both human toxicity and ecotoxicity.

FIGURE 1
Chemicals at the Core of Systems Change



Plastics Scorecard v.1.0

Reflecting upon the failings of the *beta* version of the Plastics Scorecard, it became clear that downstream users of plastics needed a method for evaluating and comparing plastics based on the inherent hazards of the chemicals in plastics. As Figure 1 illustrates, chemicals are core to materials, which in turn are core to products, which in turn are core to systems. Thus changing materials like plastics to make them inherently safer across their life cycle requires addressing the inherent hazards of chemicals.

Today's fossil fuel-based plastics rely primarily upon inherently hazardous chemicals—chemicals that are likely to be carcinogens, reproductive/developmental toxicants, or endocrine disruptors. In short, chemicals that are unhealthy for humans and the environment.

Today's fossil fuel-based plastics are not manufactured according to the Principles of Green Chemistry. They rely primarily upon inherently hazardous chemicals—chemicals that are likely to be carcinogens, reproductive/developmental toxicants, or endocrine disruptors. In short, chemicals that are unhealthy for humans and the environment. Examples abound of the inherent hazards of the fossil fuel-based plastics. Polyvinyl chloride (PVC) plastic is made from the carcinogens vinyl chloride monomer (VCM) and ethylene dichloride. Polystyrene plastic is made from the carcinogens benzene and styrene. Polycarbonate is made from the endocrine disruptor, bisphenol A (BPA).

The most effective means for reducing the risks from CoHCs in plastics is to avoid their use in the first place. In so doing, workers and local communities and environments are not exposed from manufacturing practices, consumers are not exposed during use, and again workers and local communities and environments are not exposed during recycling, incinerating, or landfilling at end of life. Using inherently safer chemicals has positive repercussions throughout the life cycle of a plastic product.

Green chemistry, as defined by Anastas and Warner (1998) is the "the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture and application of chemical products." Their 12 Principles of Green Chemistry define an alternative path to manufacturing plastics based on the pursuit of processes that reduce and eliminate the use or generation of hazardous substances in the design, manufacture, and application of chemical products. The Plastics Scorecard addresses four of the 12 Principles of Green Chemistry:

#3. Design less hazardous chemical syntheses: Design syntheses to use and generate substances with little or no toxicity to humans and the environment.
#4. Design safer chemicals and products: Design chemical products to be fully effective, yet have little or no toxicity.
#8. Use safer solvents and reaction conditions: Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are necessary, use innocuous chemicals.
#12. Minimize the potential for accidents: Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment.

The Plastics Scorecard brings a unique lens to evaluating plastics with its focus on the inputs into production versus the outputs of production. How do we move to inherently safer chemicals in manufacturing and in products? How do we optimize safer chemicals in plastics? The Plastics Scorecard helps to identify and score chemicals that are used to produce plastics based on inherent hazard. The scores allow the user to evaluate the progress to safer chemicals in manufacturing as well as the overall chemical footprint of plastic products.

The following chapters of the Plastics Scorecard v1.0 report are:

- ***Chapter 2. Why Plastics?*** An overview of the deep and impactful connections between plastics, chemicals, and human health and the environment.
- ***Chapter 3. Measuring the Chemical Footprint of Plastics***
  - A method for evaluating the chemical footprint of polymer manufacturing and plastic products.
  - Applying the method to two plastic products: intravenous (IV) bags and electronic enclosures.
- ***Chapter 4. Strategies for Reducing the Chemical Footprint of Plastics***

The strength of the Plastics Scorecard v1.0 is in its clear focus on advancing inherently safer chemicals across the life cycle of plastics. To advance a green chemistry economy, the current practices of plastics manufacturing and their associated high consumption of inherently high hazard chemicals needs to shift to inherently safer chemicals.

Photo: © Thinkstockphoto/LDProd

CHAPTER 2

Why Plastics

The image of plastics and the environment and human health is a complex one. On its surface, the immediate perspective is one of plastic waste. Images of plastic bags caught in trees and vegetation across the landscape, gyres of plastics in the oceans, whales caught in plastic netting, beaches littered with plastic debris disgorged from the ocean, and skeletal seagull remains filled with plastic beads. Plastic waste is a story of the persistence of plastic—powerful polymers resisting the degradation powers of the environment, enabling them to travel the globe and to wreak havoc on humans and wildlife. Increasingly the image of plastic waste in aquatic environments is growing more complex as plastic fragments collect toxic chemicals onto their surface and as finely degraded bits of plastics find their way into the tissues of aquatic organisms. As one scientist has stated "One of the most ubiquitous and long-lasting recent changes to the surface of our planet is the accumulation and fragmentation of plastics" (Barnes, et al., 2009).

It is more challenging to see the role of plastics in polluting people and the planet with chemicals of high concern (CoHCs). Much smaller than the smallest particles of plastics found in aquatic organisms, chemicals such as phthalates, Bisphenol A (BPA), and brominated flame retardants are invisible to the naked eye. Yet plastics play the largest singular role of any material in the global use of hazardous chemicals, with sizable impact on human health and the global environment.

This chapter starts by tracking the material flows of fossil fuels into chemicals and on into plastics, documenting the sheer volume of raw materials, chemicals, and CoHCs consumed by plastics. The chapter then turns to the human health and environmental implications of CoHCs in plastics across their life cycle and finishes with leading business initiatives to advance safer chemicals in plastic products.

Material Flows—from Fossil Fuels to Chemicals to Plastics

Plastics drive the chemicals economy. To the extent that green chemistry is a goal for the chemicals economy, its achievement will only occur if plastics are made from inherently less hazardous chemicals.

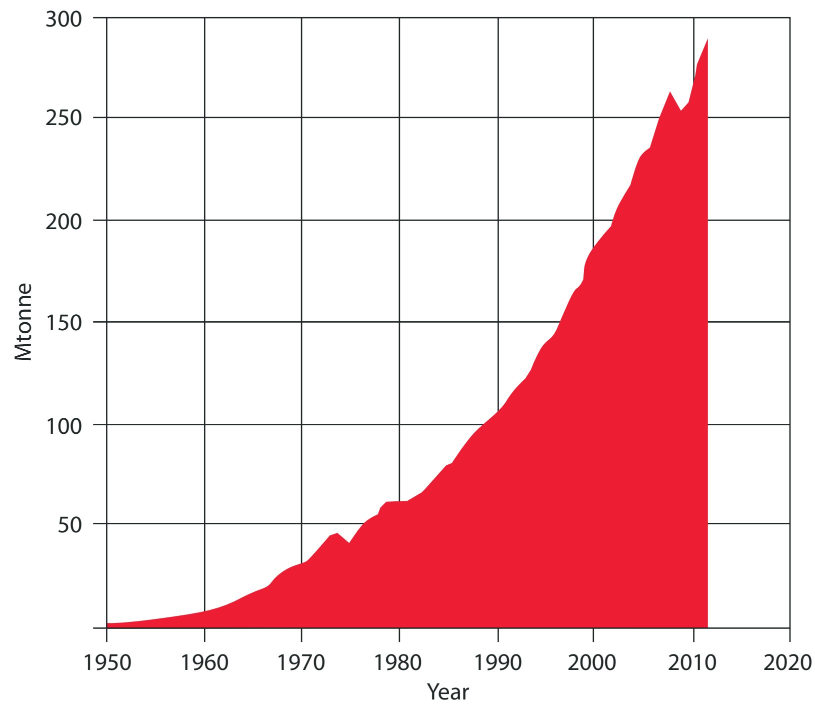
Synthetic plastics are a newcomer to the family of materials manufactured and used by humans. Over the past 70 years, plastics grew from a bit player in the material economy—with less than a million pounds produced globally in 1944—to a material behemoth, with global production at 288 million metric tons or 634 billion pounds in 2012. Figure 2 depicts the rapid growth of plastics in the global economy following World War II.

Producing those 634 billion pounds of plastics requires a huge input of resources beginning with fossil fuels. Around 4% of world oil and gas production is used as a feedstock for plastic production and a further 3–4% is used as energy in their manufacture (Hopewell, et al., 2009). From the crude oil and natural gas come chemicals, many of which are CoHCs to human health or the environment. These chemicals in turn are converted into plastics. The material flow for plastics, from crude oil and natural gas, to chemicals, to final product is huge (see Table 1 and Figure 3).

The plastics manufactured in the greatest volume globally are polyethylene,[4] polypropylene, polyvinyl chloride (PVC), polyethylene terephthalate (PET), polystyrene, acrylonitrile butadiene styrene (ABS), and polycarbonate. Together these seven different plastics accounted for 77% of total global production in 2012 or

4 Plastics manufacturers produce three different grades of polyethylene: high density polyethylene (HDPE), linear low density polyethylene (LLDPE), and low density polyethylene (LDPE).

FIGURE 2 **World Plastics Production 1950–2012**



Includes thermoplastics, polyurethanes, thermosets, elastomers, adhesives, coatings and sealants and PP-fibers. Not included PET-, PA- and polyacryl-fibers.

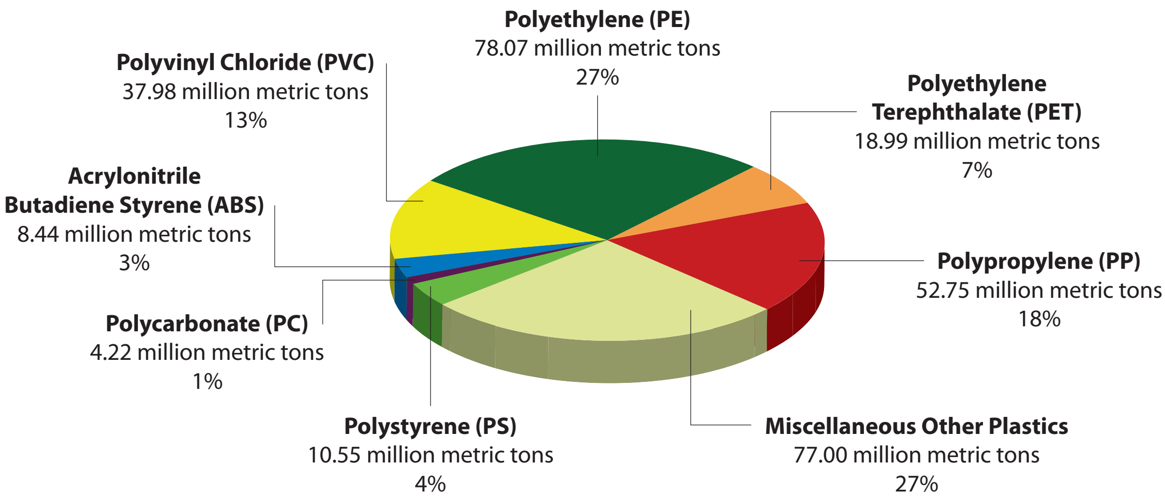
Source: Plastics Europe, 2013.

TABLE 1 **Primary Chemicals Consumed by Plastics**

Primary Chemicals	Total Global Consumption—All End Uses (million metric tons)	Consumed by Plastics (%)	Consumed by Plastics (million metric tons)
Ethylene[a]	113.18	84%	95.13
Propylene[a]	74.90	82%	61.66
Xylenes[b]	42.89	88%	37.62
Benzene[a]	39.67	85%	33.52
Chlorine[c]	56.21	42%	23.55
Butadiene[a]	9.28	94%	8.75
Methanol[a]	41.86	10%	4.19
Total	**377.99**	**70%**	**264.41**

"Primary chemicals" are the building block chemicals used to manufacture plastics and other chemicals.
a. 2008 data, b. 2009 data, c. 2010 data
Source: Chemical Economics Handbook, articles (a), (d), (e), (i), (j), (r), (s).

FIGURE 3 **Global Production of Plastics (2012)**



Total = 288 Million Metric Tons

Sources: Plastics Europe, 2013; Sagel, 2012.

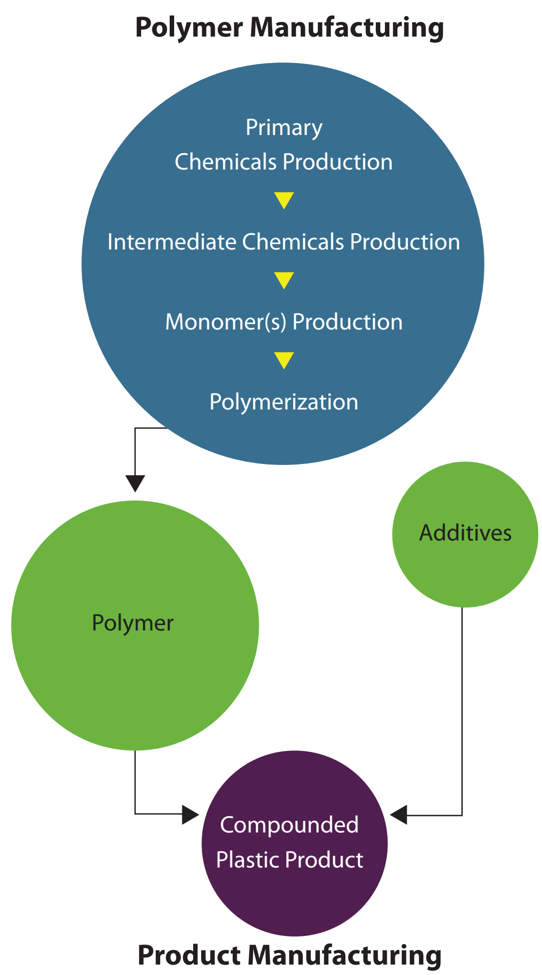
211 million metric tons; with the remaining 23% or 77 million metric tons spread across miscellaneous other plastics such as nylon, polyurethane, silicone, and styrene butadiene rubber (see Figure 3).

The production of plastics involves a series of steps that begin with fossil fuels (see Figure 4). While fossil fuels are the dominant raw material resource for plastics, manufacturers can also use biobased resources to produce plastics including corn, sugar cane, algae, waste methane from landfills, etc. The potential of using various bio-based resources for manufacturing chemicals for plastics are as diverse as our ecosystems.

From fossil fuels the next step on the manufacturing journey to plastics is primary chemicals—building block chemicals from which many other chemicals are derived. Table 1 lists the primary chemicals as well as the percent consumed by plastics. Ethylene, propylene, xylenes, benzene, chlorine, butadiene, and methanol are building block chemicals. Roughly 70% of annual primary chemical production, or approximately 264 million metric tons of primary chemicals,[5] eventually finds its way into plastics.

5 Note that the data points are for multiple years, thus 264 million metric tons is a rough approximation of chemicals consumed per year in 2008 and 2009.

FIGURE 4 **Steps in Manufacturing a Plastic Product**



The next steps in plastics production after primary chemical production (depicted in Figure 4), are the manufacture of intermediate chemicals, which are converted into monomers, which are then linked together into long molecular chains called polymers. In Figure 4 these steps are rolled up into the circle labeled "polymer manufacturing." Table 2 details the primary chemicals, intermediate chemicals, and monomers used to manufacture the plastics produced in the greatest volumes and highlights in red those chemicals that are CoHCs.[6]

Similar to the primary chemicals listed in Table 1, the volume of chemicals consumed at each of the other steps in polymer manufacturing—intermediate chemicals and monomers—is hundreds of millions of metric tons per year globally. Of the CoHCs consumed in the steps of polymer manufacturing, plastics consume 90% of those chemical markets or approximately 244 million metric tons per year as detailed in Table 3.[7] Among those CoHCs are well known, highly hazardous chemicals, including benzene, Bisphenol A (BPA), styrene, and vinyl chloride monomer (VCM). Note the 244 million metric tons or 536 billion pounds is a minimal estimate as it does not include all the CoHCs used in the manufacture of all plastics, including additives, as well as the fact that the data are from 2008 and 2009, in the midst of the great recession. See Appendix 1 for a detailed list of the health hazards of the chemicals listed in Table 3.

Polymers are then mixed (called "compounding") with additives to impart the unique properties needed in specific products (see Figure 4). Typical additives include flame retardants, plasticizers, antioxidants, antistatic agents, and colorants. Plastic compounding is the process of mixing or blending polymers and additives in a molten state to achieve desired properties. Once all processing steps are complete, the material is cooled and extruded into pellets,

6 The Plastics Scorecard uses the same criteria as BizNGO (2008) for defining chemicals of high concern.

7 Note that the data points are for multiple years, thus 244 million metric tons is a rough approximation of chemicals consumed per year in 2008 and 2009. Given those were recession years, this is a lower estimate of total consumption of CoHCs by plastics.

TABLE 2 **Plastics and the Chemicals they Consume**

Steps in Polymer Manufacturing	Plastic Polymers							
Core Chemical Inputs	**ABS**	**PC**	**PE**	**PET**	**PLA**	**PP**	**PS**	**PVC**
Primary Chemical Inputs								
1,3-Butadiene	■ ●							
Benzene	■ ●	■ ●					■ ●	
Chlorine		■ ●						■ ●
Ethylene	●		●				●	●
Glucose					●			
Methanol				■ ●				
Propylene	●	●				●		
Xylenes (p-Xylene)				■ ●				
Intermediate Chemical Inputs								
Acetic acid				●				
Acetone		■ ●						
Ammonia	●							
Cumene		■ ●						
Dimethyl terephthalate / Terephthalic acid				●				
Ethylbenzene	■ ●						■ ●	
Ethylene dichloride								■ ●
Ethylene glycol				■ ●				
Lactic Acid					●			
Phenol		■ ●						
Monomer Inputs								
1,3-Butadiene	■ ●							
Acrylonitrile	■ ●							
bis(2-hydroxyethyl) terephthalate				●				
Bisphenol A (BPA)		■ ●						
Ethylene			●					
Lactide					●			
p-tert-Butylphenol		■ ●						
Propylene						●		
Styrene	■ ●						■ ●	
Vinyl chloride monomer								■ ●

ABS = Acrylonitrile Butadiene Styrene
PC = Polycarbonate
PE = Polyethylene
PET = Polyethylene Terephthalate
PLA = Polylactic Acid
PP = Polypropylene
PS = Polystyrene
PVC = Polyvinyl Chloride

■ Chemical of High Concern to human health or the environment

● Chemical is an input in the manufacture of the indicated polymer which are then packaged for distribution or sale to companies that will re-melt and mold the pellets into plastic parts or products (see Figure 4 for a shorthand version of those steps).

Human and Environmental Exposure to CoHCs in Plastics

Human and environmental exposure to chemicals related to plastics occurs every day. With plastics ubiquitous in manufacturing facilities, offices, cars, homes, and yards, people and the environment are exposed every day to the chemicals that break free from plastic products. Natural degradation forces—sunlight, oxygen, heat, abrasion—release residual monomers (monomers remaining in the product from incomplete polymerization) and the additives (incorporated into the polymer during compounding) into the environment, which then make their way into wildlife and people through the air, dust, water, and food.

While pure plastic polymers, long chain molecules without additives, are typically not regarded as hazardous, there is significant and growing evidence that many of the chemical building blocks and additives currently used to make plastics so versatile are also highly hazardous to humans and the environment (Meeker, et al., 2009; and Oehlmann, et al., 2009). For example, PVC as a pure, standalone polymer without the additives necessary to make it useful in a product, without considering the

TABLE 3 **Plastics and the Chemicals of High Concern they Consume**

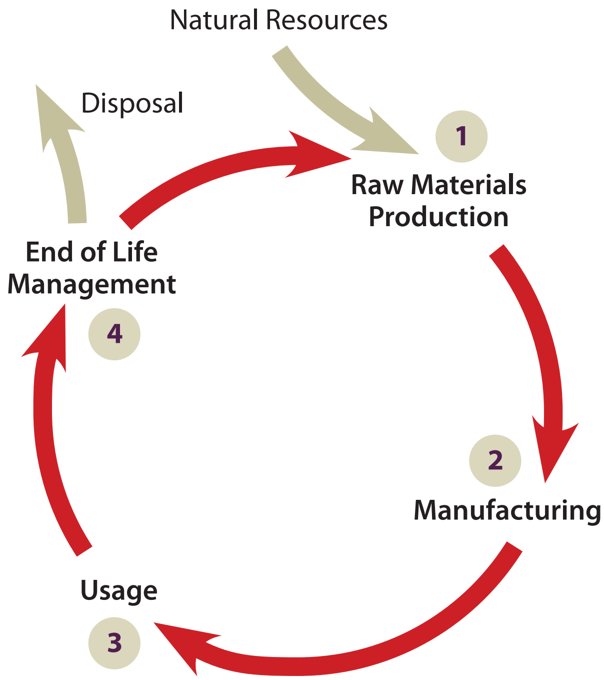
Chemicals of High Concern (plastics)	Total Global Consumption (million metric tons)	Consumed by Plastics (%)	Consumed by Plastics (million metric tons)
Ethylene dichloride (PVC)[b]	43.45	97%	42.14
para-Xylene (PET)[b]	42.89	88%	37.62
Benzene (PS)[b]	39.67	85%	33.52
Vinyl chloride monomer (PVC)[b]	32.79	97%	31.80
Ethylbenzene (ABS, PS)[b]	27.57	99%	27.29
Styrene (ABS, PS, SAN, SBR)[b]	23.63	91%	21.38
Ethylene glycol (PET, Nylon)[a]	21.00	80%	16.80
Cumene (PC)[b]	12.23	84%	10.27
Butadiene (ABS, SBR)[b]	9.28	94%	8.75
Acrylonitrile (ABS)[a]	5.35	96%	5.16
Phenol (PC)[c]	8.90	55%	4.88
Bisphenol A (PC, epoxy resins)[c]	4.04	96%	3.86
Acetone (PC)[d]	5.67	45%	2.53
Total	**270.79**	**90%**	**243.48**

"Chemicals of High Concern" to human health or the environment = carcinogen, mutagen, reproductive / developmental toxicant; persistent, bioaccumulative, toxicant (PBT); endocrine disruptor; or chemical of equivalent concern.

ABS = Acrylonitrile Butadiene Styrene
PC = Polycarbonate
PE = Polyethylene
PET = Polyethylene Terephthalate
PLA = Polylactic Acid
PP = Polypropylene
PS = Polystyrene
PVC = Polyvinyl Chloride
SAN = Styrene Acrylonitrile
SBR = Styrene Butadiene Rubber

Source: Chemical Economics Handbook articles (c), (d), (e), (f), (g), (l), (m), (n), (o), (p), (q), (s), (t)

FIGURE 5 **Life Cycle Stages of a Plastic Product**



chemicals used in its manufacturing, or without considering its end of life impacts, is typically considered a non-hazardous material. But once the building block chemicals of PVC (for example, vinyl chloride monomer) and additives like the plasticizer di(2-ethylhexyl) phthalate (DEHP) and the stabilizer lead are considered, PVC is no longer a benign polymer.

Figure 5 depicts the four primary stages of the life of a plastic product: raw materials production (usually fossil fuels), manufacturing, use, and end of life management. At each stage in the life cycle of a plastic product beyond raw material production, human and environmental exposure to chemicals related to plastics occurs. This section briefly examines the chemicals and health concerns that arise from exposure to CoHCs related to plastics manufacturing, use, and end of life management.

Exposure to CoHCs from Plastics during Manufacturing

Recent epidemiological data points to major occupational health concerns related to plastics manufacturing. A 2011 review of the epidemiological and toxicological literature funded by Health Canada explored the occupational exposures in producing plastics and the potential health risks particularly to a heavily female workforce in this sector (De Matteo, et al., 2011.) The review:

> demonstrates that workers are exposed to chemicals that have been identified as mammary carcinogens and endocrine disrupting chemicals, and that the work environment is heavily contaminated with dust and fumes. Consequently, plastics workers have a body burden that far exceeds that found in the general public. The nature of these exposures in the plastics industry places women at disproportionate risk, underlining the importance of gender.

A parallel epidemiological study of 1,005 women workers and 1,146 controls showed a five-fold elevated risk of premenopausal breast cancer among women in two occupations: the manufacture of automotive plastics and food processing (Brophy et al., 2012). It should be noted that this five-fold elevated risk is in addition to an escalating risk of breast cancer in the general population (Blue Green Alliance, 2013).

DeMatteo et al. point out that workers in the plastics industry are exposed to a "multitude of toxic chemicals used in plastics production, including styrene, acrylonitrile, vinyl chloride, phthalates, bisphenol-A (BPA), brominated flame retardants, heavy metals, solvents and other complex chemical mixtures." This is of major concern as:

> . . . occupational exposures to chemicals used in the plastics industry may contribute to the development of breast cancer and reproductive problems, because they either act as mammary carcinogens or disrupt the normal functioning of the body's endocrine system, or both. A recent study found that most plastic products release estrogenic chemicals [Yang, EHP, 2011]. Such endocrine-disrupting chemicals (EDCs) as phthalates, brominated flame retardants, and BPA are ubiquitous in the plastics work environment.

DeMatteo et al., provide considerable detail on the major processes involved in both polymer and plastic product manufacturing, and the documented occupational routes of exposure to unreacted monomers, processing chemicals, and plastics additives during various manufacturing processes. The authors' literature review found evidence that plastics processing workers consistently had higher body burdens of acrylonitrile, styrene, phthalates and BPA than the general population. Their research found that:

> . . . [I]t is generally accepted that the plastics processing work environment is potentially contaminated by residual monomers, polymers, and various additives, including plasticizers, stabilizers, pigments/colorants, flame retardants, activators, lubricants, and fillers, as well as solvents, paints, and finishing agents used in the decorating process. Some of these substances are mutagenic and known to cause cancer in humans, some are suspected of causing cancer, and some have been identified as endocrine-disrupting chemicals that may promote cancer.

DeMatteo et al., point out that while monomers are generally used up during polymerization, residual monomers including vinyl chloride, styrene, acrylonitrile, BPA, formaldehyde, butadiene, ethylene and urethane can still be released during resin production or thermal processing. In addition to the monomers, plastics processing involves the use of the solvents benzene, methyl ethyl ketone (MEK), and toluene, which are all mammary carcinogens. The manufacture of plastic products includes the use of a vast array of potential additives, including phthalates, heavy metals (lead, cadmium, tin, barium, and antimony) as pigments and stabilizers, and polybrominated diphenyl ethers (PBDEs), all of which are CoHCs.

DeMatteo et al. conclude with the following statements:

> . . . [t]hrough a review of the known health effects of substances used in the plastics industry we were able to ascertain that workers are chronically exposed to substances that are potential carcinogens and endocrine disruptors. This situation is aggravated by the fact that workers are exposed to complex mixtures of hazardous substances that may have additive and/or synergistic effects . . . we found through our review of the literature that workers carry a body burden of plastics-related contaminants that far exceeds those documented in the general public . . . existing epidemiologic and biological evidence indicates that women in the plastics industry are developing breast cancer and experiencing reproductive problems at elevated rates as a result of these workplace exposures.
>
> Finally, it has been demonstrated that many plastics-related substances are EDCs with adverse effects at very low levels. The ability of EDCs to disrupt the endocrine system at low levels lends biological plausibility to the link between workplace exposures and increased risk of breast cancer and reproductive problems for women working in the plastics industry.

The U.S. Environmental Protection Agency provides some indication of the sheer volume of chemicals to which communities in the U.S. are potentially exposed. An EPA report identified 38,265,753 million pounds of waste generated and disposed of both on-site and off-site by plastics and rubber facilities.

While workers are at the front line of exposure in manufacturing, local communities and environments are at the back end of exposure to the CoHCs used to manufacture plastics. The U.S. Environmental Protection Agency's (EPA's) Toxics Release Inventory (TRI) provides some indication of the sheer volume of chemicals to which communities in the United States are potentially exposed. A search via the U.S. EPA's TRI 2012 reporting data for the North American Industry Classification System (NAICS) 326, which encompasses Plastics and Rubber production, showed a reported 38,265,753 million pounds of waste generated and disposed of both on-site and off-site by reporting facilities. The results of the search includes many of the primary, intermediate, and monomer chemicals highlighted previously, as well as chemicals in the many classes of additives added to plastics in the process of making plastic products (U.S. EPA, 2014).

Exposure to CoHCs from Plastics during Usage and End of Life Management

There are many examples of plastic products that have been shown over time to contain chemicals that are detrimental to the health of consumers and the environment. Table 4 contains several well-known examples: BPA in baby and water bottles made from polycarbonate, DEHP in PVC IV bags, and brominated flame retardants (BFRs) in electronic products.

Recent books and articles continue to highlight consumer concerns around plastic products, including the 2011 book, *Plastic: A Toxic Love Story,* in which journalist Susan Freinkel follows the life cycles of eight common plastic products: the comb, a chair, the Frisbee, an IV bag, the disposable lighter, grocery bag, soda bottle, and credit card. Freinkel summarizes her key theme as follows:

> Plastic built the modern world. Where would we be without pacemakers, polyester, computers, cellphones, sneakers or chewing gum. . . . But a century into our love affair with plastic, we're starting to realize it's not such a healthy one. Plastics draw on dwindling fossil fuels, leach harmful chemicals, litter landscapes, and destroy marine life. And yet each year we use and consume more; we've produced as much plastic in the past decade as we did in the entire twentieth century. We're trapped in an unhealthy dependence—a toxic relationship.

Research continues to accumulate that highlights the hazards of exposure to products in our homes, particularly to children. For example, a May 2014 article in *Environmental Health Perspectives* linked prenatal exposure to flame retardants to lower IQs and greater hyperactivity at five years of age. A 10-fold increase in PBDE concentrations in early pregnancy was associated with a 4.5 point decrease in IQ, comparable to the well-documented exposure to lead in the environment (Chen, et. al, 2014). A February 2014 article in the Journal of Epidemiology and Community Health outlined the necessity for and challenges inherent in studying human exposure to food contact materials (FCM) as a

TABLE 4 **Examples of Plastic Products and their Associated Chemical Hazards**

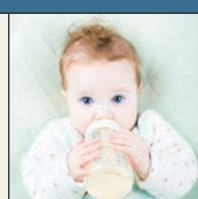
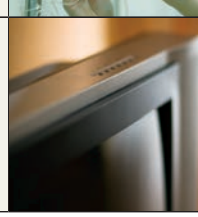
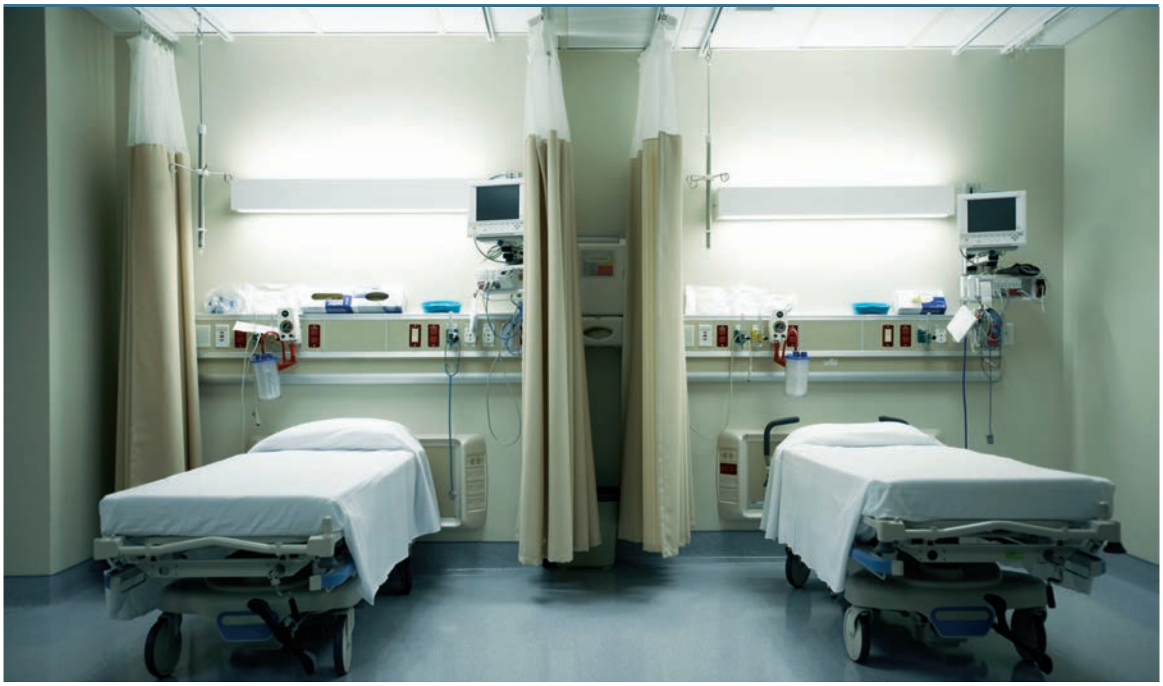
Plastic Product		Chemical Hazards
Baby bottles made from polycarbonate		Leaching of endocrine disruptor Bisphenol A (BPA)
Intravenous (IV) bags made from polyvinyl chloride (PVC)		• Leaching of endocrine disruptor and reproductive toxicant DEHP plasticizer • Use of carcinogen, vinyl chloride monomer (VCM) in manufacturing • Formation of carcinogenic dioxins during manufacture and end of life burning
Plastic housings for electronic products made from polystyrene with brominated flame retardants (BFRs)		Shedding of reproductive and developmental toxicant BFRs into household dust

Photo: © (top) Thinkstockphoto/FamVeld; (middle) © Thinkstockphoto/whitetag; (bottom) © Thinkstockphoto/agencyby



significant source of chemical food contamination. The authors state: "Most often FCMs are made of plastic or have a synthetic material in direct contact with the foodstuff. . . . Importantly, most FCMs are not inert. Chemicals contained in the FCM, such as monomers, additives, processing aids or reaction by-products, can diffuse into food" (Muncke, et al., 2014).

End of life concerns with chemicals in plastics emerge for all the various management options. For the reuse and recycling of plastics, the presence of "legacy" CoHCs will impede the reuse/recycle of plastic products as well as expose workers handling the materials to the CoHCs. For example, the persistent, bioaccumulative, and toxic flame retardant, pentabromodiphenyl ether (pentaBDE) in furniture foam, now creates a major barrier to the recycling of the foam; with similar issues happening with the recycling of electronic enclosures containing decaBDE. For the incineration of plastics, any heavy metals in the plastic, like lead or cadmium will either become airborne or will contaminate the fly ash that must be disposed of (or recycled). For other plastics with bromine or chlorine content there will be emissions of brominated and chlorinated dioxins and furans. Finally, if plastics are landfilled at end of life, chemicals can leach from the plastics, through the landfill and into neighboring groundwater.

These examples and other research highlight the need to reduce the hazards of plastic chemicals both in production and in products.

Leading Business Sectors Search for Safer Plastics

Current initiatives in the health care, electronics, apparel and footwear, and building products sectors highlight the drivers for incorporating safer chemistry in decisions on plastics and other materials, the attributes considered, and the methods that these systems use to assess and select safer plastics. These practices are driven by a range of motivations, such as:

- regulatory compliance
- marketplace advantage
- green certification
- government procurement specifications
- improvements in indoor air quality (e.g., for building products and furnishings)
- corporate commitment to actively avoid high hazard chemicals

The Sector Initiatives box (page 22) spotlights growing demands for plastics made without CoHCs in the health care, apparel and footwear, and building product sectors. These initiatives provide instructive examples of how organizations within three sectors are already trying to move their sector or company to safer plastics.

Photo: © Thinkstockphoto/Fuse

BOX 1 **Sector Initiatives to Reduce Chemicals of High Concern (CoHC) in Plastics**

Health Care

Initiative

Practice Greenhealth's Standardized Environmental Questions for Medical Products (PGH, 2011)

Drivers

To use purchasing practices to selectively choose medical products for hospitals and other healthcare facilities that are inherently safer for patients, workers, and the environment; and to increase demand for and supply of these products.

How the initiative addresses safer chemicals in plastics

A questionnaire for health care purchasers asks a series of questions related to chemicals in products being evaluated, with preferred responses. Questions address the presence of polyvinyl chloride (PVC), phthalates, bisphenol A (BPA), halogenated organic flame retardants, mercury, latex, and carcinogens and reproductive toxicants, as well as the generation of hazardous waste.

Example question

Is this product free of intentionally added Bisphenol A (BPA) or BPA derived plastics (such as polycarbonate plastic and resins)? (Yes/No) Preferred response is "yes."

Apparel & Footwear

Initiative

Nike's Materials Sustainability Index (MSI) (Nike, 2012)

Drivers

To provide product creation teams at Nike with a tool to select environmentally better materials.

How the initiative addresses safer chemicals in plastics

The Nike MSI scoring framework includes a chemistry score, which is calculated using an algorithm and data addressing "significant chemical substances" across the cradle-to-gate life cycle of a material. For polymers, significant chemical substances are those present in principal reactions, including known catalysts, from the raw material source through polymer formation. The chemistry score combines human health hazard evaluations for carcinogenicity, acute toxicity, chronic toxicity, and combined reproductive toxicity, and endocrine disruption with assumptions about potential exposures during the life cycle. Eco-toxicity is not considered. For components, such as molded parts, foams and buttons, the assessment spans from raw materials to the creation of the basic material (called Phase 1, e.g., polymer pellets) and the additional processes that transform the basic material into the materials that are shipped to an assembly facility (called Phase 2, e.g., processing pellets into a foam).

Nike has made the MSI available to other companies and to the general public through the Sustainable Apparel Coalition.

Building Products

Initiative
Perkins+Will Precautionary List (P+W, 2014)

Drivers
The goal of this program is to provide information to the building industry on chemicals of concern in building materials and safer alternatives.

How the initiative addresses safer chemicals in plastics
The Perkins+Will Precautionary List includes a total of 25 substances, groups of substances or materials commonly found in building products that are listed by government agencies or identified in scientific research as having negative health impacts. The list includes bisphenol A (BPA), halogenated and brominated flame retardants, phthalates, polyurethane foam, and polyvinyl chloride (PVC). Perkins+Will's public Transparency website contains the Precautionary List of chemicals, detailed information on the health effects of the substances, building products that typically contain substances (by CSI MasterFormat™ division and section), as well as alternatives.

CHAPTER 3

Measuring the Chemical Footprint of Plastics

In evaluating the chemical footprint of plastics, the Plastics Scorecard v1.0 differentiates between chemicals used in polymer manufacturing and the final plastic product. Version 1.0 of the Plastics Scorecard measures the chemical footprint of plastics at two levels:

1. Manufacturing: the core chemical inputs used to manufacture a polymer.
2. Product: all chemicals contained in a final, homogeneous, compounded plastic product.

Both the manufacturing data and data on the final homogenous compounded plastic product provide important information on the potential risk to consumers and the environment from the use of certain polymers.

"Chemical footprint" is the measure by number and mass of chemicals of high concern, as determined by hazard level, in products and supply chains. "Hazard level" can be specified using the GreenScreen® benchmarks or an equivalent method. Chemical footprinting is the process of evaluating progress away from chemicals of high concern to human health or the environment to chemicals that have a lower hazard profile than the ones they replace. In this way, a chemical footprint is a measure of the actions an organization takes to advance the development and use of safer chemicals in products and across supply chains.

The following sections first describe the Plastics Scorecard method, then apply that method to two plastic products, IV bags and electronic

Photo: © Thinkstockphoto/Fuse

enclosures, with a comparison of two different plastic materials for each product.

Measuring the Progress to Safer Chemicals in Polymer Manufacturing

The Plastics Scorecard v 1.0 assesses the hazards associated with polymer manufacturing by evaluating the core chemical inputs of the manufacturing process:

- primary chemicals,
- intermediate chemicals, and
- monomers.

For example, in evaluating the manufacture of the polymer, polystyrene, v1.0 assesses the hazards of the following chemicals:

- ethylene and benzene (primary chemicals),
- ethylbenzene (intermediate chemical), and
- styrene (monomer).

The Plastics Scorecard evaluates the hazards posed by each chemical to human health or the environment using the GreenScreen® for Safer Chemicals (see Appendix 2 for details). Version 1.0 of the Scorecard assessed 10 polymers and their core chemical inputs.

The method applied to create the Progress to Safer Chemicals in Polymer Manufacturing Score is as follows:

1. Identify primary chemicals, intermediate chemicals, and monomers by Chemical Abstract Services Registry Number (CAS #) for each polymer. See Appendix 3 for the 10 polymers included in v1.0 and the 28 chemicals used to manufacture those polymers.
2. Evaluate the hazard profile of each chemical. Version 1.0 used two online resources that aggregate chemical hazard data: the Pharos[8] chemical and material library and the Chemical Hazard and Alternatives Toolbox, ChemHAT.[9]
3. Version 1.0 of the Plastics Scorecard adapted the GreenScreen® method to categorize chemicals on a scale of red to green, with "red" being a chemical of high concern to human health or the environment and "green" being a chemical of low concern to human health or the environment. The adapted method is:
   a. Red Chemical: GreenScreen® Benchmark 1 or GreenScreen® Benchmark Possible 1; or chemical for which data are insufficient to perform a hazard assessment.
   b. Orange Chemical: GreenScreen® Benchmark 2 chemical or no hazard data that indicates the chemical is a GreenScreen® Benchmark 1 chemical.
   c. Yellow Chemical: Based on a verified GreenScreen® assessment, the chemical is a GreenScreen® Benchmark 3 chemical.
   d. Green Chemical: Based on a verified GreenScreen® assessment, the chemical is a GreenScreen® Benchmark 4 chemical.
   e. Grey Chemical: Based on a verified GreenScreen® assessment, the chemical is a GreenScreen® Benchmark U (unspecified) chemical.

The Plastics Scorecard assesses the hazards associated with polymer manufacturing by evaluating the core chemical inputs of the manufacturing process: primary chemicals, intermediate chemicals, and monomers.

4. Assign a hazard level to the chemical using the following steps:
   a. First, is the chemical flagged in Pharos as a GreenScreen® Benchmark 1 or GreenScreen® Benchmark Possible 1 chemical?[10] If yes, then flag it as a "red chemical."

8 See Pharos chemical and material library at *http://www.pharosproject.net*.

9 See *www.ChemHAT.org*.

10 Ideally, each chemical would be scored based on full GreenScreen® assessments, i.e., a toxicologist's assessment of the chemical along all 18 hazard endpoints. In the absence of full assessments, the chemicals were assessed with the GreenScreen® List of Lists Translator. The List Translator screens each chemical against authoritative and screening chemical hazard lists to determine whether the chemical is a definitive Benchmark 1 chemical.

   b. Second, if not flagged as red chemical, is there a publicly verified GreenScreen® assessment of the chemical? If yes, apply that benchmark (see Appendix 2).
   c. Third, if no publicly available verified GreenScreen® assessment, consider hiring a licensed GreenScreen® profiler to perform an assessment.
      i. Clean Production Action, for example, hired ToxServices LLC to complete eight GreenSreen® assessments of the chemicals used to manufacture:
         - polyethylene terephthalate (PET): acetic acid, ethylene glycol, terephthalic acid, and bis-(2-hydroxyethyl)-terephthalate;
         - polylactic acid (PLA): glucose, lactic acid, and lactide; and
         - polypropylene: propylene.

         Summaries of these assessments are included in Appendix 2 and the full assessments are available at *www.bizngo.org*.
   d. Fourth, apply the verified GreenScreen® assessment benchmark to the chemicals.
   e. Fifth, for the remaining chemicals, review hazard data to assess whether the chemical might meet the criteria of a chemical of high concern (see definition in Glossary of Terms). If yes, assign chemical as "red chemical", if no, assign chemical as "orange chemical". Appendix 3 lists the 28 chemicals used as a primary chemical, intermediate chemical, and/or monomer in the manufacture of ten different polymers. Of the 28 chemicals, 18 are red chemicals, eight are orange chemicals, one is a yellow chemical, one is a grey chemical, and zero are green chemicals.
5. Aggregate the primary chemicals, intermediate chemicals, and monomers into a single "Progress to Safer Chemicals in Polymer Manufacturing Score." Table 5 summarizes the results of applying this method. The method for scoring polymer manufacturing is as follows:
   a. First, assign a chemical input score for each polymer for each category of chemical inputs (primary chemicals, intermediate chemicals, and monomers). The chemical input score is a ratio of progress to green scaled to 100, divided into a third (such that the algorithm scales to 100 for all three categories of chemical inputs):
      i. Take the chemical inputs for that category (see Appendix 3) and assign a numeric value based on the lowest hazard level score:
         - 0 = red chemical
         - 1 = grey chemical
         - 2 = orange chemical
         - 3 = yellow chemical
         - 4 = green chemical
      ii. Apply the lowest scoring chemical input for that category. If two chemicals, take the lowest scoring chemical. For example, ethylene and chlorine (primary chemical inputs for PVC), where ethylene = 2 and chlorine = 0, take the chorine score of 0.
      iii. Calculate ratio of progress to green: hazard level score divided by 4. A green chemical has a score of 1.00 (4 divided by 4), yellow of 0.75 (3 divided by 4), orange of 0.50 (2 divided by 4), grey of 0.25 (1 divided by 4), and red of 0.00 (0 divided by 4).
      iv. Scale to 100.
      v. Divide by 3; thereby assigning a value of 1/3, 1/3, 1/3 for each manufacturing step of inputs (primary chemicals, intermediate chemicals, and monomers).
   b. Second, add up the score for each step of the manufacturing inputs: Primary Chemicals + Intermediate Chemicals + Monomers = Manufacturing Score.
   c. Third, assign color code to polymer:
      i. Red: Total Manufacturing Score = 0.00
      ii. Orange: Total Manufacturing Score = >0.00 and <34
      iii. Yellow: Total Manufacturing Score = ≥34 and ≤67
      iv. Green: Total Manufacturing Score = >67

What follows are two examples of applying the Progress to Safer Chemicals in Polymer Manufacturing method to PVC and PLA.

TABLE 5 Plastics Scorecard: Progress to Safer Chemicals in Polymer Manufacturing

Polymer	Polymer Manufacturing: Progress to Safer Chemicals Score				Number of Primary Chemicals, Intermediates, and Monomers that are Chemicals of High Concern
	Primary Chemicals	Intermediate Chemicals	Monomer(s)	Total Manufacturing	
Best Case Polymer	33.33	33.33	33.33	100.00	0
Polylactic Acid (PLA)	25.00	16.67	16.67	58.33	0
Polyethylene (PE)	16.67	16.67	16.67	50.00	0
Polypropylene (PP)	16.67	16.67	16.67	50.00	0
Ethylene Vinyl Acetate (EVA)	0.00	16.67	0.00	16.67	2
Polyethylene terephthalate (PET)	0.00	0.00	8.33	8.33	3
Polystyrene (PS)	0.00	0.00	0.00	0.00	3
Polyvinyl Chloride (PVC)	0.00	0.00	0.00	0.00	3
Styrene Butadiene Rubber (SBR)	0.00	0.00	0.00	0.00	4
Acrylonitrile Butadiene Styrene (ABS)	0.00	0.00	0.00	0.00	5
Polycarbonate (PC)	0.00	0.00	0.00	0.00	8

- Green: The manufacture of the ideal polymer uses green chemicals as defined by GreenScreen® Benchmark 4 in each manufacturing step.
- Yellow: For each manufacturing step, no core chemical inputs are chemicals of high concern as defined by GreenScreen® Benchmark 1.
- Orange: Some manufacturing steps include chemicals of high concern as defined by GreenScreen® Benchmark 1, and others do not.
- Red: Every manufacturing step involves the use of chemicals of high concern as defined by GreenScreen® Benchmark 1.
- Grey: Manufacturing step involves the use of chemicals determined to be "unspecified" due to the lack of complete hazard data using GreenScreen®.

Notes:
- Only the principal input chemicals are included in this analysis (see Appendix 3).
- For each step, the score is based on the worst performing chemical for human and environmental health. Thus, if any step includes a chemical of high concern, then it receives a zero.
- All steps are considered of equal weight and are scaled to 100—with the green polymer scoring "100" and the red polymer scoring "0".

Scoring Example #1: Scoring the Steps in Polymer Manufacturing for Polyvinyl Chloride (PVC)

1. Primary Chemicals
   - Ethylene = 2
   - Chlorine = 0
   - Primary Chemical Score = sum((0/4)*100)/3 = 0
2. Intermediate Chemical
   - Ethylene Dichloride = 0
   - Intermediate Chemical Score = sum((0/4)*100)/3 = 0
3. Monomer
   - Vinyl Chloride Monomer = 0
   - Monomer Chemical Score = sum((0/4)*100)/3 = 0
4. Total Manufacturing Score for PVC = sum (Primary+Intermediate+Monomer) = 0+0+0 = 0
5. Color Code = Red

Scoring Example #2: Scoring the Steps in Polymer Manufacturing for Polylactic Acid (PLA)

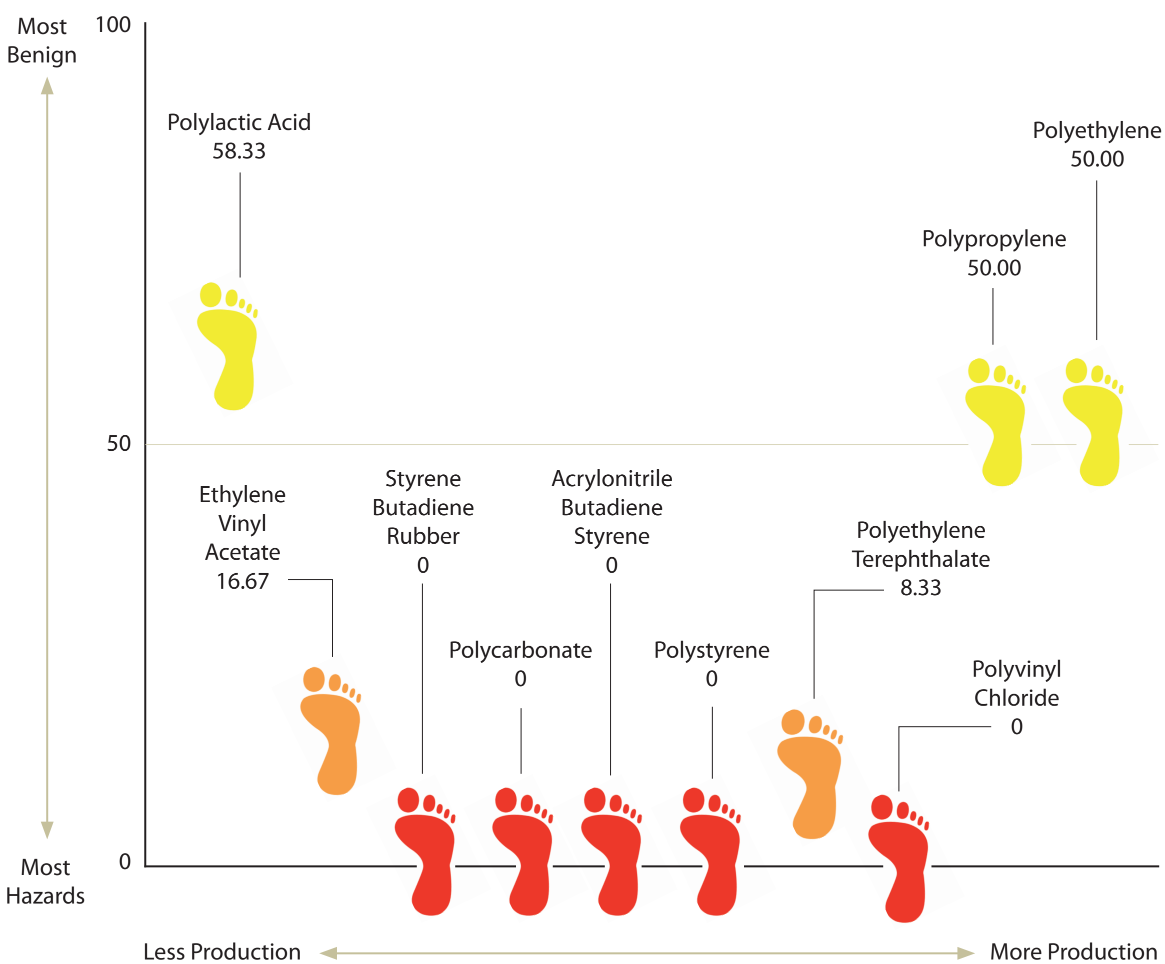
1. Primary Chemicals
   - Glucose = 3
   - Primary Chemical Score = sum((3/4)*100)/3 = 25.00

2. Intermediate Chemical
    - Lactic Acid = 2
    - Intermediate Chemical Score = sum((2/4)*100)/3 = 16.67
3. Monomer
    - Lactide = 2
    - Monomer Chemical Score = sum((2/4)*100)/3 = 16.67
4. Total Manufacturing Score for PLA = sum(Primary+Intermediate+Monomer) = 25+16.67+16.67 = 58.33
5. Color Code = Yellow

Table 5 summarizes the Progress to Safer Chemicals score for 10 polymers. An ideal polymer based on low hazard chemicals would score 100.00. Table 5 reflects the reality that today's polymers are not based on green chemistry. Five of the ten polymers score zero: ABS, PC, PS, PVC, and SBR. That means each stage of manufacturing uses as a primary input a chemical of high concern. PLA, PE, and PP are making the greatest progress to safer chemicals in manufacturing, while EVA and PET are making some progress beyond chemicals of high concern.

Figure 6 graphically illustrates Table 5. On the y-axis is progress to safer chemicals and on the x-axis is volume of production. Thus the polymers that are most widely produced and making the greatest progress to safer chemicals

FIGURE 6 **Progress to Safer Chemicals in Polymer Manufacturing**



For each manufacturing step, no core chemical inputs are chemicals of high concern as defined by GreenScreen® Benchmark 1.

Some manufacturing steps include chemicals of high concern as defined by GreenScreen® Benchmark 1, and others do not.

Every manufacturing step involves the use of chemicals of high concern as defined by GreenScreen® Benchmark 1.

are polyethylene and polypropylene. Figure 6 highlights how the vast majority of polymers hover towards the bottom on progress to the safer chemicals. PLA is an emerging polymer that has made significant progress to safer chemicals but is produced in significantly smaller volumes than the other polymers.

Version 1.0 does not address other inputs in the polymer manufacturing process, including catalysts and solvents. The Scorecard focuses on primary chemicals, intermediates, and monomers because they represent the majority of the chemical inputs into polymer manufacturing. The Scorecard can be easily adapted and scaled in the future to address these additional inputs.

Some may contend that primary and intermediate chemicals are of no to little concern to public and environmental health. But as highlighted in Chapter 2, the concerns with workers and local communities and environments being exposed to CoHCs are significant. Certainly a challenge with any polymer manufacturing based on crude oil and natural gas is that those facilities pose their own set of hazards, and it is those facilities that manufacture the primary chemicals from which all polymers are manufactured. Changing the impacts of petroleum and natural gas cracking facilities will require turning to alternative feedstocks and selecting polymers like PLA based on their alternative feedstocks.

Version 1.0 of the Plastics Scorecard also does not consider the raw material feedstocks—for example, crude oil, natural gas, corn, or sugar cane—for the polymer inputs. The Plastics Scorecard v1.0 solely assesses the chemical footprint of manufacturing and final product. It does not integrate raw material feedstocks into the assessment. If a purchaser or designer has concerns with feedstock sources, for example, use of genetically modified organisms (GMOs) in the field or use of food crops for manufacturing plastics, then the purchaser could first screen for those attributes then optimize on chemical footprint. The combination of a drive to more sustainable feedstocks, beyond corn, oil, and gas, and safer chemicals holds the potential for truly market-disruptive polymers.

The Progress to Safer Chemicals in Polymer Manufacturing Score provides a scale for assessing progress to safer chemicals across the steps of polymer manufacturing. It highlights the challenges of and opportunities for moving to inherently safer chemicals in manufacturing, and points to polymers that have made some progress to safer chemicals.

Measuring the Chemical Footprint of a Plastic Product

The Chemical Footprint of a Plastic Product measures the number and weight (or percent weight) of chemicals of high concern in a homogeneous plastic product, be it a component such as a plastic case around a computer monitor or a plastic duck (also known as a rubber ducky). The homogeneous plastic product is a "compounded plastic product" because it includes both the polymer and the additives.

The chemicals in a plastic product include:

- The base **polymer:** by weight, this is the greatest component of the product.
- **Additives:** incorporated into the plastic to enhance product performance. Additives can be a source of CoHCs and may present the relatively easiest opportunity for reducing the chemical footprint of a plastic product. Types of additives include: flame retardants, ultraviolet light (UV) stabilizers, antioxidants, colorants, and plasticizers.

Photo: © Thinkstockphoto/amstockphoto

- **Processing aids:** these are used to facilitate manufacturing processes, including to speed processing times and to easily remove a plastic from molds (including slip agents and lubricants).
- Unreacted or residual **monomer**: In the polymerization of a monomer, there is always some unreacted monomer that becomes lodged in the polymer chain. Over time and under the appropriate conditions—heat, shaking, contact with certain liquids, etc.—the unreacted monomer leaks out of the plastic and leads to human or environmental exposure.
- **Oligomers:** are byproducts of the polymerization process and reside in the polymer at low concentrations.
- Residual **catalysts:** Catalysts speed the rate at which monomers link together during the polymerization process. While manufacturers reclaim and reuse catalysts in the manufacturing process, residual amounts can end up in, and be released from, the polymer while it is in use or during disposal.

Plastic products therefore include both intentionally added chemicals—polymers and additives—as well as unintentionally present chemicals that remain from manufacturing—processing aids, unreacted monomer, residual catalysts, and oligomers. The unintentionally present chemicals are typically on or in the product at small concentrations. The concentration of unreacted monomers and catalyst residuals in polymers is low, typically below 1000 ppm (0.1% by weight) and 100 ppm (0.01%), respectively.

The Chemical Footprint of a Plastic Product is: 1) the total number of CoHCs in the product and 2) the weight (in percentage or actual volume) in the product. The goal is to reduce both the number and weight of CoHCs in a product. Calculating the chemical footprint of a product requires knowing the chemicals in the product. But given that plastics are likely to have chemicals of high concern at very low concentrations (see for example, Jenke, 2002), less than 10 ppm, a key issue is setting the threshold level for knowing chemicals in products. The Plastics Scorecard v 1.0 sets the reporting threshold for intentionally added chemicals at 1000 ppm (0.1% by weight) and for chemicals of high concern at 100 ppm (0.01%). These levels are consistent with the levels required of the U.S. EPA's Design for Environment (DfE) ecolabeling program.

The method for calculating the Chemical Footprint of a Plastic Product is easy to state but difficult to implement:

- Identify the chemicals in the product down to 1000 ppm for intentionally added chemicals.
- Identify which of the intentionally added chemicals are CoHCs. A reference source for identifying CoHCs is the Pharos chemical and material library. Take the list of chemicals in the product and use the Pharos database to identify which chemicals are a GreenScreen® Benchmark 1 or Possible Benchmark 1 chemical.
- Research through suppliers and the technical literature CoHCs likely to be in the plastic product.
- Work with suppliers to disclose CoHCs in the product down to 100 ppm.
- List number of CoHCs in product and percent or volume by weight.

Companies that truly want to measure their progress to safer chemicals will identify CoHCs

Photo: © Thinkstockphoto/nuiiko

in their plastic products and the percent weight of these CoHCs, calculate the number of products sold, multiply the weight of CoHCs by number of products sold and thereby know the company's total consumption of CoHCs. That knowledge will enable companies to demonstrate their overall reduced use of CoHCs over time.

From the perspective of potential risk, the primary concern with plastic materials in products is what happens to the chemicals contained in the plastic itself during the product's use and disposal. Will chemicals leak out of the product during use or end of life management—when exposed to sunlight, air, heat or certain types of liquids; or when abraded? And what happens when these chemicals are released into the environment, people and animals—do they breakdown into more toxic byproducts? The best means for preventing the release of CoHCs during use and disposal is to use inherently safer chemicals in the formulation of the product.

The next two sections apply the Chemical Footprint of Plastic Products to two plastic products: 1) intravenous (IV) bags and 2) electronic enclosures.

Chemical Footprint of Plastic Intravenous (IV) Bags

The two IV plastic products evaluated and compared in Plastics Scorecard v1.0 are:

- PVC plasticized with di(2-ethylhexyl) phthalate (DEHP) and
- polyolefin bags made from layers of polyethylene and polypropylene.

PVC/DEHP IV bags dominate the market, although one of the top three producers of IV bags in the U.S.—B Braun—sells primarily polyolefin-based IV bags. As noted in Chapter 2, due to the life cycle concerns with PVC/DEHP IV bags, many hospitals are transitioning to IV bags manufactured without PVC/DEHP. For example, many of the 12 health care systems in the Healthier Hospitals Initiative, which comprise over 490 hospitals with over $20 billion in purchasing power, are taking the Safer Chemicals Challenge to reduce PVC/DEHP products used in health care.[11]

Key sources used to estimate the number and percent weight of CoHCs in PVC/DEHP and polyolefin bags data were:

- Jenke (2002), article on "Extractable/Leachable Substances from Plastic Materials Used as Pharmaceutical Product Containers/Devices", which reviews the literature on the chemicals extracted and leached from plastic materials used in health care, including PVC with DEHP and polyolefins;

From the perspective of potential risk, the primary concern with plastic materials in products is what happens to the chemicals contained in the plastic itself during the product's use and disposal.

- European Commission (2007) *Preliminary Report on the Safety of Medical Devices Containing DEHP Plasticized PVC or Other Plasticizers on Neonates and Other Groups Possibly At Risk*;
- Danish Technological Institute (2013) report on *Hazardous Substances in Plastic Materials*; and
- Ed Phillips, Basell Polyolefins (Phillips, 2001) presentation on additives in polyolefin laminates used in health care.

Overall the most definitive data points on chemicals in IV bags as a percent by weight were from:

- The European Commission (2007), which stated that:
  - DEHP is added to PVC as a plasticizer at 30% by weight.
  - BPA is added as antioxidant at 0.5% by weight.
- Phillips (2001) presentation that listed additives and their percent level found in polyolefin IV bags.

11 See *http://healthierhospitals.org/hhi-challenges/safer-chemicals.*

TABLE 6 Plastic Intravenous (IV) Bag

Estimated Chemical Footprint of Polyvinyl Chloride (PVC) Plasticized with Di(2-Ethylhexyl) Phthalate (DEHP)

Functional Use: Chemical Ingredients	Weight (%)	Chemicals of High Concern (CoHCs)	
		Chemicals	%
Polymer: PVC[1]	68.80%	*	*
Plasticizer: DEHP[2]	30.00%	DEHP	30.00%
Antioxidants: including Bisphenol A (BPA)[3]	0.50%	BPA	0.50%
Heat stabilizers[4]	0.50%	unknown	unknown
Lubricants[5]	0.10%	unknown	unknown
Slip Agents[6]	0.10%	unknown	unknown
Monomers and oligomers—residual: vinyl chloride monomer (VCM)[7]	0.0001%	VCM	0.0001%
Solvent—residual[8]	unknown	unknown	unknown
Catalyst—residual	unknown	unknown	unknown
Total	**100.00%**	**at least 3**	**30.50%**

Chemical is a chemical of high concern

Unknown whether chemicals of high concern from that functional use are present

* Polymers are generally considered to be of low concern to human health and the environment (European Commission 2012b). This product assessment of polymer hazard excludes other life cycle hazards, including manufacturing and end of life management.

Sources of Weight: 1. Estimated, 2. European Commission, 2007, 3. European Commission, 2007, 4. Danish Technological Institute, 2013, 5. Danish Technological Institute, 2013, 6. Danish Technological Institute, 2013, 7. Jenke, 2002; European Pharmacopoeia, 2005, 8. Jenke, 2002,

In addition, the Danish Technological Institute report provided generic data points on additives and likely concentrations in specific polymers. And the Jenke, 2002 article listed confirmed chemicals found in PVC and polyolefin extraction studies.

Tables 6 and 7 list the functional uses of chemicals in the IV plastic products (for example, plasticizer); when known, the specific chemical used (for example, DEHP as a plasticizer); the estimated weight of the chemical in the product; and whether or not the chemical is a known CoHC.

Key results from Tables 6 and 7 include:

- DEHP makes up a significant percentage of the PVC IV bag because plasticizers are necessary to make PVC flexible. Polyolefins are naturally flexible and to the extent they use plasticizers, use them at much lower levels. For example, Basell Polyolefins reported using plasticizers at 0.003% (30 ppm) (Phillips, 2001).
- Unreacted monomers will be at very low levels for medical grade polymers because they are closely regulated.
- Knowledge gaps: the specific chemicals (for example, by CAS #) used as additives is not readily available. For example, researchers and technical experts know in general that PVC products contain heat stabilizers, but the specific heat stabilizers used in a specific product is difficult to ascertain.

Figure 7 illustrates the benefits of substituting PVC/DEHP with polyolefins for plastic IV bags. Polyolefin polymers (polypropylene and polyethylene) score much higher, 50.0, on the Plastics Scorecard's "progress to safer chemicals score"

TABLE 7 **Plastic Intravenous (IV) Bag**

Estimated Chemical Footprint of Composite Polyolefin Product

Functional Use: Chemical Ingredients	Weight (%)	Chemicals of High Concern (CoHCs)	
		Chemicals	%
Polymer: Composite of Polyolefin / Polypropylene[1]	99.39%	*	*
Antioxidants	0.20%	unknown	unknown
Hindered phenols[2]	0.10%	unknown	unknown
Phosphates[3]	0.10%	unknown	unknown
Antacids: Stearates[4]	0.10%	unknown	unknown
Lubricants[5]	0.10%	unknown	unknown
Slip agents[6]	0.10%	unknown	unknown
Peroxide[7]	0.09%	unknown	unknown
Catalyst—residual[8]	0.015%	unknown	unknown
Plasticizer: phthalates[9]	0.003%	unknown	unknown
Monomers and oligomers—residual[10]	unknown	unknown	unknown
Solvent—residual[11]	unknown	unknown	unknown
Adhesive: urethane-based[12]	unknown	unknown	unknown
Total	**100.00%**	**best possible scenario—0**	**0.00%**

Chemical is a chemical of high concern

Unknown whether chemicals of high concern from that functional use are present

* Polymers are generally considered to be of low concern to human health and the environment (European Commission 2012b). This product assessment of polymer hazard excludes other life cycle hazards, including manufacturing and end of life management.

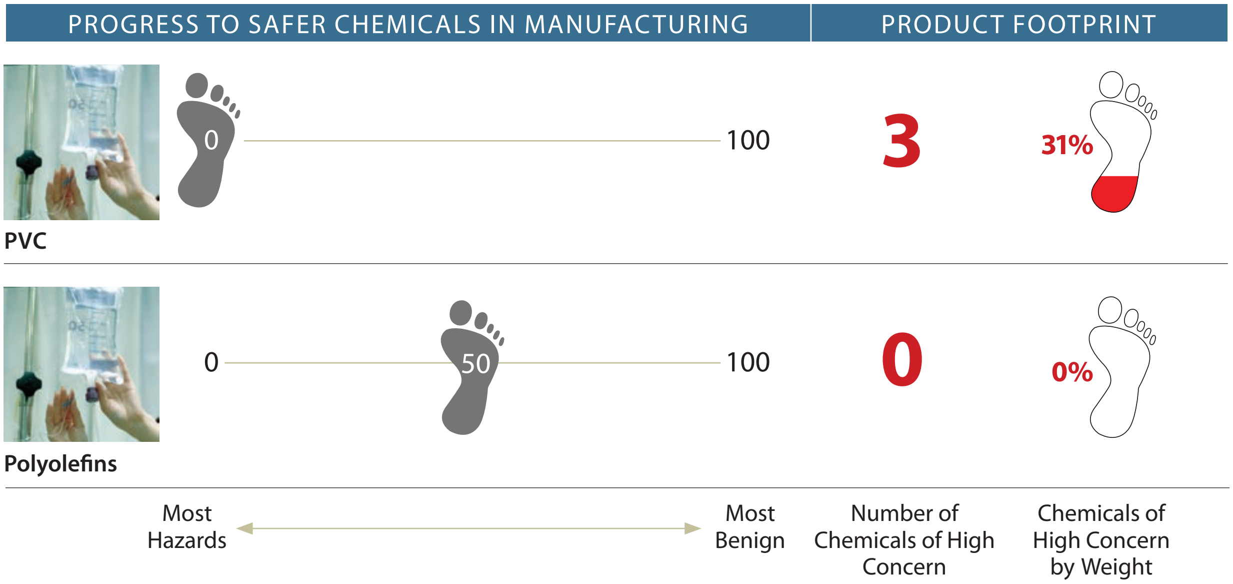
Sources of weight: 1. Estimated, 2. Basell Polyolefins, 2001, 3. Basell Polyolefins, 2001, 4. Basell Polyolefins, 2001, 5. Jenke, 2002; Danish Technological Institute, 2013, 6. Danish Technological Institute, 2013, 7. Basell Polyolefins, 2001, 8. Basell Polyolefins, 2001, 9. Jenke, 2002; Basell Polyolefins, 2001, 10. Jenke, 2002, 11. Jenke, 2002, 12. Jenke, 2002

than PVC, which scores 0.0. In addition, the polyolefin bags greatly reduce the chemical footprint of the products. The PVC/DEHP IV bags contain a significant percentage of CoHCs, 30% DEHP and 0.5% BPA by weight, in comparison to the estimated 0% by weight for polyolefins. But even if all the polyolefin additives were CoHCs, the percent CoHCs would only be 0.61% in the polyolefin bags. Thus switching from PVC/DEHP bags presents a significant opportunity to reduce the percentage of CoHCs in IV bags by approximately 30% by weight.

Dignity Health's (formerly Catholic Healthcare West) switch from PVC/DEHP IV bags to B Braun's polyolefin-based product in 2008 demonstrates the reduced chemical footprint of polyolefin IV bags. Over the six year period from 2008 to 2013, Dignity Health reduced the chemical footprint of its IV bags by:

- Eliminating 1,543,467 pounds of PVC polymer (excludes additives):
  - PVC as a polymer scores "0," whereas the polyolefins (polypropylene and polyethylene)

FIGURE 7 **Chemical Footprint of IV Bags Made from PVC/DEHP & Polyolefins**



PVC = Polyvinyl chloride; DEHP = di(2-ethylhexyl) phthalate

Collecting data on the chemical ingredients in electronic enclosures involved combing through a variety of resources. Studies on the flame retardants in electronic enclosures and their hazards were particularly helpful in specifying both the chemicals and their percent concentration.

score 50.0, on the Plastic Scorecard's progress to safer chemicals scale (the higher the score the more preferable the product is for the environment and human health).

- Reducing Chemicals of High Concern:
  - Eliminated 673,023 pounds of DEHP.
  - Eliminated 33,651 pounds of BPA.[12]

Chemical Footprint of Plastic Electronic Enclosures

"Electronic enclosures" are the plastic housings surrounding an electronic product, such as a television (TV), computer monitor, or laptop. Manufacturers add flame retardants to plastic enclosures because the materials are flammable and exposed to heat during use. Amid growing concerns of the flame retardants leaking out of the plastics, in particular decabromodiphenyl ether (decaBDE), regulators in Europe and in states like Maine and Washington, took action in the 2000's to restrict the use of decaBDE. In anticipation of the regulations, manufacturers searched about for alternatives, with some choosing to continue with other brominated flame retardants while others opted to eliminate all brominated and chlorinated flame retardants. The movement away from decaBDE and other brominated flame retardants in electronic enclosures also led to the search for alternative plastics. High Impact Polystyrene (HIPS), a relatively inexpensive polymer, flame retarded with decaBDE or another brominated flame retardant dominated the market because it was an effective and low cost solution to housing electronic devices.

As manufacturers searched for non-brominated and non-chlorinated flame retardants, they discovered that the alternative flame retardants required alternative polymers. Polycarbonate (PC)/Acrylonitrile Butadiene Styrene (ABS) polymers with phosphorous-based flame retardants

12 Calculated reductions in PVC, DEHP, and BPA based on estimate of reduced PVC material use in Kudzia, et al., 2008.

emerged as the most popular non-halogenated solution to HIPS with decaBDE enclosures. This transition away from HIPS/decaBDE to PC/ABS with RDP provides a good case study for assessing whether manufacturers made a regrettable substitution—substituting known CoHCs with unknown alternatives that are later found to also be a chemical of high concern.

Collecting data on the chemical ingredients in electronic enclosures involved combing through a variety of resources. Studies on the flame retardants in electronic enclosures and their hazards were particular helpful in specifying both the chemicals and their percent concentration, including:

- Lowell Center for Sustainable Production (LCSP, 2005) report on *Decabromodiphenylether* and
- Washington State Department of Ecology (2008) report on Alternatives to DecaBDE.

In terms of other additives contained in HIPS and PC/ABS products a range of resources were particularly helpful in specifying percent concentrations and/or specific chemicals, including:

- Danish Technological Institute (2013) report on Hazardous Substances in Plastic Materials and
- Jenke (2002) article on extractable and leachable chemicals in plastic materials used in health care products.

Industry resources were helpful in specifying concentrations of co-polymers in the products, including:

- International Institute of Synthetic Rubber Producers on concentration of polybutadiene in HIPS and
- CEFIC (2014) summary on chemistries of electronics enclosures on percent of ABS in PC/ABS polymers.

Finally a variety of articles beyond those mentioned above were helpful to understanding residual monomers in products, mostly notably

Photo: © Getty Images News/Mario Tama

TABLE 8 **Plastic Electronic Enclosure**

Estimated Chemical Footprint of High Impact Polystyrene (HIPS) with Decabromodiphenyl Ether (DecaBDE) Flame Retardant

Functional Use: Chemical Ingredients	Weight (%)*	Chemicals of High Concern (CoHCs)	
		Chemicals	%
Polymer: Polystyrene[1]	73.55%	*	*
Flame Retardant:	16.00%		
DecaBDE[2]	11.64%	DecaBDE	11.64%
Nonabromodiphenyl ether[3]	0.36%	NonaBDE	0.36%
Antimony trioxide[4]	4.00%	Antimony trioxide	4.00%
Polymer: Polybutadiene[5]	7.00%	not of high concern	not of high concern
Antioxidants, Processing Stabilizers, and UV Stabilizers[6]	3.00%	unknown	unknown
Lubricants and slip agents[7]	0.20%	unknown	unknown
Monomers and oligomers—residuals: includes styrene and butadiene[8]	0.15%	Styrene, Butadiene	0.15%
Antistatic agents[9]	0.10%	unknown	unknown
Colorants[10]	unknown	unknown	unknown
Catalysts: residual	unknown	unknown	unknown
Total	**100.00%**	**at least 5**	**16.15%**

Chemical is a chemical of high concern

Unknown whether chemicals of high concern from that functional use are present

* Polymers are generally considered to be of low concern to human health and the environment (European Commission 2012b). This product assessment of polymer hazard excludes other life cycle hazards, including manufacturing and end of life management.

Sources of Weight: 1. Estimated, 2. LCSP, 2005; WA State 2008, 3. LCSP, 2005, 4. LCSP, 2005, 5. IISRP, 2014, 6. Danish Technological Institute, 2013; Jenke 2002, 7. Danish Technological Institute, 2013; Jenke 2002, 8. Araujo, et al, 2002; Jenke 2002, 9. Danish Technological Institute, 2013; Smith, 1998, 10. Danish Technological Institute 2013

the research by Araújo, et al. (2002) on residual monomer content in polymers.

Tables 8 and 9 list the functional uses of chemicals in plastic electronics enclosures; when known, the specific chemical used (for example, the specific chemicals contained in RDP formulations for flame retarding PC/ABS); the estimated weight of the chemical in the product; and whether or not the chemical is a known CoHC.

Key results from Tables 8 and 9 include:

- Residual **monomers:** The presence of residual monomers in plastic products is well documented and research and development into methods for reducing residual monomers is a well-developed field of activity. Yet what is not known is what levels of residual monomer are generally found in a class of products like electronic enclosures. Manufacturing

Plastics Scorecard

TABLE 9 Plastic Electronic Enclosure

Estimated Chemical Footprint of Polycarbonate (PC) / Acrylonitrile Butadiene Styrene (ABS) with Resorcinol bis(diphenylphosphate) (RDP) Flame Retardant

Functional Use: Chemical Ingredients	Weight (%)	Chemicals of High Concern (CoHCs)	
		Chemicals	%
Polymer: Polycarbonate[1]	51.45%	*	*
Polymer: ABS[2]	25.00%	*	*
Flame Retardant: RDP constituents[3]	20.00%		
Phosphoric acid, 1,3-phenylene tetraphenyl ester (CAS# 57583-54-7)[4]	14.50%	not of high concern	not of high concern
Phosphoric acid, bis[3-[(diphenoxyphosphinyl)oxy] phenyl] phenyl ester (CAS# 98165-92-5)[5]	4.50%	not of high concern	not of high concern
Triphenyl phosphate (CAS# 115-86-6)[6]	1.00%	Triphenyl Phosphate	1.00%
Antioxidants, Processing Stabilizers, and UV Stabilizers[7]	3.00%	unknown	unknown
Drip resistance: Polytetrafluoroethylene[8]	0.30%	unknown	unknown
Monomers and oligomers: residuals[9]	0.25%	Bisphenol A, Acyrlonitrile, Butadiene, Styrene	0.25%
Antistatic agents[10]	0.10%	unknown	unknown
Colorants[11]	unknown	unknown	unknown
Catalysts: residual	unknown	unknown	unknown
Total	**100.00%**	**at least 5**	**1.25%**

Chemical is a chemical of high concern

Unknown whether chemicals of high concern from that functional use are present

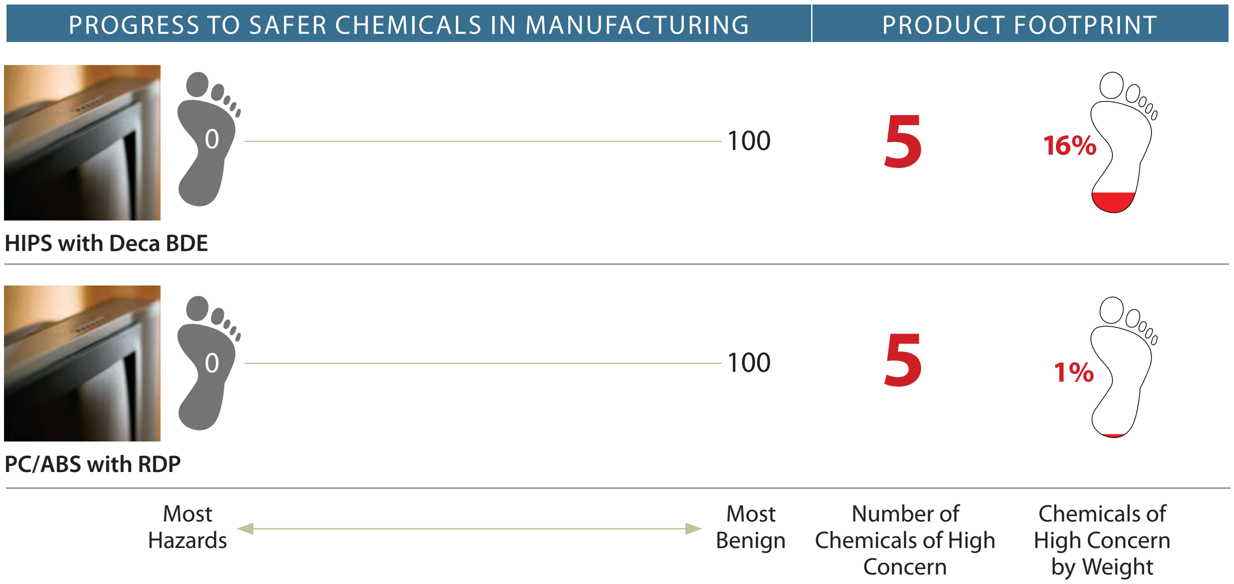
* Polymers are generally considered to be of low concern to human health and the environment (European Commission 2012b). This product assessment of polymer hazard excludes other life cycle hazards, including manufacturing and end of life management.

Sources of Weight: 1. Estimated, 2. Cefic, 2014, 3. Washington State, 2008, 4. Washington State, 2008, 5. Washington State, 2008, 6. Washington State, 2008, 7. Danish Technological Institute, 2013; Jenke 2002, 8. Lowell Center for Sustainable Production, 2005, 9. Jenke 2002; Danish Technological Institute, 2013; Choi and Kim, 2012; Araujo, et al., 2002; REACH, 2012, 10. Danish Technological Institute 2013, 11. Danish Technological Institute 2013

practices clearly determine levels of residual monomers. Given the uncertainty about residual monomers in product, however, the preventive solution is to avoid monomers that are CoHCs.

- Residual **catalysts:** Like residual monomers, researchers in polymeric chemistry know that residual catalysts are present in the product. But again similar to residual monomers, they are at low levels and their presence will vary with manufacturing processes.
- Knowledge gaps in **additives:** As with the IV bag comparison in the preceding section, data are sparse on the specific chemicals used in the more obscure additive functions. Public knowledge on additives is greatest and most accurate where the spotlight of public attention focuses. In the case of electronic enclosures, that is on flame retardant additives, where researchers learned the specific chemical additives in flame retardant formulations and their concentrations.

FIGURE 8 **Chemical Footprint of Electronic Enclosures Made from High Impact Polystyrene (HIPS) with DecaBDE & PC/ABS with RDP**



ABS = Acrylonitrile Butadiene Styrene; DecaBDE = Decabromodiphenyl Ether; PC = Polycarbonate; RDP = Resorcinol Diphenylphosphate

Figure 8 illustrates the benefits of substituting a HIPS with DecaBDE enclosure with a PC/ABS with RDP enclosure. At the product level the PC/ABS enclosure reduces the volume of CoHCs from 16% to 1% by weight of product. The key actor in the beneficial result is the elimination of the CoHC, decaBDE, and its replacement with RDP. While RDP is by no means a green flame retardant, its ingredients overall are less hazardous than decaBDE. The electronic enclosures story is one where the opportunities to green the final product are fairly limited. Given price and performance needs, PC/ABS is the most effective solution. While the volume of CoHCs decline with the use of RDP, the number of CoHCs in the product remains unchanged. Similarly, the progress to safer chemicals in manufacturing score remains at 0.0.

Is PC/ABS with RDP a regrettable substitution for HIPS/ decaBDE? The above data indicate it is not, and at the aggregate level it results in significant reductions in CoHCs by percent weight. Yet there are many unknowns. The science on the health effects of phosphorous-based chemistry continues to develop; unknown health hazards may arise with this chemistry. At the same time, the small amounts of unknown additives as well as the residual monomers (like BPA) may prove to be problematic in the future. It is clear PC/ABS with RDP is a less bad solution, but it is hardly an optimal solution. The ideal plastic is a safer polymer with additives of low concern to humans and the environment.

CHAPTER 4

Strategies for Reducing the Chemical Footprint of Plastics

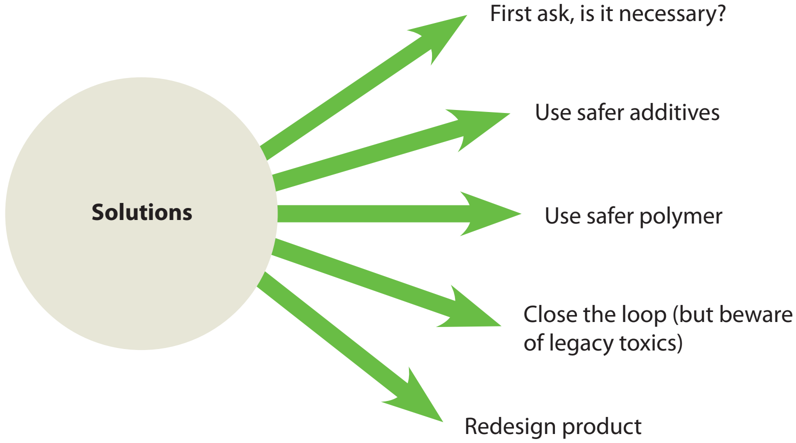
The Plastics Scorecard is a means for improving the human health and environmental performance of plastics. It is not designed to compare across material types, say from aluminum to plastics, or to assess impacts across the entire life cycle of a plastic product. Rather it provides the means for knowing the chemical footprint of plastics and how they compare to each other on this attribute. The Plastics Scorecard provides value to both those that want to demonstrate the lowered chemical footprint of polymer manufacturing or final product, as well as for those designers, specifiers, and purchasers that want to select products with a lesser chemical footprint. Figure 9 depicts the core solutions to making plastics safer in terms of human health and environmental impacts. Reducing the chemical footprint of plastics is a challenging endeavor to which these solutions provide a path forward.

Is it necessary? A critical approach to chemicals in products in general and plastics in particular, especially plastic additives, is to ask the question: Is it necessary? For example, is a flame retardant in nap mats even necessary?[13] The flame retardant may be in nap mats due to historical reasons or a failure to even know that the foam contains flame retardants in the first place.

13 For example, see California Priority Products listing under Safer Consumer Product Regulations—*https://dtsc.ca.gov/SCP/PriorityProducts.cfm.*

Photo: © Pixland/Jupiterimages

FIGURE 9 **Solutions to Reducing Chemical Footprint of Plastics**



Thus manufacturers may be able to eliminate the flame retardant with no consequence to the product or meeting regulatory requirements. For many plastic additives, a good starting point is to ask, is it necessary for the performance of the product.

Using PCR content in the manufacture of a product holds the potential of significantly reducing the chemical footprint of a plastic product by bypassing the impacts of polymer manufacturing.

Find safer additives. For those manufacturers or purchasers that don't answer, "this additive or product is unnecessary," there remain a variety of routes for reducing a product's chemical footprint. First, and often the relatively easiest route, is to substitute CoHC additives with safer alternatives. The most dramatic example of additive substitution is happening in the PVC industry. PVC consumes many CoHC additives, including phthalates such as DEHP, lead and cadmium stabilizers, and BPA as an antioxidant. In an effort to "green" their image, PVC manufacturers are aggressively reducing their use of CoHC additives:

- In Europe, the PVC industry will comply with REACH requirements that require reducing most uses of the phthalates DEHP, butyl benzyl phthalate (BBP), and dibutyl benzyl phthalate (DBP) by 2015 and will voluntarily eliminate the use of lead stabilizers by 2015 (Roberts, 2014a).
- Similarly the South African Vinyl Association announced in April 2014 it will: eliminate lead stabilizers by 2015; all cadmium stabilizers should have been eliminated by 2013 (although apparently have not); hexavalent chromium pigments, similarly should have been eliminated by 2013 (but have not yet been); BPA by 2015; and partial reductions of DEHP by 2015 (Roberts, 2014b).

The electronics enclosures comparison in Chapter 3 is an example of substituting a CoHC additive—decaBDE flame retardant—with a safer flame retardant, thereby reducing the chemical footprint of the product.

Use safer polymers. Another solution is to select a polymer that is further along the path to safer chemicals in manufacturing. The IV bag comparison in Chapter 3 is an example of both eliminating the need for a CoHC additive—DEHP plasticizer—and improving the progress to safer chemicals in polymer manufacturing by the substitution of polyolefin-based polymers for PVC.

Close the loop and use post-consumer recycled (PCR) content. Using PCR content in the manufacture of a product holds the potential of significantly reducing the chemical footprint of a plastic product by bypassing the impacts of polymer manufacturing (for example, see Wolf, 2011). In general using PCR content is a preferred route for reducing the chemical footprint of a polymer and a plastic product. Yet using PCR content seldom eliminates the need for virgin plastic because: 1) frequently companies do not use 100% PCR content for performance reasons, and thus require continued production and use of some virgin polymer content; and 2) even if 100% PCR content is used, some virgin content is required to flow into the economy given the wastage, leakage, and degradation of recycled content over time.[14]

14 In other words, a completely 100% PCR economy is not viable if all manufacturers use PCR content. But given that is not the case, virgin plastic continues to flow into the economy enabling some manufacturers to use 100% PCR.

Finally PCR content is challenged by the legacy of the past use of CoHCs in plastics manufacturing. For example, the recycling and reuse of polyurethane foam means that companies continue to keep the flame retardant, pentabromodiphenyl ether (pentaBDE) in the economy, thereby continuing to expose more people and the environment to this persistent, bioaccumulative, toxic chemical. The drive to greater PCR content should be a significant driver to reduce the chemical footprint of plastics.

Redesign the product. Product redesign holds the potential of both enhancing the value of the product while reducing its chemical footprint. For example, companies can redesign electronic products such that plastic parts do not come into contact or into proximity with parts that heat up, thereby obviating the need for flame retardants. The redesign of chairs to use wire mesh instead of foam both reduces the weight of utilized material and avoids the use of foam that frequently requires flame retardancy.

Ultimately the success of reducing the chemical footprint of plastics will require greater transparency around the chemicals in products. Chemical footprinting holds the potential of creating a metric for measuring progress away from CoHCs as well as towards safer alternatives. A challenge to managing CoHCs in products and supply chains has been, as the business adage goes, "you can't manage what you can't measure." To date companies have lacked clear metrics for measuring progress to safer chemicals. The Plastics Scorecard, by creating a framework for chemical footprinting, creates a metric by which companies can manage chemicals and measure progress.

CHAPTER 5

Conclusions

Reducing the chemical footprint of plastics is a significant challenge. Starting from their feedstock base of fossil fuels, CoHCs litter the plastics pathway from primary chemicals to intermediates to monomer to final product compounded with additives. Exposure to a wide array of CoHCs during manufacturing, usage, and disposal poses a significant risk to the health of workers, communities, and the global environment. Reducing CoHCs in manufacturing will improve the health and safety of workers and communities, both by reducing the number of hazardous chemicals and their overall volume. In addition, safer chemicals and materials can generate innovative new markets for companies, workers, and communities alike.

It is important to note that the Plastics Scorecard v1.0 did not address the thorny issue of comparing feedstocks. Potential questions in this arena, for example, could include: is polystyrene derived from the Alberta tar sands preferable or not to PLA derived from genetically modified (GM) corn? The reality is that fossil fuel-based plastics largely get a pass on the feedstock question, with few people asking did that crude oil come from Alberta, Nigeria, Texas, Venezuela, or Saudi Arabia. Comparing fossil fuel feedstocks in terms of their chemical footprints to PLA derived from GM corn clearly opens a significant topic for further research.

In Measuring Progress to Safer Chemicals in Polymer Manufacturing the Plastics Scorecard v1.0 clearly illustrates the lack of polymers based

Photo: © Thinkstockphoto/Totojang

on green chemistry, and thereby the need for new, greener chemistries like PLA. The fossil fuel based chemistries of the 20th century rest largely upon CoHCs, and their dominance and scale in the global plastics economy makes them very difficult to displace.

In terms of the chemicals in products, additives are the key driver affecting the Chemical Footprint of Plastic Products. Residing in the product in the greatest concentrations beyond the polymer, additives dictate the concentration of CoHCs in plastic products. Companies are reducing CoHCs in plastic products by eliminating the need for the additive, changing additives, or changing polymers to avoid the need for the additive in the first place.

The chemical footprints of IV bags and electronic enclosures clearly demonstrate that material designers and purchasers can select alternative products that avoid most CoHCs and can document that progress. Plastic markets are shifting more quickly to safer additive packages because that is the often the easiest route to reducing the chemical footprint of a plastic product. Witness the PVC industry's recent plans to eliminate the use of lead and cadmium stabilizers, certain phthalates like DEHP, and BPA. Reducing the use of CoHCs in plastics is good news, but as the Progress to Safer Chemicals in Manufacturing component of the Plastics Scorecard illustrates, safer additive packages on their own do not reduce the hazards of polymer manufacturing.

Among the challenges of effectively evaluating the hazards of additives include the absence of relevant publically available data for the various additive chemistries. As companies move away from well-known CoHCs it will drive down the percentage of CoHCs in products. What will remain are questions around the chemicals used in manufacturing, the hazard profiles of the alternative additives, as well as the levels of residual monomers like BPA and residual catalysts in final products. The knowledge gaps on chemicals in additive packages will become increasingly significant along with the necessity for full hazard assessments of the substitutes. Additives are another area ripe for research and green chemistry solutions.

Manufacturers and purchasers are making progress on the pathway to safer chemicals in plastics. From polymer manufacturing to final products, safer chemical use is growing. That said, much progress is still to be achieved. The plastics economy, from cradle to grave, remains largely based on CoHCs. The Plastics Scorecard v1.0 presents a novel method for evaluating the chemical footprint of plastics, selecting safer alternatives, and measuring progress away from CoHCs. Version 1.0 supports the design, production, and selection of safer and healthier plastics.

The goals of the Plastics Scorecard are to inform the selection of safer plastics by businesses and catalyze manufacturers to reduce the number and volume of CoHCs in manufacturing processes and products. Truly achieving these goals will require:

- Knowing all the chemical constituents in a compounded plastic product.
- Knowing whether chemicals of high concern (CoHCs) are used in manufacturing or contained in the final product.
- Prioritizing CoHCs for avoidance or substitution.
- Selecting safer alternatives.
- Continuous improvement—reducing the number and volume of CoHCs over time.

The overarching philosophy that underpins v1.0 is that the optimum route to addressing the life cycle concerns of chemicals in plastics is to use inherently safer chemicals in manufacturing and in products, thereby eliminating concerns surrounding CoHCs in manufacturing, usage, and end of life management of plastics. Hazardous chemicals in plastics create legacy issues that block closed loop systems. To effectively close the loop plastics need safer chemical inputs. Polymers are a bedrock of nature and the human economy—now the challenge is making plastics that are safer for humanity and the environment.

APPENDIX 1

Health Hazards of Chemicals of High Concern (CoHCs) in Plastics Production

Chemical / CAS #	Adverse Health Effects / why CoHC	Red List
Acetone/67-64-1	Potential reproductive harm	German Occupational Health Commission (MAK)
Acrylonitrile/107-13-1	Probable human carcinogen	Chemicals Known to the State to Cause Cancer or Reproductive Toxicity, Safe Drinking Water and Toxic Enforcement Act Of 1986 (California Prop 65)
1,3-Butadiene/ 106-99-0	IARC Group 1 Carcinogen; reproductive toxicant; acute organ toxicity, NIOSH occupational health hazard	California Prop 65; International Agency for Research on Cancer (IARC); MAK, US Centers for Disease Control, National Institute for Occupational Safety and Health Carcinogen List (CDC/NIOSH)
Benzene/71-43-2	IARC Group 1 Carcinogen; reproductive toxicant; acute organ toxicity, NIOSH occupational health hazard; potential endocrine disruptor	California Prop 65; CDC/NIOSH; IARC; MAK; Endocrine Disruption Exchange (TEDX)
Bisphenol A/80-05-7	Reproductive toxicant/Suspected reproductive toxicant; endocrine disruptor	US Dept. of Health & Human Services Reports & Monographs on Reproductive & Developmental Toxicity; MAK; European Commission Endocrine Disruption Priority List
Cumene/98-82-8	IARC Group 2B possible human carcinogen	IARC; California Prop 65; MAK
Ethylene dichloride/ 107-06-2	IARC Group 2B possible human carcinogen; NIOSH occupational carcinogen	IARC; California Prop 65; CDC/NIOSH; MAK; US Dept. of Health and Human Services 12th Report on Carcinogens
Ethylene glycol/ 107-21-1	Developmental toxicant; occupational neurotoxicant	MAK; US Dept. of Health & Human Services Reports & Monographs on Reproductive & Developmental Toxicity
Ethylbenzene/100-41-4	IARC Group 2B possible human carcinogen	California Prop 65; IARC
Methanol/67-56-1	Developmental toxicant	MAK; US Dept. of Health & Human Services Reports & Monographs on Reproductive & Developmental Toxicity
p-tert-butylphenol/ 98-54-4	Possible skin sensitizer	European Commission Risk Phrases - R43, H317
p-Xylene/106-42-3	Reproductive harm; systemic organ toxicity	US Environmental Protection Agency (EPA), Toxic Substances Control Act (TSCA) criteria
Phenol/108-95-2	Reproductive toxicant; suspected of causing genetic defects; mutagen	Globally Harmonized System of Classification and Labelling of Chemicals (GHS) Category 1B; European Commission Mutagen Category 2
Styrene/100-42-5	IARC 2B Possible carcinogen; Suspected reproductive toxicant (GHS 1B); potential endocrine disruptor	MAK; IARC; TEDX; US Dept. of Health & Human Services 12th Report on Carcinogens; US EPA TSCA criteria
Vinyl acetate/108-05-4	IARC 2B: possible human carcinogen; germ cell mutagen, GHS Category 2; potential endocrine disruptor	IARC; GHS; TEDX
Vinyl chloride monomer/ 75-01-4	IARC 1B: known human carcinogen; germ cell mutagenicity, GHS Category 2; potential mammary carcinogen	California Prop 65; CDC/ NIOSH; IARC; US Dept. of Health & Human Services 12th Report on Carcinogens; Silent Spring Institute Mammary Carcinogens

APPENDIX 2

GreenScreen® and Assessment of Eight Chemicals Used to Manufacture Polymers

The GreenScreen® for Safer Chemicals was used to assess and determine the hazard level of chemicals in the Plastics Scorecard. The GreenScreen® is a chemical hazard assessment tool developed by Clean Production Action. The GreenScreen® defines four benchmarks on the path to safer chemicals, with each benchmark defining a progressively safer chemical:

Benchmark 1
"Avoid—Chemical of High Concern"

Benchmark 2
"Use but Search for Safer Substitutes"

Benchmark 3
"Use but Still Opportunity for Improvement"

Benchmark 4
"Prefer—Safer Chemical"

Each benchmark includes a set of hazard criteria that a chemical, along with its known and predicted breakdown products and metabolites, must pass. There are 18 hazard endpoints addressed in the GreenScreen® Hazard Criteria (CPA, 2014b).

To better understand the complete hazard profiles of polymer manufacturing for three plastics that prima facie seemed less hazardous than other polymers, Clean Production Action contracted with ToxServices LLC to perform GreenScreen® assessments on eight chemicals related to the polymer manufacturing of polyethylene terephthalate (PET), polylactic acid (PLA), and polypropylene. For PET the chemicals are: acetic acid, ethylene glycol, terephthalic acid, and bis-(2-hydroxyethyl) terephthalate. For PLA the chemicals are: d-glucose, lactic acid, and lactide. For polypropylene the chemical is propylene. The table below lists the verified GreenScreen® benchmarks for each of these chemicals.

The complete verified GreenScreen® assessments are available at *www.bizngo.org*.

The executive summaries for the eight verified GreenScreen® assessments, listed in alphabetical order below, can be found on pages 46–53:

- Acetic Acid (CAS #64-19-7)
- bis(2-Hydroxyethyl) Terephthalate (CAS #959-26-2)
- Ethylene Glycol (CAS #107-21-1)
- Glucose (CAS #50-99-7)
- Lactic Acid (CAS #50-21-5)
- Lactide (CAS #4511-42-6 and 615-95-2)
- Propylene (CAS #115-07-1)
- Terephthalic Acid (CAS #100-21-0)

APPENDIX 1 **Summary of Eight GreenScreen® Assessments**

Plastic	Chemical	Chemical Abstract Services (CAS) Number	GreenScreen® Benchmark
Polyethylene Terephthalate (PET)	Acetic Acid	64-19-7	Benchmark 2
	Ethylene Glycol	107-21-7	Benchmark 1
	Terephthalic Acid	100-21-0	Benchmark 2
	bis-(2-hydroxyethyl) terephthalate	959-26-2	Benchmark Unspecified
Polylactic Acid (PLA)	D-Glucose	50-99-7	Benchmark 3
	Lactic Acid	50-21-5	Benchmark 2
	Lactide	4511-42-6; 615-95-2	Benchmark 2
Polypropylene (PP)	Propylene	115-07-1	Benchmark U/2*

GreenScreen® Benchmark 3 | GreenScreen® Benchmark 2 | GreenScreen® Benchmark 1 | GreenScreen® Benchmark Unspecified

Note: *While a data gap with propylene literally results in a Benchmark Unspecified, if that data gap was filled, no matter its level of concern, propylene would still be a Benchmark 2—therefore propylene is appropriately considered a Benchmark 2.

GreenScreen® Executive Summary for Acetic Acid (CAS #64-19-7)

Acetic acid is a chemical that functions as an acidifier in the food and pharmaceutical industries, and has been used in commercial organic synthesis of pesticides, as well as in a variety of other applications.

Acetic acid was assigned a GreenScreen® Benchmark Score of 2 ("Use but Search for Safer Substitutes") based on a Very High (vH) score for Group II Human Toxicity. This corresponds to GreenScreen® benchmark classification 2f (Very High T) in CPA 2011. Data gaps (dg) exist for Reproductive Toxicity (R) and Endocrine Activity (E). As outlined in CPA (2013) Section 12.2 (Step 8 – Conduct a Data Gap Analysis to assign a final Benchmark score), acetic acid meets requirements for a GreenScreen® Benchmark Score of 2 despite the hazard data gaps. In a worst-case scenario, if acetic acid were assigned a High score for the data gaps Reproductive Toxicity (R) or Endocrine Toxicity (E), it would be categorized as a Benchmark 1 Chemical.

GreenScreen® Benchmark Score for Relevant Route of Exposure

All exposure routes (oral, dermal and inhalation) were evaluated together, as a standard approach for GreenScreen® evaluations, so the GreenScreen® Benchmark Score of 2 ("Use but Search for Safer Substitutes") is applicable for all routes of exposure.

GreenScreen® Hazard Ratings for Acetic Acid

Group I Human					Group II and II* Human									Ecotex		Fate		Physical	
C	M	R	D	E	AT	ST		N		SnS*	SnR*	IrS	IrE	AA	CA	P	B	Rx	F
						SINGLE	REPEATED*	SINGLE	REPEATED*										
L	L	DG	L	DG	M	M	L	L	L	M	M	vH	vH	M	L	vL	*vL*	M	M

Note: Hazard levels (Very High (vH), High (H), Moderate (M), Low (L), Very Low (vL)) in *italics* reflect estimated (modeled) values, authoritative B lists, screening lists, weak analogues, and lower confidence. Hazard levels in **BOLD** font are used with good quality data, authoritative A lists, or strong analogues. Group II Human Health endpoints differ from Group II* Human Health endpoints in that they have four hazard scores (i.e., vH, H, M and L) instead of three (i.e., H, M and L), and are based on single exposures instead of repeated exposures. Please see end of this Appendix for a glossary of the hazard acronyms.

Glossary of GreenScreen® Hazard Benchmark Acronyms:

AA Acute Aquatic Toxicity
AT Acute Mammalian Toxicity
B Bioaccumulation
C Carcinogenicity
CA Chronic Aquatic Toxicity
Cr Corrosion/ Irritation (Skin/ Eye)
D Developmental Toxicity
E Endocrine Activity
F Flammability
IrE Eye Irritation/Corrosivity
IrS Skin Irritation/Corrosivity
M Mutagenicity and Genotoxicity
N Neurotoxicity
P Persistence
R Reproductive Toxicity
Rx Reactivity
SnS Sensitization (Skin)
SnR Sensitization (Respiratory)
ST Systemic/Organ Toxicity

GreenScreen® Executive Summary for bis(2-Hydroxyethyl) Terephthalate (CAS #959-26-2)

bis(2-Hydroxyethyl) terephthalate is a chemical that functions as a reactant in the production of polyethylene terephthalate plastics.

bis(2-Hydroxyethyl) terephthalate was assigned a GreenScreen® Benchmark Score of U ("Unspecified") as there are insufficient data to determine a majority of the hazard rankings for this chemical. Data gaps (DG) exist for Carcinogenicity (C), Reproductive Toxicity (R), Developmental Toxicity (D), Endocrine Activity (E), Acute Toxicity (AT), Systemic Toxicity (single and repeat dose) (ST), Neurotoxicity (single and repeat dose) (N), Skin Sensitization (SnS), Respiratory Sensitization (SnR), Skin Irritation (IrS), Eye Irritation (IrE), Reactivity (Rx), and Flammability (F). The data gaps for bis(2-hydroxyethyl) terephthalate do not meet the minimum data requirements for a Benchmark Score of 2 and the available data do not suggest a high enough hazard for a Benchmark Score of 1 as detailed in CPA (2013) Section 12.2 (Step 8 – Conduct a Data Gap Analysis). In a worst-case scenario, if Bis(2-hydroxyethyl) terephthalate were assigned a High score for Carcinogenicity (C), Reproductive Toxicity (R), Developmental Toxicity (D), or Endocrine Activity (E), it would be categorized as a Benchmark 1 Chemical.

GreenScreen® Hazard Ratings for bis(2-Hydroxyethyl) Terephthalate

Group I Human					Group II and II* Human									Ecotex		Fate		Physical	
C	M	R	D	E	AT	ST		N		SnS*	SnR*	IrS	IrE	AA	CA	P	B	Rx	F
						SINGLE	REPEATED*	SINGLE	REPEATED*										
L	L	DG	L	DG	M	M	L	L	L	M	M	vH	vH	*L*	*L*	*M*	*vL*	DG	DG

Note: Hazard levels (Very High (vH), High (H), Moderate (M), Low (L), Very Low (vL)) in *italics* reflect estimated (modeled) values, authoritative B lists, screening lists, weak analogues, and lower confidence. Hazard levels in **BOLD** font are used with good quality data, authoritative A lists, or strong analogues. Group II Human Health endpoints differ from Group II* Human Health endpoints in that they have four hazard scores (i.e., vH, H, M and L) instead of three (i.e., H, M and L), and are based on single exposures instead of repeated exposures. Please see end of this Appendix for a glossary of the hazard acronyms.

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AA Acute Aquatic Toxicity
AT Acute Mammalian Toxicity
B Bioaccumulation
C Carcinogenicity
CA Chronic Aquatic Toxicity
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D Developmental Toxicity
E Endocrine Activity
F Flammability
IrE Eye Irritation/Corrosivity
IrS Skin Irritation/Corrosivity
M Mutagenicity and Genotoxicity
N Neurotoxicity
P Persistence
R Reproductive Toxicity
Rx Reactivity
SnS Sensitization (Skin)
SnR Sensitization (Respiratory)
ST Systemic/Organ Toxicity

GreenScreen® Executive Summary for Ethylene Glycol (CAS #107-21-1)

Ethylene glycol is a chemical that functions as a monomer in the production of polyethylene terephthalate (PET) plastic. , It is also used as an antifreeze and deicing/anti-icing solution, as an ingredient in resins, inks, paints, waxes, heat transfer fluids, hydraulic fluids, and surfactants, and is a component of electrical boards and electrical condensers.

Ethylene glycol was assigned a GreenScreen® Benchmark Score of 1 ("Avoid – Chemical of High Concern") as it has a High hazard score for developmental toxicity (D). This corresponds to GreenScreen® benchmark classification 1e (High T (Group I Human)) in CPA 2011.

Data gaps (DG) exist for respiratory sensitization (SnR). As outlined in CPA (2013) Section 12.2 (Step 8—Conduct a Data Gap Analysis to assign a final Benchmark score), ethylene glycol meets requirements for a GreenScreen® Benchmark Score of 1based only on the high hazard score for developmental toxicity. In a worst-case scenario, if ethylene glycol were assigned a High score for respiratory sensitization, it would still be categorized as a Benchmark 1 Chemical.

GreenScreen® Benchmark Score for Relevant Route of Exposure:

All exposure routes (oral, dermal and inhalation) were evaluated together, as a standard approach for GreenScreen® evaluations, so the GreenScreen® Benchmark Score of 1 ("Avoid—Chemical of High Concern") is applicable for all routes

GreenScreen® Hazard Ratings for Ethylene Glycol

Group I Human					Group II and II* Human									Ecotex		Fate		Physical	
C	M	R	D	E	AT	ST		N		SnS*	SnR*	IrS	IrE	AA	CA	P	B	Rx	F
						SINGLE	REPEATED*	SINGLE	REPEATED*										
L	L	M	H	*L*	M	vH	H	H	L	L	DG	M	M	L	L	vL	L	L	L

Note: Hazard levels (Very High (vH), High (H), Moderate (M), Low (L), Very Low (vL)) in *italics* reflect estimated (modeled) values, authoritative B lists, screening lists, weak analogues, and lower confidence. Hazard levels in **BOLD** font are used with good quality data, authoritative A lists, or strong analogues. Group II Human Health endpoints differ from Group II* Human Health endpoints in that they have four hazard scores (i.e., vH, H, M and L) instead of three (i.e., H, M and L), and are based on single exposures instead of repeated exposures. Please see end of this Appendix for a glossary of the hazard acronyms.

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IrS Skin Irritation/Corrosivity
M Mutagenicity and Genotoxicity
N Neurotoxicity
P Persistence
R Reproductive Toxicity
Rx Reactivity
SnS Sensitization (Skin)
SnR Sensitization (Respiratory)
ST Systemic/Organ Toxicity

GreenScreen® Executive Summary for Glucose (CAS #50-99-7)

Glucose is a chemical that functions as a food component and additive, as a nutrient replenisher in pharmaceuticals and a fluid replenisher.

Glucose (anhydrous solid) was assigned a GreenScreen® Benchmark Score of 3 ("Use But Still Opportunity for Improvement") as it has moderate Rx (Reactivity). This corresponds to GreenScreen® benchmark classification 3d in CPA 2011. A data gap exists for E (Endocrine Activity). Glucose meets the criteria for a benchmark 3 chemical despite the data gap. In a worst case scenario, if glucose were assigned a score of High for E, it would be classified as a GreenScreen® benchmark 1 chemical.

GreenScreen® Benchmark Score for Relevant Route of Exposure:

All exposure routes (oral, dermal and inhalation) were evaluated together, as a standard approach for GreenScreen® evaluations, so the GreenScreen® Benchmark Score of 3 ("Use But Still Opportunity for Improvement") is applicable for all routes of exposure.

GreenScreen® Hazard Ratings for Glucose

Group I Human					Group II and II* Human									Ecotex		Fate		Physical	
C	M	R	D	E	AT	ST		N		SnS*	SnR*	IrS	IrE	AA	CA	P	B	Rx	F
						SINGLE	REPEATED*	SINGLE	REPEATED*										
L	L	*L*	*L*	DG	L	L	L	L	L	*L*	*L*	*L*	*L*	*L*	*L*	*vL*	*vL*	M	L

Note: Hazard levels (Very High (vH), High (H), Moderate (M), Low (L), Very Low (vL)) in *italics* reflect estimated (modeled) values, authoritative B lists, screening lists, weak analogues, and lower confidence. Hazard levels in **BOLD** font are used with good quality data, authoritative A lists, or strong analogues. Group II Human Health endpoints differ from Group II* Human Health endpoints in that they have four hazard scores (i.e., vH, H, M and L) instead of three (i.e., H, M and L), and are based on single exposures instead of repeated exposures. Please see end of this Appendix for a glossary of the hazard acronyms.

Glossary of GreenScreen® Hazard Benchmark Acronyms:

AA Acute Aquatic Toxicity
AT Acute Mammalian Toxicity
B Bioaccumulation
C Carcinogenicity
CA Chronic Aquatic Toxicity
Cr Corrosion/ Irritation (Skin/ Eye)
D Developmental Toxicity
E Endocrine Activity
F Flammability
IrE Eye Irritation/Corrosivity
IrS Skin Irritation/Corrosivity
M Mutagenicity and Genotoxicity
N Neurotoxicity
P Persistence
R Reproductive Toxicity
Rx Reactivity
SnS Sensitization (Skin)
SnR Sensitization (Respiratory)
ST Systemic/Organ Toxicity

GreenScreen® Executive Summary for Lactic Acid (CAS #50-21-5)

Lactic acid is a chemical that functions as an acidulant in food, beverage and bakery products; it is used in the textile and leather industries as a mordant in printing woolen goods, a solvent for water-insoluble dyes, and to reduce chromates in mordanting wool, and dehairing, plumping, and decalcifying hides, and in the chemical industry for various purposes.

GreenScreen® Benchmark Score for Relevant Route of Exposure:

Lactic acid (in liquid form) was assigned a GreenScreen® Benchmark Score of 2 ("Use but Search for Safer Substitutes") as it has a Very High hazard score for Skin and Eye Irritation/Corrosivity which are Group II* Human endpoints, due to the corrosiveness of highly concentrated lactic acid solutions. This corresponds to GreenScreen® benchmark classification 2f in CPA 2011. A data gap (DG) exists for Respiratory Sensitization (SnR*). Although a data gap exists, lactic acid meets requirements for a GreenScreen® Benchmark Score of 2 as outlined in CPA (2013) Section 12.2 (Step 8 – Conduct a Data Gap Analysis to assign a final Benchmark score), even with its hazard data gap. In a worst-case scenario, if lactic acid were assigned a H score for respiratory sensitization, the overall Benchmark Score for lactic acid will not be affected because it has been assigned hazard scores of vH for both eye and skin irritation.

GreenScreen® Hazard Ratings for Lactic Acid

Group I Human					Group II and II* Human									Ecotex		Fate		Physical	
C	M	R	D	E	AT	ST		N		SnS*	SnR*	IrS	IrE	AA	CA	P	B	Rx	F
						SINGLE	REPEATED*	SINGLE	REPEATED*										
L	L	*L*	L	*L*	M	L	L	M	*L*	L	DG	vH	vH	L	L	L	vL	L	L

Note: Hazard levels (Very High (vH), High (H), Moderate (M), Low (L), Very Low (vL)) in *italics* reflect estimated (modeled) values, authoritative B lists, screening lists, weak analogues, and lower confidence. Hazard levels in **BOLD** font are used with good quality data, authoritative A lists, or strong analogues. Group II Human Health endpoints differ from Group II* Human Health endpoints in that they have four hazard scores (i.e., vH, H, M and L) instead of three (i.e., H, M and L), and are based on single exposures instead of repeated exposures. Please see end of this Appendix for a glossary of the hazard acronyms.

Glossary of GreenScreen® Hazard Benchmark Acronyms:

AA Acute Aquatic Toxicity
AT Acute Mammalian Toxicity
B Bioaccumulation
C Carcinogenicity
CA Chronic Aquatic Toxicity
Cr Corrosion/ Irritation (Skin/ Eye)
D Developmental Toxicity
E Endocrine Activity
F Flammability
IrE Eye Irritation/Corrosivity
IrS Skin Irritation/Corrosivity
M Mutagenicity and Genotoxicity
N Neurotoxicity
P Persistence
R Reproductive Toxicity
Rx Reactivity
SnS Sensitization (Skin)
SnR Sensitization (Respiratory)
ST Systemic/Organ Toxicity

GreenScreen® Executive Summary for Lactide (CAS #4511-42-6 and 615-95-2)

Lactide is a chemical that functions as a pH regulator in food, a swelling agent in bakery products, a bacteriostat in meat emulsions, a reagent for chemical reactions that do not produce water molecules, a destabilizer for production of porous ceramics, and an electrolyte in lithium batteries.

Lactide was assigned a GreenScreen® Benchmark Score of 2 ("Use but Search for Safer Substitutes") as it was assigned a score of High for Skin Irritation (IrS) and a score of Very High for Eye Irritation (IrE) for Group II Human. This corresponds to GreenScreen® benchmark classification 2f in CPA 2011. A data gap (DG) exist on Respiratory Sensitization (SnR*). As outlined in CPA (2013) Section 12.2 (Step 8 – Conduct a Data Gap Analysis to assign a final Benchmark score), lactide meets requirements for a GreenScreen® Benchmark Score of 2 despite the hazard data gap. In a worst-case scenario, if lactide were assigned a High score for the data gap SnR*, it would still be categorized as a Benchmark 2 Chemical.

GreenScreen® Benchmark Score for Relevant Route of Exposure:

All exposure routes (oral, dermal and inhalation) were evaluated together, as a standard approach for GreenScreen® evaluations, so the GreenScreen® Benchmark Score of 2 ("Use but search for safer substitutes") is applicable for all routes of exposure.

GreenScreen® Hazard Ratings for Lactide

Group I Human					Group II and II* Human									Ecotex		Fate		Physical	
C	M	R	D	E	AT	ST		N		SnS*	SnR*	IrS	IrE	AA	CA	P	B	Rx	F
						SINGLE	REPEATED*	SINGLE	REPEATED*										
L	L	*L*	L	*L*	L	L	L	M	*L*	L	DG	H	vH	*M*	*M*	*M*	*vL*	L	L

Note: Hazard levels (Very High (vH), High (H), Moderate (M), Low (L), Very Low (vL)) in *italics* reflect estimated (modeled) values, authoritative B lists, screening lists, weak analogues, and lower confidence. Hazard levels in **BOLD** font are used with good quality data, authoritative A lists, or strong analogues. Group II Human Health endpoints differ from Group II* Human Health endpoints in that they have four hazard scores (i.e., vH, H, M and L) instead of three (i.e., H, M and L), and are based on single exposures instead of repeated exposures. Please see end of this Appendix for a glossary of the hazard acronyms.

Glossary of GreenScreen® Hazard Benchmark Acronyms:

AA Acute Aquatic Toxicity
AT Acute Mammalian Toxicity
B Bioaccumulation
C Carcinogenicity
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Cr Corrosion/ Irritation (Skin/ Eye)
D Developmental Toxicity
E Endocrine Activity
F Flammability
IrE Eye Irritation/Corrosivity
IrS Skin Irritation/Corrosivity
M Mutagenicity and Genotoxicity
N Neurotoxicity
P Persistence
R Reproductive Toxicity
Rx Reactivity
SnS Sensitization (Skin)
SnR Sensitization (Respiratory)
ST Systemic/Organ Toxicity

GreenScreen® Executive Summary for Propylene (CAS #115-07-1)

Propylene is a major chemical intermediate in the chemical industry and in the production of a large range of chemicals.

Propylene (gas) was assigned a GreenScreen® Benchmark Score of U ("Unspecified"). This chemical has High Flammability and High Reactivity, which corresponds to GreenScreen® benchmark classification 2g (High Flammability or High Reactivity) in CPA 2011a. Data gaps (dg) exist for Skin Irritation (IrS), Skin Sensitization (SnS*) and Respiratory Sensitization (SnR*). However, as outlined in CPA (2013) Section III (1) (Benchmarking Chemicals with Data Gaps), propylene fails the requirements for a GreenScreen® Benchmark Score of 2 due to data gaps. As a result, a Benchmark Score of U is assigned. In a worst-case scenario, if propylene were assigned a High score for these data gaps (Skin irritation, Skin and/or Respiratory Sensitization), it would be categorized as a Benchmark 2 Chemical and be classified as both 2f (Very High T or High T) and 2g (High Flammability or High Reactivity). Therefore, the highest and lowest possible Benchmark scores for propylene are both Benchmark 2.

GreenScreen® Benchmark Score for Relevant Route of Exposure:

All exposure routes (oral, dermal and inhalation) were evaluated together, as a standard approach for GreenScreen® evaluations, so the GreenScreen® Benchmark Score of U ("Unspecified") is applicable for all routes of exposure.

GreenScreen® Hazard Ratings for Lactide

Group I Human					Group II and II* Human									Ecotex		Fate		Physical	
C	M	R	D	E	AT	ST		N		SnS*	SnR*	IrS	IrE	AA	CA	P	B	Rx	F
						SINGLE	REPEATED*	SINGLE	REPEATED*										
L	L	L	L	*L*	L	L	L	M	L	DG	DG	DG	M	*M*	*M*	L	*vL*	*H*	H

Note: Hazard levels (Very High (vH), High (H), Moderate (M), Low (L), Very Low (vL)) in *italics* reflect estimated (modeled) values, authoritative B lists, screening lists, weak analogues, and lower confidence. Hazard levels in **BOLD** font are used with good quality data, authoritative A lists, or strong analogues. Group II Human Health endpoints differ from Group II* Human Health endpoints in that they have four hazard scores (i.e., vH, H, M and L) instead of three (i.e., H, M and L), and are based on single exposures instead of repeated exposures. Please see end of this Appendix for a glossary of the hazard acronyms.

Glossary of GreenScreen® Hazard Benchmark Acronyms:

AA Acute Aquatic Toxicity
AT Acute Mammalian Toxicity
B Bioaccumulation
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CA Chronic Aquatic Toxicity
Cr Corrosion/ Irritation (Skin/ Eye)
D Developmental Toxicity
E Endocrine Activity
F Flammability
IrE Eye Irritation/Corrosivity
IrS Skin Irritation/Corrosivity
M Mutagenicity and Genotoxicity
N Neurotoxicity
P Persistence
R Reproductive Toxicity
Rx Reactivity
SnS Sensitization (Skin)
SnR Sensitization (Respiratory)
ST Systemic/Organ Toxicity

GreenScreen® Executive Summary for Terephthalic Acid (CAS #100-21-0)

Terephthalic acid is a chemical that functions as a monomer for polyester which has a variety of applications including adhesives, tire cord, beverage bottles and magnetic recording tapes. In addition, terephthalic acid is used as an OH trap in the fluorescent detection of hydroxylated terephthalate for monitoring OH generation in plant tissue under heavy metal stresses.

TPA was assigned a GreenScreen® Benchmark Score of 2 ("Use but Search for Safer Substitutes") as it has Moderate (M) Toxicity (T) for Carcinogenicity, Endocrine Activity, Reproductive Toxicity and Developmental Toxicity (Group I Human). This corresponds to GreenScreen® benchmark classification 2e in CPA 2011. A data gap (DG) exists for Respiratory Sensitization (SnR*). Although a data gap exists, TPA meets requirements for a GreenScreen® Benchmark Score of 2 as outlined in CPA (2013) Section 12.2 (Step 8 – Conduct a Data Gap Analysis to assign a final Benchmark score), even with its hazard data gap. In the worst case scenario, TPA would still be categorized as a Benchmark 2 chemical even if it were assigned a High score for the data gap for Respiratory Sensitization.

GreenScreen® Benchmark Score for Relevant Route of Exposure:

All exposure routes (oral, dermal and inhalation) were evaluated together, as a standard approach for GreenScreen® evaluations, so the GreenScreen® Benchmark Score of 2 ("Use but search for safer substitutes") is applicable for all routes of exposure.

GreenScreen® Hazard Ratings for Terephthalic Acid

Group I Human					Group II and II* Human									Ecotex		Fate		Physical	
C	M	R	D	E	AT	ST		N		SnS*	SnR*	IrS	IrE	AA	CA	P	B	Rx	F
						SINGLE	REPEATED*	SINGLE	REPEATED*										
M	L	M	M	*M*	L	M	L	M	L	L	DG	L	M	L	L	vL	*vL*	M	L

Note: Hazard levels (Very High (vH), High (H), Moderate (M), Low (L), Very Low (vL)) in *italics* reflect estimated (modeled) values, authoritative B lists, screening lists, weak analogues, and lower confidence. Hazard levels in **BOLD** font are used with good quality data, authoritative A lists, or strong analogues. Group II Human Health endpoints differ from Group II* Human Health endpoints in that they have four hazard scores (i.e., vH, H, M and L) instead of three (i.e., H, M and L), and are based on single exposures instead of repeated exposures. Please see end of this Appendix for a glossary of the hazard acronyms.

Glossary of GreenScreen® Hazard Benchmark Acronyms:

- AA Acute Aquatic Toxicity
- AT Acute Mammalian Toxicity
- B Bioaccumulation
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- CA Chronic Aquatic Toxicity
- Cr Corrosion/ Irritation (Skin/ Eye)
- D Developmental Toxicity
- E Endocrine Activity
- F Flammability
- IrE Eye Irritation/Corrosivity
- IrS Skin Irritation/Corrosivity
- M Mutagenicity and Genotoxicity
- N Neurotoxicity
- P Persistence
- R Reproductive Toxicity
- Rx Reactivity
- SnS Sensitization (Skin)
- SnR Sensitization (Respiratory)
- ST Systemic/Organ Toxicity

APPENDIX 3

Polymers and Hazard Rankings of their Primary Chemicals, Intermediate Chemicals, and Monomers

Polymer	Primary Chemicals (CAS #)	Intermediates (CAS #)	Monomer(s) (CAS #)
Acrylonitrile Butadiene Styrene (ABS)	Propylene* (115-07-1)	Ammonia (7664-41-7)	Acrylonitrile (107-13-1)
			1,3-Butadiene (106-99-0)
	Ethylene(74-85-1)	Ethylbenzene (100-41-4)	Styrene (100-42-5)
	Benzene(71-43-2)		
Ethylene Vinyl Acetate (EVA)	Ethylene (74-85-1)	Acetic Acid* (64-19-7)	Ethylene (74-85-1)
	Methanol (67-56-1)		Vinyl Acetate (108-05-4)
Polycarbonate (PC)	Benzene (71-43-2)	Cumene (98-82-8)	Bisphenol A (80-05-7)
		Sulfuric Acid (7664-93-9)	
	Propylene (115-07-1)	Phosgene (75-44-5)	
	Chlorine (7782-50-5)	Acetone (67-64-1)	p-tert-butylphenol (98-54-4)
		Phenol (108-95-2)	
Polyethylene (PE)	Ethylene(74-85-1)	Ethylene(74-85-1)	Ethylene(74-85-1)
Polyethylene Terephthalate (PET)—Terephthalic Acid (TPA) Route	para-Xylene (106-42-3)	Ethylene Glycol* (107-21-1)	Bis-(2-hydroxyethyl)-terephthalate* (BHET) (959-26-2)
	Methanol (67-56-1)	Acetic Acid* (64-19-7)	
		Terephthalic Acid* (TPA) (100-21-0)	
Polylactic Acid (PLA)	Glucose* (50-99-7)	Lactic Acid* (50-21-5)	Lactide* (L-lactide - 4511-42-6; DL-lactide - 615-95-2)
Polypropylene (PP)	Propylene* (115-07-1)	Propylene* (115-07-1)	Propylene* (115-07-1)
Polystyrene (PS)	Ethylene (74-85-1)	Ethylbenzene (100-41-4)	Styrene (100-42-5)
	Benzene(71-43-2)		
Polyvinyl Chloride (PVC)	Ethylene (74-85-1)	Ethylene Dichloride (EDC) (107-06-2)	Vinyl Chloride Monomer (75-01-4)
	Chlorine (7782-50-5)		
Styrene Butadiene Rubber (SBR)	Ethylene (74-85-1)	Ethylbenzene (100-41-4)	1,3-Butadiene (106-99-0)
	Benzene (71-43-2)		Styrene (100-42-5)

- Red: GreenScreen® Benchmark List Translator 1 or GreenScreen® Benchmark Possible 1
- Orange: GreenScreen® Benchmark 2; or no data that defines the chemical as a GreenScreen® Benchmark List Translator 1 or GreenScreen® Benchmark Possible 1.
- Yellow: Verified GreenScreen® Benchmark 3
- Gray: Actual GreenScreen® assessment with determination of GreenScreen® Benchmark Score of U - unspecified.

* = verified GreenScreen® assessment

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About the Authors

Mark S. Rossi, Ph.D.

Mark Rossi is Co-Director at Clean Production Action and Founder and Chair of BizNGO. Established in 2006, BizNGO is a unique collaboration of businesses and environmental organizations working together to advance the development and use of safer chemicals and sustainable materials. BizNGO's listserv now reaches over 1,000 business, government, university, and environmental leaders. Mark has the unique ability to bring together a diverse community of stakeholders, focus them on a given project, skillfully forge a dedicated team, and guide them towards an honest resolution.

Mark is a leader in developing solutions to the problems of toxic chemicals. In 2001, with Health Care Without Harm he co-founded *CleanMed,* which is now the leading conference for greening health care. Mark is the co-author of the *GreenScreen for Safer Chemicals,* a leading chemical hazard assessment tool. He is the lead author of the *Lowell Center Framework for Alternatives Assessment* and the *BizNGO Chemical Alternatives Assessment Protocol*—two of the leading frameworks for selecting safer alternatives to toxic chemicals. Mark has a B.A. from Muhlenberg College and a Ph.D. in Environmental Policy from the Massachusetts Institute of Technology.

Ann Blake, Ph.D.

Ann Blake is Founder and Principal of Environmental & Public Health Consulting. Ann is an independent consultant with over 20 years of experience finding safer alternatives to industrial chemicals in global manufacturing. Her work has included creating criteria for environmentally preferable purchasing, ecolabels and product rating systems as well as local, national and international chemicals policy reform. Ann's current clients include the City of San Francisco's Department of Environment, UCLA Law's Sustainable Technology and Policy Program (STPP), the International POPS Elimination Network, and the Blue Green Alliance. Ann currently serves on the board of Women's Voices for the Earth.

Ann has created curricula in green chemistry, chemicals policy and alternatives assessment for UC Berkeley Extension's professional certificate in Green Chemistry. She is a member of the California Green Ribbon Science Panel. Prior to consulting, Ann worked for the California Environmental Protection Agency's Department of Toxic Substances Control as a hazardous waste inspector and Pollution Prevention Coordinator. Ann has a B.A. from Mount Holyoke College in Massachusetts, and a Ph.D. in molecular genetics and neural development from the University of Oregon.

THE PLASTICS SCORECARD

Evaluating the Chemical Footprint of Plastics

VERSION 1.0

Goals: inform the selection of safer plastics by businesses and catalyze manufacturers to reduce the number and volume of chemicals of high concern (CoHCs) in manufacturing processes and products.

Potential Impacts: advance the development and use of plastics that use inherently safer chemicals in all steps of polymer production as well as in the selection of additives.

Value: The use of inherently safer chemicals in manufacturing will greatly reduce the costs of hazardous chemicals all along the plastics life cycle, from manufacturing to usage to end of life management.

Who: The Plastics Scorecard is for anyone interested in identifying and selecting plastics based on inherently less hazardous chemicals. Product designers, material specifiers and purchasers will all find value in the both the criteria for evaluating plastics as well as the assessments of individual plastics.

Method: Scores plastics on—

- **Manufacturing:** Progress to Safer Chemicals in Manufacturing Score; and
- **Product:** The Chemical Footprint of Plastic Products.

Findings—Manufacturing:

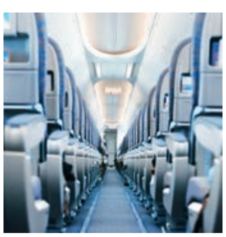
- **Safer polymers:** Polylactic acid (PLA), polyethylene (PE), and polypropylene (PP)
- **Polymers of high concern include:** Polyvinyl chloride (PVC), polystyrene (PS), polycarbonate (PC), acrylonitrile butadiene styrene (ABS)

Findings—Products:

- **IV Bags:** PE/PP bags have significantly lower chemical footprint than PVC bags
- **Electronic enclosures:** PC/ABS products can lower additive footprint over PS products, but both are polymers of high concern

Solutions

- First ask, is it necessary?
- Use safer additives.
- Use safer polymers.
- Close the loop and use post-consumer recycled (PCR) content (but beware of legacy CoHCs).
- Redesign the product.



CLEAN PRODUCTION ACTION

1310 Broadway, Suite 101, Somerville, MA 02144

www.cleanproduction.org • moreinfo@cleanproduction.org