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General Introduction

This introductory chapter will address fundamental, current questions of interest related to plastics and sustainability. As with the other chapters in this book, this chapter will begin with a brief outline of its contents. This will be followed by an episode from a fictional scenario about plastics industry people who are dealing with real-world sustainability decisions. Each of the following chapters will continue this story, following the characters' progress as they consider how to best reduce the overall environmental impact from the selection, processing, use, and disposal of plastic materials. The main content of each chapter provides details that the characters – and similarly interested readers – might consider when making sustainability decisions about plastics.

This chapter will define terms and arguments related to issues of environmental sustainability, restating arguments in ways that best highlight the challenges that plastics-consuming companies can focus their energies on. It will briefly introduce issues that are covered later in the book in more detail, also linking some

well-known plastics controversies with the broader context of this book. Specifically, this chapter will:

- define environmental sustainability in terms of plastics production and use (1.1);
- present an overview of the sometimes contradictory positive and negative features of polymer-based materials (1.2);
- illustrate consumers' dependence on plastics in their plastics-based lifestyles (1.3);
- provide a brief history of recent (and often controversial) sustainability issues concerning plastics (1.4);
- discuss the "need for green" – especially the social pressures that are forcing plastics manufacturers to take sustainability seriously (1.5); and
- provide an overview of the chapters in the remainder of the book (1.6).

Part 1: Company at a Crossroads

It's 2011, and SureShot Inc. finds itself at a crossroads after fifteen years of existence. It started as a relatively small company making injection-molded rigid food containers and housewares, mainly made from polyethylene and polypropylene. A few years ago, the company expanded the plant, adding a couple of thermoforming lines to produce PET food containers, such as clear clamshells and trays for produce and deli foods. The company managed to survive the 2008–2010 "Great Recession" with relatively few layoffs, though some areas of its production floor that it had planned to fill with activity are still inactive (or empty).

Business is slowly returning to pre-2008 levels, but new issues are growing in importance. Calls for environmental sustainability are focusing more attention on the plastic packaging industry's roles and responsibilities in determining how its products are created, used, and discarded. Governments are considering bans on various single-use plastic products, and the plastics consuming public seems to be more conscious of the material that is used for these products, where the material comes from, and how it's disposed of.

Considering all of these issues is Guy Winston, general manager of SureShot's 150-employee operation. He's proud of his 20-year career in the plastics industry, but lately he's been wondering about his company's role in the sustainability argument. He knows his operation covers the basics of environmentally efficient production – his equipment is fairly

energy-efficient (except for a few older machines), the plant's scrap material is fed back into appropriate processes and products when possible, and the company even manufactures a line of lettuce containers that contain some post-consumer recycled PET bottle content (although this business is less than 3% of the company's total production). But he's starting to think that they could do more.

The industry trade journals are stuffed with articles about bioplastics, bioresins, bioadditives, and "bio-everything-else." Plastics made from renewable feedstock materials rather than fossil fuels seem to be the next big thing. But what is the market for these materials? Don't they cost more? Wouldn't SureShot have to increase its prices? Do bioresins have adequate properties, compared with the current PET, PE, and PP grades the plant uses? Do they process as easily and as consistently too?

Sheila Wolfe, SureShot's young head of engineering development, was recently hired after business started to improve last year. With a Master's Degree in Engineering and an MBA in hand, she certainly has an educational background that Guy doesn't. And she's extremely excited to try out bioresins in a couple of product lines. "We have to start making the shift to bioresins as soon as possible, or we'll be left behind," is her consistent position. She's enthusiastic, but fortunately is still mostly objective – yet Guy wonders if her inexperience with high-volume packaging operations hurts her credibility on this issue. After all, she was in elementary school when Guy started his career as a manufacturing engineer. Sometimes it's obvious that she didn't witness firsthand how much SureShot's business suffered during the recession.

In Guy's mind, the "Great Recession" period still weighs heavily. "We have to make sure we keep on making money and keep everyone employed," is an obsessive thought he continues to have – and he cannot shake the nervousness he experienced when hearing about the bad fortunes of other similar-size plastics products companies that shut down operations in recent years.

Another colleague is influencing Guy's thoughts. Often seen wandering through the plant is Paul "Tubs" Kirmidgin, SureShot's hands-on president, CEO, and founder. He's definitely "old school," and not a strong supporter of many pro-environmental initiatives, to say the least. "Now they've got even The Wall Street Journal *convinced that these bioplastics are going to be important," he complained to Guy one day. "Ridiculous – making plastics from crops – our food – plus it's expensive. No, there's plenty of natural gas and oil in the ground to make plastics from, and only a few percent of that is used to make plastics anyway. Guy, I trust you already know all these things." Fortunately for Guy, the wiry, energetic 70-year-old (usually) resists interfering with Guy's management of the*

operation. Even though behind the scenes they often disagree, Guy was originally hired and promoted by Paul, who remains a father figure to him, of a sort.

With Sheila's and Paul's diverse opinions surrounding him, Guy has decided to thoroughly study all the issues related to plastics' environmental footprints and bio-based plastics. There are some real questions to consider first off. For example, has the traditional plastics industry gone in wrong directions in the past – hurting its image and even creating real harm to the environment? And are developments such as bio-based plastics better directions in which the industry – and SureShot Inc. – should be moving?

1.1 What is Environmental Sustainability?

In its most common use, the term *sustainability* is used as a shorthand term for *environmental sustainability*, which concerns human interactions with nature and technology. Often, sustainability simply relates the use of renewable, natural materials to the use of extracted, refined materials – usually favoring the former over the latter. Many non-industrial cultures, such as traditional Native American cultures, have practiced environmental sustainability as a normal, fundamental driver of their social practices. And any brief tour of a history museum reveals how ingenious pre-industrial societies of only two hundred years ago were in their use of natural materials such as plant and animal fibers, wood, stone, and bone.

Sustainability is now often defined as a goal, such as the goal of using technology and resources to "meet our current needs without preventing future generations from meeting their needs." (Some cite Thomas Jefferson as being one of the first modern Westerners to phrase the concept of sustainability in this way [1].) Sustainability's focus can be expanded to include the broader natural world, with its goal being to maintain our technological lifestyles while allowing all species of organisms to maintain their current numbers and lifestyles as well.

The concept of sustainability is often commingled with issues about the health effects or damage to natural processes from the use of certain products or materials. Here, it is easier to identify what is unsustainable than to define what is sustainable. Any product

that potentially has negative effects on human (or animal or plant) health, or that accumulates as waste in the environment, could also be thought of as unsustainable. Or, sustainability is often tied to the issue of global climate change and energy use, accompanying arguments that current rates of greenhouse gas production and fossil fuel use are unsustainable.

Thus many people have many views about sustainability. Since success in sustainable manufacturing and marketing depends on having friendly, accessible markets and consumers, this book will take a broad view of sustainability, based on how it is widely defined by or thought of by experts and the public, rather than limit its definition in an academic or industry-preferred way. (And one might especially consider how a younger generation of consumers views issues of plastics and sustainability [consider Figure 1.1].)

Narrowing our scope to plastics, but otherwise still keeping a broad view of the issue, there are many arguments to be offered in favor of or against their sustainability. The arguments involve the real or theorized large-scale environmental impacts related to the fossil fuels on which most plastics are based. These fossil fuel reserves are dwindling or becoming harder to extract, resulting in higher prices and economic disruptions that eventually will result from the unrestrained consumption of nonrenewable resources. There is also damage anticipated from the global warming caused by greenhouse gas emissions, effects which are linked to the fossil-fuel-based economic infrastructure that keeps plastics cheap and disposable. And there are issues of waste and litter that the public is now more aware of, such as the Pacific Ocean "garbage patch" – a gyre composed of floating waste plastic and other products that has been reported on in recent years. Figure 1.2 illustrates the pressures of the above forces, including pressures from consumers and retailers and the increasing demand for plastics worldwide.

However, there are also sustainability arguments that often conflict with the goals of environmental sustainability. These emphasize another kind of sustainability: economic sustainability. Here sustainability is defined more as the ability of an economy or company to survive, long-term. For plastics-creating- and using-industries, economic sustainability typically requires avoiding higher costs – even when those costs come from using environmentally sustainable materials and processes. Questions about the quality of new sustainable materials, unresolved issues about

Figure 1.1 This piece of public art created by Michigan children shows the obvious concerns that young consumers have about sustainability. The "Trash Tree" sculpture was accompanied by a sign explaining that 80% of what Americans throw out is recyclable, though only a fraction of that is actually recycled. (Photo courtesy of S. Kalaj.)

processing these new materials, and consumers' interests in low prices all have the potential of overwhelming pro-environmental sustainability arguments. Meanwhile, a question remains as to whether business sustainability may eventually require proof that a company's products are also environmentally sustainable.

This book will attempt to balance and synthesize these views by demystifying some issues related to plastics and sustainability. It will take a fresh look at how renewable, bio-based plastics compare with traditional fossil-fuel-based materials. The book will not just focus on technical details and analyses, but also will consider consumer values, product requirements, market demands, laws and regulations, and basic practical issues. In addition, this book will try to find the ways in which economic sustainability and environmental sustainability can be linked by companies involved in the processing and use of plastics – especially those that are most often under scrutiny in terms of sustainability.

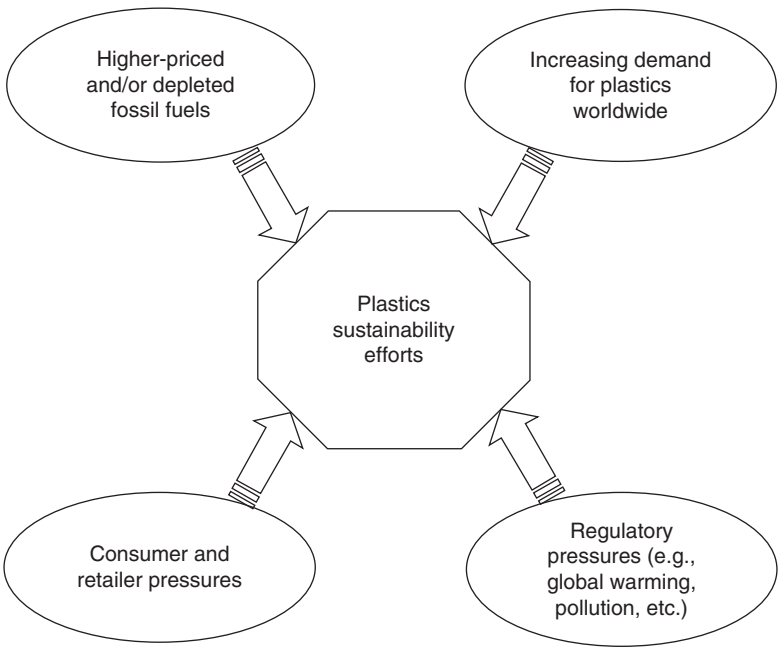

Figure 1.2 Large-scale social and natural forces are pressuring efforts toward making plastics and plastic products more sustainable and environmentally friendly.

1.2 Facing the Contradictions of Plastics

An honest assessment of plastics as being useful, important materials also requires admitting that plastic products' shapes, forms, compositions, uses, and material qualities are somewhat enigmatic or contradictory. Plastic products sometimes resemble objects from nature, although sometimes an alien, even science fiction form of nature. But normally they are not considered as being like anything that is natural; after all, plastic compositions are created by chemists and are mysterious to those uneducated in organic chemistry.

The term "plastics" is itself inadequate and misleading in that it refers to a wide range of materials. Some plastics are rubbery and some do not melt when heated; some are strengthened with glass fiber to become composites, while others are used in the form of simple films or foams. Certain plastic products are weak, cheap, and disposable; others are strong and durable – yet all are labeled simply as plastic.

Other contradictions below relate to plastics' place in our economy and in our larger natural environment:

- Plastics are inexpensive… but their properties can be tailored for very high-value, engineering purposes.
- Plastics often have relatively simple chemical structures… but they can be extremely resistant to processes of natural decay, guaranteeing their long-term persistence in the environment.
- Plastic products are lightweight… but millions of tons of them have been consumed and disposed of.
- Plastics are made from high-energy chemical feedstock, becoming in essence "frozen fuel"… but plastic products and their inherent energy are commonly treated as waste for landfills, often after very brief lifetimes of use (unlike liquid or gaseous fuels, whose energy content is converted directly into heat or motion).
- Most waste plastics can be reprocessed at relatively low temperatures and energies…. but their relative low cost means their collection, separation, and recycling is often not cost-competitive with the production of new, virgin plastic.

- Different plastics are considered by the public as being very similar, and their differences are often hard to distinguish by eye… yet their tailored chemistries, mechanical properties, and additives content often tie each plastic to a specific use (which also makes them harder to recycle and reuse in multiple applications).

Thus, even though plastic products are sophisticatedly designed and fabricated for even the simplest uses… most are still typically destined to become (very durable) trash.

At least one of these contradictions is directly focused on in this book: the use of valuable fossil fuels to create low-cost plastics. This is generally the case, though slowly in recent years, the existence of plastics is becoming less dependent on supplies of fossil fuels. More plastics are being made from renewable, biological sources. The growth rate of bio-based plastics is estimated to be 15–20% in 2011, and this growth is expected to continue at multiple times the rate of all plastics growth for the long term (with estimates varying from 12–40% annually) [2].

Bio-based polymers right now include the increasingly popular corn ethanol-based polylactic acid (PLA). But the bio-based field may soon become dominated by conventional, well understood polymers, such as polyethylene and polypropylene, that are based on feedstock made from plant resources such as Brazilian sugarcane instead of fossil fuels. For example, Braskem SA in 2010 opened a plant in Brazil to make 400 million lb/yr of sugarcane-based polyethylene. The company has also dedicated $100 million for a 66-million lb/year bio-based polypropylene plant slated to begin operation by 2013 [3]. Although these materials will initially be priced at a premium compared with fossil-fuel-based PE and PP, they stand as signs that the industry is indeed able to develop bio-based options for plastics.

As discussed in future chapters, many biological resources are being considered for creating bio-based plastics, ranging from food crops to bacteria, and from agricultural wastes to algae. As we will see, key questions about these bioresins concern their properties and prices relative to those of fossil-fuel-based polymers – with many environmental, design, and social factors influencing the choices of manufacturers and consumers regarding bio- versus non-bio-based plastics.

1.3 Plastics at Play in Consumer Lifestyles

Another plastics contradiction concerns consumers both in developed countries and, increasingly, in developing countries: Consumers have become incredibly dependent on plastic materials, even without understanding many of the details of their composition or how they are manufactured.

There is something almost fantastic about plastic products – their shapes and colors, their textures and smooth forms. In the more exciting early days of plastics, people might have even been tempted to reference science fiction author Arthur C. Clarke's "Third Law" from 1962: "Any sufficiently advanced technology is indistinguishable from magic" [4]. However, now, after never really achieving the sensationalistic appeal of space flight, personal computers, or the cell phone, plastics are no longer new. The most common popular polymers have outlived their inventors, and any sense of plastics' magic or fascination for consumers is lost behind the banality of the many products they are used in. Rather, a more common question overheard today would be: "Do we really need plastics?"

Thus, ignorance, indifference, hostility, or ambivalence might be better terms for describing consumers' views of plastics today. These views have resulted in the easy demonization of certain forms of plastics, with a complete obliviousness about other potential problems associated with the ways we use all materials in industrialized society – metals, wood, and minerals, as well as plastics. Humans have consumed more of all these materials in the past 50 years than in all previous years combined – at increasing rates. And the vast majority of industrial materials are not based on naturally renewing resources, unlike in 1900, when over 40% of all materials used in the United States were based on forestry, agriculture, or other renewable industries [5]. These trends, coupled with incredible population growth, have definitely stressed the environment.

Plastics simply reflect these trends, though perhaps more prominently because they are used for so many visible, high-volume consumer items. In fact, the average consumer is the plastics industry's biggest supporter, whether he or she is aware of it or not. Between 1965 and 2005, the growth of plastic materials in the United States averaged close to 8% per year, currently with higher growth rates than that in India and China, as their populations' lifestyles become more industrialized [6]. There is no doubt that worldwide consumer

interest in and dependence on plastic-based products will continue for as long as it takes to develop equally versatile materials of another kind.

Consider the ubiquity or "everywhereness" of plastics by looking at a day in the life of an adult in an industrialized country. When she wakes up, the first thing she touches is probably plastic: an alarm clock. Walking across the (nylon) carpet to the bathroom, brushing her teeth, washing her hair, and using other personal care items, she encounters a variety of plastics. The clothing she dresses herself in likely contains some polyester or another synthetic fiber. Her juice bottle and cup is plastic, as is her coffeemaker. She wraps her lunch in a plastic film or bag and places it in a reusable polymer-fiber sack. She drives to work in a car whose interior is almost completely covered in various polymer-based materials. She uses a coded plastic ID card to get into her workplace, grabs a (PET) bottle of water from the office refrigerator, and sits in front of a plastic-enclosed computer to spend the day tapping on plastic keys. Later, her evening at home or out on the town consists of similar contact points with plastics…

When looked at this way, the prevalence of plastics can be striking. In fact, their importance seems directly proportional to the degree to which the consumer does *not* notice that he or she is actually using a polymer-based product (especially in the case of beverage bottles, toothbrushes, shoes, cell phones, food packaging, and car interiors). Even though today most plastic items are banal and uninteresting to the user/consumer, a day without their use would be unthinkable. Some people have tried to demonstrate that we can live our lives without plastics, but they have met only limited success, facing continual frustration from not ever being able to totally succeed.

1.4 Controversies Concerning Plastics: Recent Examples

Despite the consumer marketplace's apparent desire for products made from plastics, the materials have faced a history of intense public scrutiny. Some early commercial plastics formulations were dependent on ingredients, such as heavy metals, with negative human health or environmental effects. Most of these compositions have since been eliminated, but enough similar applications remain

to keep public watchdogs skeptical about the health impacts of plastics. The scrutiny continues and will continue, given plastic products' new compositions, new forms, and complete integration with everyday life. Acknowledging that this skepticism will continue is important for those who specialize in introducing new forms of plastics into the marketplace (even when these materials are based on natural, renewable resources).

Examples of plastics under scrutiny go back decades, and many controversies continue. Plastic additives, such as lead- and cadmium-based stabilizers and colorants were once heavily used in polyvinyl chloride (PVC) and other plastics. Since then, there has been general acknowledgement that there is potential harm in using heavy metal-based additives and coatings, resulting in a strong trend in the industry to eliminate them. For similar reasons, electronics manufacturers are avoiding plastics that include halogenated flame-retardant additives, given concerns about the chemicals' environmental effects and persistence. And calls continue for eliminating the use of PVC itself, given its chlorine content and chlorinated-compound emissions during its manufacturing.

Another obvious example concerns many consumers' dislike of the use of expanded foam polystyrene products. The material is associated with possibly carcinogenic styrenic petrochemicals, ozone-layer-depleting blowing agents (once in common use), and its single-use, disposable, non-biodegradable nature. The feelings are intense enough that even the use of a Styrofoam coffee cup can draw someone's judgmental stare. A future alternative to achieving the lightweight insulation properties of expanded PS may be bio-based plastic foams, though the negative image of plastic foam may remain [7].

Three other recent controversies related to plastics are of interest. These deserve more discussion below, and have been discussed frequently in the news media over the last few years. Unless they and some lesser-known issues can be resolved, these and other issues will likely keep plastics in general under intense public/governmental scrutiny – perhaps even transferring over to polymers made from renewable, bio-friendlier resources or processes.

1.4.1 PVC and Phthalate Plasticizers

Polyvinyl chloride, or simply PVC or "vinyl," has progressed down a rocky road from its original high mountaintop location of being

one of the most affordable, adaptable, and widespread polymers for plastic products. Since then, both the material's origin and end-of-life have been questioned in terms of environmental and health impacts. When concerns about persistent industrial chemicals in the environment became more prominent over the past few decades, the potential toxicity of PVC's chlorine chemistry itself was scrutinized. Its production depends on using cancer-causing vinyl chloride, which can escape into the environment if not carefully controlled, along with small amounts of chlorinated dioxins (which are carcinogenic and persistent in the natural environment). Heavy metal-based additives (mentioned above), once commonly used in vinyl, are largely being phased out, but not after somewhat damaging PVC's reputation. And vinyl products are not of much interest in major recycling efforts, given all the varieties of PVC compounds in use and the challenges involving their collection and separation.

Yet no final resolution about vinyl's use is evident. It continues to be used in high volumes for siding and roofing in building and construction, and in some consumer products and packaging. However, governmental and environmental group efforts are having some effects in discouraging its use in electronics and consumer goods. In 2010, the European Union moved to require special assessments of PVC's use in electrical devices, outside of the EU's already restrictive REACH (Registration, Evaluation and Authorization of Chemicals) system and RoHS (Restriction of Hazardous Substances) directive [8]. Even the giant retailer Walmart tried to get suppliers to eliminate PVC from packaging in the United States by 2007 (though without complete success) [9]. This news is nearly the only kind of media attention vinyl gets today, and millions of consumers by now have a negative PVC taste in their mouth from the publicity.

In the 1990s, health concerns arose related to the phthalate chemical plasticizing additives used to soften PVC. Commonly used phthalate plasticizers are not chemically tied to the polymer backbone, so they have a tendency to migrate to the surface of the product. Their effect on children was of particular concern, and children were the driving force of the controversy, because they tend to place flexible vinyl toys and products into their mouths. After years of studies about how phthalates disrupt the endocrine system of humans, and counter studies saying the opposite (often funded by an industry that relies on using phthalates for PVC), regulations began to be passed that restricted the use of common

phthalates. Apart from outright bans in some western countries, the US Consumer Product Safety Commission in 2009 restricted to very low concentrations a number of common phthalates in products used by children under twelve years old [10]. In response, additive suppliers have created lines of plasticizer alternatives, some of which are bio-based or which bond to the PVC polymer matrix [11].

Perhaps there are lessons to be learned from the history of PVC, as new bio-based plastics are introduced. Some resin suppliers are already considering questions like the following before the large-scale marketing of their fossil-fuel-based resins or their bioresins:

- What compounds are emitted during the production of the raw polymers, and during their compounding? Are they dangerous to workers? Would any regulatory agency consider them so?
- What additives are compounded into the plastic? Are any controversial? Have they been tested and confirmed to be non-toxic in every situation in which a user might encounter them? Are they tightly bound in the final plastic composition, or can they be extracted from the plastic part during use?
- Can a recycling infrastructure potentially be created for the material, if it does not already exist (or a composting infrastructure, if the material is compostable)?

1.4.2 Plastic Shopping Bags

The issue of banning single-use plastic shopping bags illustrates the concept that the more an inexpensive plastics technology grows in popularity, the greater the potential for controversy. There is a reasonable motivation driving the desire to reduce or eliminate the use of lightweight plastic shopping bags: reducing litter. Polyethylene blown-film bags are lightweight and designed mainly for a single use; thus they are treated as low value, trivial products by the consumer. They are also easily littered, intentionally or accidentally, and are easily transported by the wind and waterways far from where they were littered. They are also resistant to degradation by weather or water. Plastic litter in general is colorful, durable, noticeable litter, especially when it is reported as collecting on beaches or in giant floating "patches" in ocean gyres. These problems are

argued very persuasively and visually, with pictures of wildlife harmed by ingesting plastic.

Thus explains the rash of plastic bag bans proposed or enacted by regional governments around the world. By the start of 2011, various bans of conventional, non-biodegradable grocery bags had gone into effect in coastal communities across Europe, in parts of Asia, and in San Francisco, Washington, D.C., and other cities in the USA. Some governments have banned bags outright, or collect a fee or tax levied on each bag used [12]. Corporate retailers have even developed their own self-imposed bag bans; in 2009 Walmart reportedly reduced its plastic waste by the equivalent of about 4.8 billion bags, a 16% waste reduction from 2007 [9]. (The company's goal is a 33% shopping bag waste reduction by 2013, and it has already reported a 69% reduction at its stores in China.)

Yet despite litter concerns and bag bans, the use of plastic packaging overall has continued to grow. In end-markets where plastic packaging competes with paper packaging (such as bags), plastic packaging is growing faster than paper, and is expected to nearly catch up to paper by 2012 in terms of packaging pounds used per year [13].

There are other contradictions in the bag ban trend. One often cited observation is that by eliminating single-use plastic bags, bans encourage the use of more paper bags, which are heavier and less energy-efficient to manufacture. In a study concerning the banning of plastic carryout bags in Los Angeles County, researchers calculated that replacing 6 billion plastic bags per year with 4 billion paper bags would create additional CO_2 emissions equivalent to tens of thousands of additional vehicles on the road. Moreover, paper bags that are landfilled rather than recycled quickly degrade, seemingly a good thing except for the production of methane, a potent greenhouse gas that many landfills are not equipped to capture [14].

Another opposing argument is that any fee levied per bag, such as $0.05 to $0.25, unfairly impacts low-income people as a regressive tax, while not itself accumulating into a significant source of government revenue. And bag bans may not be effective in reducing bag use long-term. Since Ireland began taxing grocery bags in 2002, a 10% *increase* in plastic bag use has been reported, as well as a large increase in sales of plastic trash can liners, which has been a common reuse application of grocery bags [15, 16]. These trends seem to indicate that some people are using more plastic shopping bags now than in 2002, and that those who are not, probably use shopping bags for more than just their initial use.

There are also counterproposals for fixing the problems related to plastic bags. Industry organizations such as the American Chemistry Council argue that strong public education programs that discourage bag littering and promote bag recycling are more effective approaches to handling the issue. In response to future bag bans in Europe and elsewhere, bioplastics producers have reportedly been preparing for an increase in demand for blown film made from bioresins. Bio-based and/or biodegradable plastics may be sustainable alternatives for shopping bags, whose manufacture uses tens of millions of oil-equivalent barrels of fossil fuel each year [17]. Yet experts point out that bioplastic bags still cost more than the PE bags and use more water and energy to manufacture. And even many biodegradable bioresin bags do not completely or quickly degrade when littered, scarcely helping to solve the littering problem [12]. Meanwhile, more consumers are getting into the habit of using reusable cloth grocery bags (although ironically, concerns have arisen about elevated levels of lead in some of these bags, as well as potential *E. coli* contamination if the bags are not washed after transporting food) [18].

This continuing plastic shopping bag saga indicates at least three questions to consider when making sustainable plastic product decisions for single-use products in particular:

- Is the product designed so as to seem very disposable and trivial, making a "littering controversy" inevitable? Or can its recyclability and multiple uses be emphasized by its design or marketing?
- If the product is likely to become litter, is its material formulated to degrade under non-composting, natural conditions? If not, what will its effect on wildlife and the natural environment likely be if littered?
- Can a significant percentage of post-consumer recycled material be used in the single-use product, emphasizing that there is value in and a need for a stream of recycled materials of the same kind?

1.4.3 Health Effects of BPA (Bisphenol-A)

A distant relative of the PVC/phthalate controversy is the more recent concern raised about residual bisphenol-A in polycarbonate

(PC) containers and epoxy-based metal can liners. BPA is one of the building blocks of PC and epoxy polymers, and residual BPA can be detected in measurable amounts in final products and on their surfaces. Like phthalates, BPA has been classified as an endocrine disruptor; various laboratory studies have pointed to BPA as disrupting the glandular systems and development of mammals in various degrees, depending on concentration and intake amounts. Studies continue to emphasize widespread exposure of the general population to BPA and the possible effects on children, though the studies are heavily scrutinized and criticized by industry groups [19].

Still, manufacturers and retailers began phasing out PC baby bottles in 2008. As of July 2010, seven US states had established laws restricting BPA in various types of containers. And the US Food and Drug Administration changed its views on BPA in early 2010, saying it is "taking reasonable steps to reduce human exposure to BPA in the food supply," and is considering adding it to its "chemicals of concern" list [20, 21].

Reports about BPA studies have led to various bans of PC products in various western countries and US states and cities. The bans focus particularly on containers used by children, who are in sensitive phases of endocrine system and hormonal development. Various large retailers are also phasing out all water- or food-related PC products, responding quickly to mass media reports, public concerns, and governmental warnings. Canned foods appearing with the label "BPA free" are appearing on grocery store shelves. Even the common 5-gallon PC water cooler bottle used in offices around the world is being redesigned to be molded in non-BPA-containing copolyester resin [22].

Thus, public opinion and even the views of some of its own member companies have turned against the plastics industry's official positions on BPA. At least one writer has even compared the industry's response with the tactics of tobacco companies that had denied the health effects of cigarettes [23]. For the plastics industry, the issue has become a "damage limitation exercise," given all of the common plastic products BPA can be found in, the vast majority of which are not food/drink related [24].

The process by which BPA-based plastics have become undesirable includes key themes common in chemical controversies. One basic issue is that BPA is a man-made chemical, widely used by the often distrusted chemical industry. BPA is also somewhat

mysterious – it may be present in our food and drink containers, but it cannot be detected by our senses, and consumers do not know when they are being exposed to excessive amounts of it. Inside the human body, its effects sound disturbing; studies indicate it can mimic estrogen, a hormone whose proper levels are critical for the sexual development of fetuses and children. This makes the issue even more compelling and emotionally driven [25]. And even alternative, non-BPA-containing plastics used for children's food products are now suspect, guilty by association, making them more difficult to market [26].

Given these conflicting issues, biases, and emotions, a couple of questions might be addressed before any new plastic or product line is introduced for a human-contact application:

- In addition to its additives, what other residual materials in the plastic might have questionable health-affecting or environmentally controversial backgrounds, inviting scrutiny?
- Can issues with the plastic's composition be connected with recent plastics controversies? And if so, will that hinder its acceptance by retailers or consumers?

Negative reactions from all controversies about plastics or their ingredients ultimately spread and become intensified in the general public discourse. Some of the mainstream media reports are written by journalists who tend to oversimplify and overgeneralize, lumping more common plastics in with the controversial types, and even inaccurately implying that all common plastics share the same questionable characteristics (e.g., [27, 28]). The writers sometimes even imply that a number of common modern health ailments may be the result of plastics use alone, despite all the other materials, pollution, technologies, radiation, stress, and processed foods that people are exposed to. Such writers and their hasty generalizations can be taken to task in the industry press (e.g., [29]), but even with the Internet, such technical corrections are not likely to be understood (or even read) by the general public audience of the original, more dramatic mainstream reports.

Current controversies also invite increased future scrutiny on plastics when other health issues arise. Sometimes intense scrutiny is helpful, contributing to safer products in the long term. But any

questionable plastic compound ingredient can quickly become the focus of intense studies funded by various groups. The intensity of the scrutiny may border on irrational reasoning, as in a reported case of excessive antimony detected in packaged fruit drinks in Denmark [30]. In this case, the main focus was the antimony trioxide used as a catalyst in the production of PET packaging – making the PET the prime suspect source – even though high antimony was also found in *non-plastic* packaged fruit drinks.

The mainstream, traditional plastics industry is typically the focus of this kind of scrutiny. But although manufacturers of bio-based plastics may get better press because of the natural origin of their materials, even they should anticipate greater scrutiny once their products become more established.

1.5 The Desire to be "Green"

Given these kinds of controversies, plus consumers' other environmental concerns about plastics, we again notice contradictions and conflicts. Consumers want to be green, but they also apparently want plastic products. This section (and the remainder of this book) looks at how these often conflicting intentions might be resolved.

1.5.1 Consumer Interest in Sustainability

Consumers are interested in environmental sustainability, though their behaviors may not reflect their interest. In one recent survey, over 80% of consumers expressed concern about the environmental impact of their choices, and said they thought retailers' environmental efforts are important [31]. But fewer than 10% would sacrifice convenience to buy sustainable products. And for many, the term "sustainable" itself has little meaning, or the meaning is unclear [32]. Most people feel recyclability is important, though in general consumers do not display diligence in their green behaviors overall, especially behaviors related to plastics. For example, consider…

- their rampant littering, which clutters the sides of roads, clogs waterways, and mars natural scenery (and here plastics make up a minor but very noticeable proportion of littered materials);

- their inclination to throw easily recycled bottles into garbage cans rather than recycling bins;
- their favoring of factory-made products that are heavily packaged with plastics and other materials; and
- their constant replacement and disposal of electronic devices and media, most of which are encased in plastics,

to cite just a few observations. These real world tendencies might not change much, and plastics producers and designers interested in sustainability must design around them as much as possible to "pollution proof" devices and packaging, and to make their recycling as easy as possible.

Recycling is something every school child learns about at an early age, but our society recycles plastics relatively poorly, especially in the United States. For example, despite some gains in recent years, the United States' recycling rate for PET and other bottles has remained under 30% through 2009 [15, 33]. Europe recycles better, especially in PET bottle recycling, with a rate of about 48%, or 3 billion pounds of PET bottles collected per year (equaling roughly 48 billion standard bottles). But experts say a sub-50% PET recycling rate is still not high enough to offset the net carbon emissions of processing, collecting, and reprocessing PET – or to bring the recycled PET's price low enough to be really competitive with virgin resin [33, 34]. Only collection rates of over 50% will result in a noticeable amount of material being reused in new PET products, including not just fibers and low-end products, but also new bottles and food packaging.

On the other hand, given their desire to be environmentally sustainable, efforts are being made to lead consumers to greener products and companies. As a result, major US retailers and suppliers of consumer products, such as Walmart in 2007 and Procter & Gamble in 2010, have introduced sustainability "scorecards" for their suppliers. These systems evaluate the carbon emission and resource and energy "footprints" of their products and operations [35]. Meanwhile, marketers are responding to consumer interest by touting environmental claims for products and processes (though some of the claims are better supported than others).

These seemingly positive developments can be read in complex ways, however. Demands for environmental sustainability are often motivated mainly by a company's simple interest in reducing

energy, shipping, or material costs. Or green efforts may be used to increase sales by stressing relatively minor sustainability improvements using major marketing campaigns. Some claims fall into the unsubstantiated "greenwashing" category of exaggeration, pseudo logic, or lack of objective verification.

Greenwashing has become such a concern that the US Federal Trade Commission proposed new "Green Guides" guidelines in 2010 about what specific green marketing language is required by companies which exhort the environmental values of their products. The term "eco-friendly" now must be more substantiated and made specific. For example, the term *biodegradable* by itself is too vague to be clear unless qualified by testing, though it has been wielded as a magic word that automatically attracts concerned consumers. Now, however, biodegradable products must be certified to degrade within one year in most US waste handling operations [32].

1.5.2 Sustainability: Views and Counterviews

Generally, this interest in "being green" makes sense; it can be assumed that everyone, theoretically at least, wants environmental sustainability. People want a clean, habitable earth with healthy places to live in, plus healthy wildlife in natural areas and oceans. However, the specific issues that determine or affect sustainability have less unanimous consensus. The concept that the earth is warming because of excess greenhouse gas emissions is mostly accepted by people around the world. However, some questions exist about the extent to which the warming is happening, or on whether human activity is mainly causing it and can stop it (with some people perhaps having an innate belief that human beings could not possibly have such influence over nature). Discussions are also related to the effects of the warming, with some people perhaps even doubting that the warming will be a bad thing overall.

With plastics and other consumer materials, opinions (informed and otherwise) likewise range from the simple to the complex. As we have seen with the controversies described above, educated people, though they use plastics every day, commonly have a fundamental notion that plastics are bad for environmental sustainability, except when plastic products are made from natural materials or recycled plastics. They may believe recycling is always good, as they learned in school. The emotions behind these beliefs

range from zeal (or hostility) to indifference. In the general public, the interest in the deeper science behind these issues is limited, even when the news media draws attention to controversial studies about plastics. Concerns like the BPA issue explained above have led to the media's tendency to report on every obscure negative plastic study, with most of this reporting being oversimplified, confusing consumers about what to do.

For the deeper analysis that is required, sustainability and plastics issues have drawn many different approaches from various researchers and institutions. Some of this research is politically driven by environmental groups, free-market theorists, and the plastics industry itself – each with its own inevitable bias – though this bias does not automatically make their arguments weak or illegitimate. University-based research is invaluable and is intended to be less biased, digging down into the deepest layers of specificity about polymer science and the environment.

However, mainly in the public discourse, traditional fossil fuel plastics receive much less good press than newer plastics based on renewable natural materials. People outside and inside of the industry are excited or at least curious about bioresins and whether they could solve the environmental negatives associated with traditional plastics. There are also genuine contrarian arguments about the use of chemicals and plastics in general – and about bio-based materials in particular. Below, a few of these arguments are summarized and addressed, revealing the assumptions behind the context of this book.

What Global Warming? After many years during which the concept of global climate change has been discussed, debated, and studied, there has been at times the sense that consensus has been achieved: that it is clear that greenhouse emissions caused by the burning of fossil fuels for over two hundred years indeed is causing an overall warming of the earth's climate. The US Environmental Protection Agency (EPA) cites the Intergovernmental Panel on Climate Change as stating the warming of the climate is unequivocal, and the EPA has taken the position that the warming is caused by greenhouse gas emissions, which can potentially be controlled and reduced [36].

Yet skeptics and minority views persist, and many are not simply politically motivated. A small number of reasonable and informed researchers do continue to question the accuracy of climate models and data used to support the idea that human activity

is causing significant warming. The climate is more complicated than the models predict, some argue, neglecting the cooling effects of clouds, for example, and thus overstating the amount of warming that is happening [37]. These counter-arguments might mean that major reductions in the use of fossil fuels are not critically important; and likewise, that developing alternative, renewable sources of materials and energy may be a more expensive exercise than can be justified.

This book is not meant to verify and/or support either those who agree with or disagree with various global warming projections. To some extent, the issue of using fossil fuel-based or bio-based plastics mostly side-steps the issue, since plastics production is not a significant source of greenhouse gases, compared with the sectors of transportation, general electricity production, and heating. The book does, however, take seriously the possible disastrous consequences of global warming, if the worst scenarios play out. And it takes seriously the interests and views of consumers and industries that are interested in reducing the role of fossil fuels and the greenhouse gas impact of plastics use and production. Just as importantly, this book looks to a future when alternatives to fossil fuels will be necessary – when fossil feedstock sources begin to become so depleted and expensive that renewable resource feedstocks become cost-effective options for producing plastics.

Aren't we running out of oil? Conventional plastics production is dependent on access to feedstocks produced from steady supplies of oil and natural gas. These resources are technically finite on earth, and humans have not found a competitive option to using these fuels for heating, transportation, and chemicals.

Yet, although fossil fuel extraction and production has become more technically challenging, fossil fuels continue to be found in various locations and extracted in various ways, such as from shale. Crude oil's price and the price of natural gas have continued to be stable enough to support current plastic demand, keeping plastic products affordable. Thus, this book will make the assumption that fossil fuel supplies will stay relatively affordable, but will likely increase over time as fossil fuels become more costly to extract (with occasional spikes in prices) and as demand increases from developing countries. As fossil fuel prices rise, bio-based plastics and recycled plastics will become more competitive. Markets for naturally renewable materials should expand when oil prices pass

a specific "tipping point" level that makes the need for biobased options more convincing.

People and jobs are more important than the environment, aren't they? Given the recent severe recession, it is still not uncommon to hear the argument that jobs for people are more important than environmental sustainability. Indeed, environmental issues have been rarely mentioned in the mass media and public discourse in recent years. Instead we hear that costs or taxes must be cut in order to create jobs, or to prevent additional job losses. Government subsidies for sustainability are frowned on if they do not create jobs immediately. This focus tends to hurt efforts at sustainability. For instance, efforts may be abandoned for increasing the use of bio-based materials if they initially invite extra costs that make them uncompetitive with traditional materials, even in a $100-per-barrel oil economy.

However, interest in sustainable materials is growing, and market opportunities exist. Efforts in environmental sustainability can sometimes become new ways of saving money and better ways of using materials, both fossil fuel- and bio-based. This book assumes that this interest in sustainability will continue in future years and is likely to grow among people within the plastics industry and plastics using sectors. This interest will translate into new markets which will support bioplastics use, as existing markets for conventional plastics remain strong or grow themselves.

Is a sustainable use of resources even possible? Researchers who take the long view argue that western (and now eastern) societies have increased their use of material and energy resources over time, and nothing likely will stop that trend. In terms of energy use, a strange relationship seems to exist: the more improved the energy efficiency of our technologies is, the more the total demand for, and use of, energy is [38]. For example, improvements in automotive engine efficiency since the 1970s have been accompanied by a large increase in total miles driven each year, and thus increased gasoline consumption and greenhouse gas emissions [36]. If this relationship is true, then steps toward sustainability may simply encourage people and the economy to demand and use more and more materials and energy.

An assumption behind this book is that materials use, especially plastic products use, will continue to increase globally – whether more efficient, sustainable approaches are employed in manufacturing them or not. Growing economies such as China and India

will increase their demand for plastics, perhaps to extreme levels. At the same time, no matter what raw materials they are based on, plastics will also continue to be improved in terms of their performance in applications. Other improvements will relate to the amount of energy and resources they consume when produced, how easily they can be recycled, and perhaps how well they can be composted instead of landfilled. Thus, energy and resource conservation is an adequate reason for pursuing the development of biobased plastics and greater recycling. (And it can only be a good "hedged bet" for the plastics industry to possess technologies that give it some independence from fluctuating oil- and natural gas-based feedstock costs.)

Recycling always makes sense, doesn't it? Despite the average person's belief that recycling is always a positive for the environment, there are major hurdles involved in collecting and recovering recyclable plastics from the waste stream. Plastics are recovered at lower rates from US municipal solid waste than all other major material types, even with the many curbside recycling programs now in place [36]. Separating uncontaminated plastics by type and form is not easy for consumers or recycling facilities. Also, there are often technical limits on the amount of recycled resin that can be used in a given product, and the range of products containing recycled content is limited by the quality of available recovered material. The costs and difficulties of plastics recycling – and the relatively low price of conventional virgin resins – can mean that sometimes recycled resin costs as much as virgin plastic resin, despite the strong demand for recoverable material by recycling operations around the world.

But efficiently done, plastics recycling can be a valuable way of reusing the building blocks of polymers and their chemical bond energy, rather than wasting this resource by burying it in a landfill. Recycling also reduces the amount of greenhouse gases produced; in 2006, US municipal solid waste recycling avoided the creation of nearly 183 million metric tons of carbon dioxide equivalent emissions (though this admittedly was a small fraction of the roughly 7 *billion* tons of CO_2 emitted in the United States that year) [5]. The recycling potential of both conventional and bio-based plastics is strong but mostly underdeveloped in most countries. There is much room for improvement. Meanwhile, recycling companies in China, the United States, and Europe are seeking more recycled plastics to fill their extra capacity. Public education by the plastics industry

about recycling can be improved, creating a greater stream of higher quality material. And a strong recycling industry can supply material that serves to hedge against spikes in raw material prices.

If bioplastics cost more, and we're not even sure they're truly sustainable, why should we use them? Current common bioplastics are relatively expensive because of the fuel, fertilizer, water, and energy required to grow their raw feedstock material (plants). To make them more price competitive with fossil fuel-based plastics, subsidies may be needed. Critics have argued that government subsidized materials are in fact economically *unsustainable*, distorting free market practices that normally reward materials and processes having the lowest costs. The fact that producing bioplastics requires many resources may also mean that they are environmentally unsustainable as well [39]. Various studies have tried to show that bioresins do have a lower environmental impact. However, the complex arguments required for making good life-cycle evaluations have made these studies vulnerable to criticism and rebuttal (see Chapters 2 and 3).

Admittedly, it is possible that the newest generations of bioplastics in production do not have strong economic or environmental sustainability, at least not with current technologies and volume demand. The number of factors involved in evaluating the true environmental life-cycle impacts of bio- and fossil-based plastics is staggering. However, there is a driving force that may help bioresin production become more efficient, more competitive, larger in scale, and greener: the consumer. The environmental ethics of some consumers indicate that at least for some products in some markets, there is strong market demand for bioplastics. Some consumers simply are interested in buying plastic products that are based on plants or other natural resources, even if they cost more or cannot be proven to be unequivocally environmentally sustainable. Only time will tell if makers of bioplastics and their applications will find durable long-term markets and lower costs as a result of this consumer interest.

1.6 The Course of This Book: A Chapter-by-Chapter Overview

As the following chapters will discuss in more detail, the criteria for determining what makes a plastic product "green" can include many measures, including factors related to its source

feedstock, the carbon dioxide emissions in its manufacturing, its recyclability, its biodegradability/compostability, and the toxicity of its composition. All "cradle-to-grave" lifecycle impacts must be considered: the origins of the compounded polymer material and its processing into a useful product; the product's environmental impacts during its use-life (from the time it comes out of its manufacturing facility to when it is shipped to a waste or recycling facility); and the environmental impacts from the product's disposal/recycling phase.

This book's structure attempts to serve as a template for a thorough, thoughtful analysis of plastics and sustainability. It covers the lifecycle factors influencing the selection of various plastic materials for minimal environmental impacts, with special emphasis on comparing the impacts of fossil fuel-based plastics with new biologically sourced polymers, fillers, and additives. Each aspect determining the environmental impacts of plastics (and the chapter which focuses on it) is summarized below:

The life cycles of plastics (Chapter 2): All manufactured materials and products have certain costs and impacts associated with their creation, use, and disposal (or reuse). There are numerous ways of evaluating and measuring these impacts. These are based on analyzing all the material and energy flows that are used for producing and using the material or product, as well as the costs or value, if any, that the discarded product or material might have after it has been used. Chapter 2 will review principles for evaluating the fundamental impacts of the raw feedstocks used in polymers, and summarize ways in which the total lifecycle impacts of plastics have been measured through approaches such as lifecycle assessment (LCA). It will also discuss the limitations of LCA and the factors not easily accounted for when speaking about plastics' impacts, such as biodegradability and recycling.

Material composition (Chapter 3): Various polymers require various feedstocks made from fossil fuels, or more often now, bio-based raw materials. These feedstock molecules are combined to form polymers, to which additives and fillers are added, creating plastics. Each kind of polymer/plastic impacts the environment slightly differently. This chapter will attempt to compare and contrast the impact and value of producing various commercial plastics and the polymers they are based on. It will give special attention to the composition and properties of bio-based polymers, relating their properties to those of more familiar fossil fuel-based polymers,

to create a context in which they may be compared. Questions also will be addressed about the toxicity of the materials' components, and about how the various materials are appropriately durable for use in various applications.

Applications (Chapter 4): This chapter will discuss several real life example applications in which sustainability was a factor in the choice of plastic material. The application sector areas touched on include packaging, automotive, construction, medical, electronics, and agriculture. The discussion will attempt to draw "lessons learned" from the examples that can be applied to new applications.

Design (Chapter 5): Product design decisions can reduce (or increase) the environmental impact of a plastic product. Subtle changes in a product's dimensions or in the way various materials are combined or assembled together can have large impacts on recycling and material usage. This chapter will provide basic guidelines for "green" plastic product design.

Material selection (Chapter 6): This chapter will combine the elements of Chapters 2–5, showing how various factors – including environmental impacts – can be compared and weighed for different plastic application areas. Its aim is to assist in the process of determining the optimum choice of material in terms of performance, quality, cost-effectiveness, and, especially, sustainability – a factor often not emphasized in traditional material selection methodologies.

Processing energy and waste (Chapter 7): Significant energy can be consumed when creating plastic compounds and when forming the materials into products. Because bio-based resins and fossil-based resins use essentially the same conversion technologies, this chapter mainly looks at methods used for processing and reprocessing plastics in general. Available alternative technologies and practices are presented for efficiently recycling process scrap and post-consumer resin, and for reducing the energy and water costs of conventional conversion processes.

Conclusion (Chapter 8): The final chapter presents an overview of current worldwide trends and obstacles that relate to efforts in reducing the overall environmental footprint of plastics. It will propose basic conclusions about current trends, indicating directions for the future as well as suggesting goals the industry should consider targeting, and actions it should take to enhance the sustainability profile of plastics.

References

1. Bashyal, S., Bachman, B., Baumann, M.H. (2010). Plastics packaging: A current perspective on sustainability. ANTEC 2011 (Proceedings), Society of Plastics Engineers.
2. Verespej, M. (2010, August 12). Experts predict boom in bio-based resins, *Plastics News*, http://www.plasticsnews.com, 2010.
3. Smith, C. (2010, November 1). Braskem commits to bio-based PP, *Plastics News*.
4. Jones, A.Z. (2011). 'What are Clarke's laws?' About.com. http://physics.about.com/od/physics101thebasics/f/ClarkesLaws.htm, 2011.
5. EPA (2009, June). *Sustainable Materials Management: The Road Ahead,* United States Environmental Protection Agency.
6. Baumann, M. (2005, May). History and trends in the plastics industry… implications for its future (Presentation slides).
7. Tolinski, M. (2009, January). Foams seek sustainability, *Plastics Engineering*.
8. Nuthall, K. (2010, June 7). Europeans might target PVC in electronics. *Plastics News*.
9. Wal-Mart makes progress on reducing bag use, but not on eliminating PVC packaging (2010, May 13), *Plastics News,* http://www.plasticsnews.com, 2010.
10. Martino Communications Inc. (2009, June 22). Teknor Apex now offers diverse range of alternatives to phthalate plasticizers for vinyl toys and child-care products, (Press release).
11. A new approach towards increasing the safety of phthalate-based plasticizers (2010, March 29). http://specialchem4polymers.com, 2010.
12. Verespej, M. (2010, March 9). Calif. report may encourage single-use bag bans, *Plastics News*. http://www.plasticsnews.com, 2010.
13. Plastics outpaces paper in competitive packaging markets (2009, April 20), *Plastics News*.
14. Greenhouse gas emissions will increase massively if Los Angeles County bans plastic bags and permits free paper bags (2010, January 1), SaveThePlasticBag.com, http://www.degradableplasticbag.com, 2010.
15. Markarian, J. (2010, October 25). What the plastics industry is doing about the plastics litter problem? http://specialchem4polymers.com, 2010.
16. Higginbottom, J. (2010, May 7). Bag taxes disappointing in debut, *Fiscal Fact* (no. 224). Tax Foundation, www.taxfoundation.org, 2010.
17. Clark, A. (2010, November 4). It's in the bag for Cereplast bio-based plastics, *PRW News,* http://www.prw.com, 2010.
18. Armour, S. (2010, November 22). Lead in reusable grocery bags prompts call for federal inquiry, *USA Today,* http://www.usatoday.com, 2010.

19. Verespej, M. (2010, March 24). Study says health at stake from BPA exposure, *Plastics News*, http://www.plasticsnews.com, 2010.
20. FDA says BPA poses health risk, *Plastics News,* January 17, 2010, http://www.plasticsnews.com, 2010.
21. Laurenza, P. (2010, September 10). BPA stays on regulatory watch, *Plastics News,* http://www.plasticsnews.com, 2010.
22. Hockensmith, D. (2010, February 5). Product bans have blow molders planning for bigger BPA-free bottles, *Plastics News,* http://www.plasticsnews.com, 2010.
23. Loepp, D. (2010, April 20). *Fast Company* honored for BPA coverage, *Plastics News,* http://www.plasticsnews.com, 2010.
24. Tolinski, M. (2009, March). Clear alternatives, transparent motives, *Plastics Engineering*.
25. Ropeik, D. (2010, April 19). Bisphenol A. balancing fact and fear as we face a risk, *Psychology Today,* http://www.psychologytoday.com, 2010.
26. Klara, R. (2010, April 18). True green? *Brandweek,* http://www.brandweek.com, 2010.
27. Sturm, T. (2010, May 6). Food: Back to basics, *The Valley Advocate,* http://www.valleyadvocate.com, 2010.
28. Walsh, B. (2010, April 1). The perils of plastic, *Time,* http://www.time.com, 2010.
29. Griff, A. (2010, May 7). *Time* magazine taken to task, *Plastics News,* http://www.plasticsnews.com, 2010.
30. Smith, C. (2010, February 25). Fruit drink study finds antimony, but no cause, *Plastics News,* http://www.plasticsnews.com, 2010.
31. Clark, D. (2010, July 2). Consumers – expectations and actions, 'Forward Action' (Weblog), http://amcorforwardaction.com, 2010.
32. Neff, J. (2010, October 11). FTC targets broad environmental claims, *Plastics News*.
33. Verespej, M. (2010b, October 20).Use of recycled PET rises to record level, *Plastics News,* http://www.plasticsnews.com, 2010.
34. Smith, C. (2010, October 18). Finding the true value of PET recycling, *Plastics News*.
35. Hockensmith, D. (2010, May 12). Procter & Gamble launches sustainability scorecard, *Plastics News,* http://www.plasticsnews.com, 2010.
36. EPA (2009, September). *Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices* (EPA doc. 530-R-09-017), United States Environmental Protection Agency.
37. Christy, J. (2009, February 25). Written testimony, House Ways and Means Committee, Washington, D.C.
38. Inhaber, H. (1997, October). Energy conservation doesn't happen, *Consumers' Research Magazine,* 80.
39. Jones, R.F. (2009). An overview of environmental alternatives as viewed by a plastics industry economist, ANTEC 2009 (Proceedings), Society of Plastics Engineers.