# From hydrocarbons to carbohydrates:
## *Food packaging of the future*


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# EXECUTIVE SUMMARY

Each American uses about 190 lbs of plastic a year, approximately 60 lbs of which is packaging that is discarded as soon as the package is opened. Many of these plastics end up in landfills where they will stay for centuries. The public's increasing concerns about waste coupled with growing desires for more sustainable products have led many companies to create products made from compostable polymers made from agricultural resources. We believe that these ***compostable biopolymer plastics have the potential to gain a significant percentage of the plastic food-packaging market share in the next ten years***, while lessening the environmental impacts of packaging by decreasing dependence on foreign oils, shrinking landfill requirements, and still meeting packaging demands. The market for compostable polymer packaging in the United States, Japan, and the United Kingdom has been analyzed, and suggestions are provided for market entry strategies for these polymers. Cargill Dow's PLA is considered as a baseline case.

In recent years, many nations have enacted policies such as: (1) take-back policies that make manufactures responsible for products at the end of their lifetimes; (2) policies that place the burden of waste management on manufacturers; (3) policies that restrict the amount of packaging on products; and (4) incentives for government organizations to use bio-based products. These policies help create a supportive environment for compostable polymers.

Three types of compostable polymers, poly(hydroxyalkanoates) (PHA), polylactic acid (PLA), and thermoplastic starch (TPS), have gained much attention in recent years. Cargill Dow produces PLA via fermentation of starch from feed corn. This polymer uses less fossil fuel energy than traditional plastics and completely composts within 45 days in a commercial composting facility. Unlike PLA, PHA will biodegrade in many environments (e.g. marine, soil, etc.); however at this time the production of PHA uses more fossil fuel energy than traditional plastics. PHA is only currently produced commercially by Metabolix-BASF AG. Despite the environmental benefits of these polymers, neither has gained significant market share, in part due to high cost (packaging containers tend to be two and four times the price of traditional plastics). TPS polymers, which can be 100% starch or a mixture with more 'plastic-like' polymers, currently have the largest market share of the compostable polymers. Their benefits include lower fossil fuel use, compostablility and cost competitiveness with traditional polymers.

Despite the benefits of compostable polymers there are significant barriers to entry that must be overcome such as retailer and consumer skepticism, material costs, the added costs of switching technologies, and lack of composting infrastructure.

To overcome these barriers, we suggest that Cargill Dow and its customers consider the following technical and market entry recommendations:

- Continue working on producing PLA from biomass to show commitment to the concept of sustainability as well as non-dependence on genetically modified organisms.
- Conduct extended research into modified/controlled atmosphere (MAP/CAP) packaging.

- Make PLA packaging microwaveable and biodegradable in conditions other than commercial composts.
- Continue targeting high-end groceries and short shelf-life products, e.g. in-store packaged fruits, vegetables, and bakery items, also seek organic fruit and vegetable growers and makers of "natural" or organic bulk and dried products and snack items for children and pets.
- Seek agreements with institutions, particularly "green" college campuses, large corporations that are publicly committed to sustainability, and institutions that are already composting, as well as national/state parks food service.
- Augment public education campaigns -- use trade and food shows, and foster relationships with NGOs, which have enormous distribution lists. Sponsor in-store promotions and develop school lesson plans and programs around composting and sustainability.
- Emphasize service because regardless of the environmental and other benefits of biopolymer packaging, it will not succeed unless it is provided by reliable suppliers.

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# 1 INTRODUCTION

Is there any man-made material more versatile or ubiquitous than plastic? In the past five or six decades, our world has come to depend upon plastics for almost every imaginable application: from child safety seats to credit cards, telephones to thermal underwear, cars to computers. Plastics have even staked their claim in the medical industry, with gloves, prosthetic limbs, sutures, and beyond. With all of these applications, it is the packaging industry that accounts for almost a full third of the 200 *billion* pounds of plastic produced in the U.S. every year [STE02]. While other packaging materials, such as paper and glass, are competing for market share, plastics have the advantages of low cost, light weight, and durability.

Food packaging is the largest growing sector of the plastic packaging market. Along with beverage packaging, it accounts for about 70% of the $100-billion packaging market in the U.S., and more than half of the plastics market worldwide [STE02]. While many plastic consumer products are designed for a relatively long lifetime, all of this food packaging is meant to be quickly discarded.

Although 80% of Americans have access to recycling programs, less than 10% of plastic packaging was recycled in the U.S. in the mid 1990s (not including bottles) [BRO04, EDF97]. That leaves the vast majority of plastic containers finding their way into landfills, where they will stay for centuries.

Around the world, public concern is growing on two fronts – both ends of the life cycle of packaging products. On the disposal end, many countries are facing decreasing landfill space. Although, with the exception of the northeast, the U.S. has plenty of landfill capacity, many Americans prefer to “reduce, reuse and recycle.” The U.S. will also face steeply rising costs as the price of siting new landfills increases. No one wants a new landfill in their neighborhood. In smaller, island nations such as Taiwan, Japan and the United Kingdom (U.K.), landfill capacity is becoming truly scarce, and in many nations there is also growing opposition to incineration of garbage due to air-quality concerns.

Even as the developed world is producing more and more *stuff*, and consumers are demanding convenient plastic packaging for much of it, there is also a growing awareness that this way of life is not sustainable. Although many consumers are concerned with waste, they are also concerned about the non-renewable resources used to fuel our society – including the production of plastic.

Because of these concerns, “bioplastic” packaging products have emerged as a viable alternative to traditional plastics. These bioplastics promote environmental health and resource conservation as well as a more sustainable way of life. They are not made directly from petroleum resources, but from rapidly renewable agricultural feedstock. In addition, these bioplastics are fully biodegradable and compostable – taking them off of the dead-end road to the landfill, and instead looping the feedstock back into nature. In the last two decades, many companies worldwide have developed such biopolymers.

Several types of biopolymers are currently produced or are under development for the food packaging market in the U.S. One promising polymer is PLA (poly lactic acid), developed by Cargill Dow. PLA is made from starch derived directly from corn, and it biodegrades under the right composting conditions within 47 days. If disposed of in a landfill (where it will not biodegrade) or by incineration, the PLA product will not release chemicals harmful to humans [STA04].

The major opportunity for penetration of natural, compostable plastics into the U.S. packaging market is to appeal to “green” consumers. One challenge is the notion of re-educating consumers, and testing the appeal of compostable polymers made from renewable resources vs. recyclable plastic. Another is generating sufficient demand among these “green” consumers who are willing to pay more for a perceived environmentally beneficial technology until prices become low enough to compete in the broader market with traditional plastic packaging.

In many parts of the world, large constituencies of environmentally concerned citizens have enabled governments to enact policies that are favorable to bioplastic packaging. Japanese and European governments, for example, have opted for national laws that place responsibility on manufacturers and importers to guarantee recycling of packaging. They also actively promote household pickup and composting of organic wastes. These countries, in particular, provide ample kindling for firing up the sales of bioplastics packaging.

The objective of this report is to lay out the current market condition of bioplastic packaging alternatives in terms of technological improvements, economic market conditions, and current and possible future policies. This information is then combined to show what market segment makes the most sense to target in the future, and recommendations are offered for developing the market for bioplastics food packaging in the U.S. and abroad.

We believe that ***compostable biopolymer plastics have the potential to gain a significant percentage of the plastic food-packaging market share in the next ten years***, while lessening the environmental impacts of packaging by decreasing dependence on foreign oils, shrinking landfill requirements, and still meeting packaging demands. This increase will be brought about in part by limited landfill space and increasing environmental awareness.

In order to analyze the current market condition of “green” packaging alternatives in the food industry, the first step was to create a flowchart showing each of the players. The chart that was developed (Figure 1 below) was used to help us determine our major research and focus areas. Based on this chart the research was divided into four major categories: (1) Policy, (2) Market, (3) Technology, and (4) Competitors. Although promising, non-packaging applications and the fast-food industry were considered outside the scope of this report. Instead, the focus was placed on rigid packaging for food, primarily in grocery outlets, because this is seen as a fast-growing segment of the market with many possibilities for further exploitation.

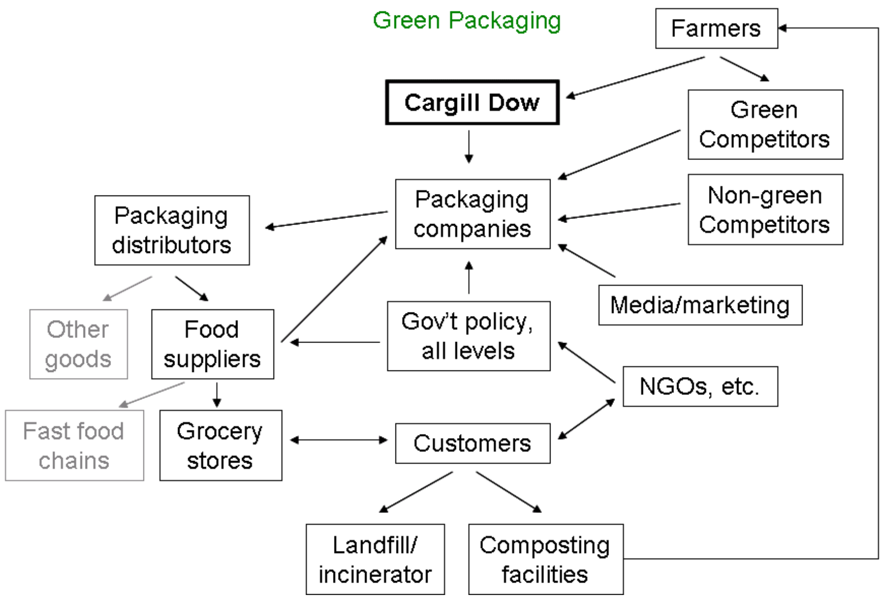


**Figure 1**: Organizational Chart of Key Players

# 2 POLICY

The food-processing industry in the U.S. accounts for nearly 26% of worldwide food processing output. There are more than 17,000 food manufacturing factories around the U.S. Excessive non-biodegradable packaging has played a role in over-burdening landfills, where solid waste disposal fees have risen from $0.75/ton in 1970 to $100 to $500 per ton [AEP03]. Because of this and other environmental concerns such as the use of fossil fuels, there has been pressure on the food industry to decrease the environmental impacts associated with food packaging.

## 2.1 Current Recycling Policies in the U.S. Food Packaging Industry

Although using recycled plastic packaging is highly recommended, there are lingering concerns that some recycled plastic may have contaminants from post-consumer materials. Because the Food and Drug Administration (FDA) is concerned about public health and safety regarding these contaminants, it has designed a document outlining the conditions for food packaging manufacturers using recycled plastic packaging. This document sets guidelines for the use of recycled plastic packaging for use in food industry and requires companies to provide extensive documentation before approving the use of recycled plastic packaging.

Despite the difficulties of using recycled plastics in the food industry, companies are being encouraged to minimize waste generation and increase recycling. The United States is continually developing incentives for companies who comply with the criteria of size minimization, ease of recycling and reusability packaging. Through these incentives, companies are encouraged to minimize waste generation within the company and meet definite recycling rates. However, these voluntary policies only go so far. Recycling rates remain flat and have even declined for certain materials. In addition, packaging designers continue to develop new plastic packaging that is not easily recyclable or biodegradable.

## 2.2 Manufacturers' Responsibility and Take-Back Policies

Many countries have enacted product take-back policies in order to decrease the amount of waste they put into landfills. These polices have been found to be effective for products that are high-value, have a high risk of being improperly disposed of, have a low rate of transactions, have centralized production and distribution, and have a close and continual relationship with the customer. The packaging industry does not have these qualities and therefore take-back policies are not a good option. This effect could be amplified in the United States, where billions of products change hands, move across an even larger geographical area, and there are a large variety of waste disposal systems [SCA01].

In addition to take-back policies, many countries have enacted policies in which the manufactures are required to take responsibility for the recycling of the packaging. They are required to make the product meet certain recycle rates and pay the recycling costs. The costs are the difference between the cost of production using virgin materials and the cost of producing at the target recycled content level, plus the waste-handling cost. The costs range from zero to over $440 per ton [SCA01]. The United States has not yet enacted manufacturer's responsibility policies on packaging.

## 2.3 Landfill Policies and Limitations

Increasing the rate of recycling or changing to biodegradable packaging could decrease solid waste disposal and help eliminate landfill problems in the future. In the U.S., however, federal and state regulations are directed at landfill owners and operators. The regulations only affect the food companies down the line with increasing landfill costs or prohibition of certain types of waste. Because the food-processing companies are not directly affected by these polices, they have no direct incentives to decrease packaging or to change to more biodegradable packaging.

## 2.4 Current Government Incentives for Biopolymers

Compostable polymers made from agricultural resources represent an important step in shifting from non-renewable resources to renewables. Eventually products at the end of their life cycle can become "biological nutrients" for other processes [MCD02]. The pursuit for biobased products is taking place with the support and leadership from the government, industry, and academia. Government support that may help drive the development of biopolymers includes the federal biomass funding activities by the U.S. Department of Agriculture and the U.S. Department of Energy [DUN03] as well as the Farm Bill, Title 9.

In 2002, the Federal Farm Bill (Farm Security and Rural Investment Act) incorporated the first ever Energy Title (Title 9). By specifically including renewable fuels and electricity, the energy title creates opportunity for development of biobased products. The energy title requires each federal agency to design a program to purchase as many biobased products as practical. The title also introduces a "U.S.D.A. Certified Biobased Product" label. One million dollars in funding has been provided each year from 2002-2007 for testing products under the label [MAZ02]. This will help smaller companies, in particular, to develop biopolymers and biopolymer-based products, but the larger companies who can afford to invest in this technology regardless of federal support are also paying attention [LEV04].

The American Society for Testing and Materials (ASTM) has also developed a standard for the biodegradability/compostablility of materials. This standard, ASTM D6400-99 "Specification for Compostable Plastics," defines biodegradability and compostability. It also specifies testing standards for biodedgradability and compostability.

### 2.4.1 Climate Change and Other Policy Drivers

Another major market driver for biopolymers is the need to address global climate change. Scientists studying climate change are moving closer to consensus that human activities are influencing the global climate [IPC01]. The public and private sectors are taking notice: a modified climate will have unknown and potentially devastating impacts on the biosphere and the economy. The Kyoto Protocol calls for scheduled reductions in $CO_2$ releases from industrial economies. Biopolymers can play a key role in $CO_2$ fixation. Biopolymers will help the economy to increase the rate at which $CO_2$ is stored relative to its overall rate of liberation, both by reducing dependence on fossil fuels, and allowing some marginal farmland to stay in production, which will absorb more $CO_2$ and act as a net "carbon sink." Currently, fossil fuel-dependent industrial economies are releasing much greater quantities of $CO_2$ than are being sequestered. Ultimately, a sustainable economy (and environment) will require that we move to a balance of $CO_2$ sequestration/release [ibid].

### 2.4.2 The Role of Non-Governmental Organizations (NGOs)

Non-Governmental Organizations (NGOs) provide a means for "the public" to better express themselves on issues relating to public policies, and many have played a large role in promoting "environmentally friendly" products and practices. NGOs can influence policies at both global and local levels by pressuring governments on environmental, or other, issues [AEP03].

In the past ten years, consumers have supported NGOs which have demanded more "environmentally friendly" packaging. With the growth of the environmental NGOs, such as Greenpeace International, Friends of the Earth International and World Wide Fund for Nature, as well as the development of various medias, especially the internet, NGOs can work collaboratively with companies to form policies to promote biopolymers.

## 2.5 Case Studies

### 2.5.1 Pacific Northwest

In Seattle, Washington, since 1986, the Seattle Solid Waste Utility (SWU) has provided residents with information and education on the benefits of backyard yard waste composting [ELW96]. A bin that adds convenience and speeds the composting process has been sold to residents at below-retail prices.

In Portland, Oregon, another environmentally progressive city, Portland City Commissioner Bob Koch developed an ordinance in the summer of 1988 to ban the use of Styrofoam for use as food and beverage containers. After more than a year of debates, Portland's city council passed the ordinance [ECK98]. North Carolina and Newark, New Jersey have also successfully banned Styrofoam food packaging. In California, the use of Styrofoam food packaging incurs a surcharge.

### 2.5.2 NGO Successes on the Environmental Front

NGOs have been involved in the ozone layer issue since the beginning of the 1970s. They have also successfully campaigned to ban the use of aerosols with CFCs and have worked to ban Styrofoam packaging at McDonald's restaurants [ROW95].

The purpose of the "McToxics" campaign was to get McDonald's to stop using Styrofoam packaging. Environmental activists, students, churches, animal rights activists and advocates of healthy foods took part in the campaign, which began in 1987. Groups fought for local ordinances banning Styrofoam. After three years, because of the intense public scrutiny, McDonalds decided to stop using Styrofoam packaging [LIP93]. The same year, Coca-Cola and Pepsi also announced they would use recycled PET bottles made of about 25% recycled plastic resin.

# 3 MARKET

## 3.1 Market Needs and Concerns

The U.S. continues to be the largest market for plastic, and plastic packaging is the largest market segment: over 23 billion pounds of resins (resin "pellets" are the raw material formed into a variety of plastic products) were used in 2002. The plastic packaging sector grew at an average rate of 5% per year between 1998 and 2002 [APC04]. As the chart in Figure 2 indicates, the U.S. and west European countries consume nearly 50% of the most common plastic resins annually.

World Consumption of Selected Thermoplastics
Of the six major thermoplastic resins, 114 million metric tons were consumed worldwide in 1999. This is a 19.2 percent increase in consumption since 1996. The annual growth rate in resin consumption from 1989-1999 was 5.6 percent, compared to a world GDP growth rate of about 3 percent.

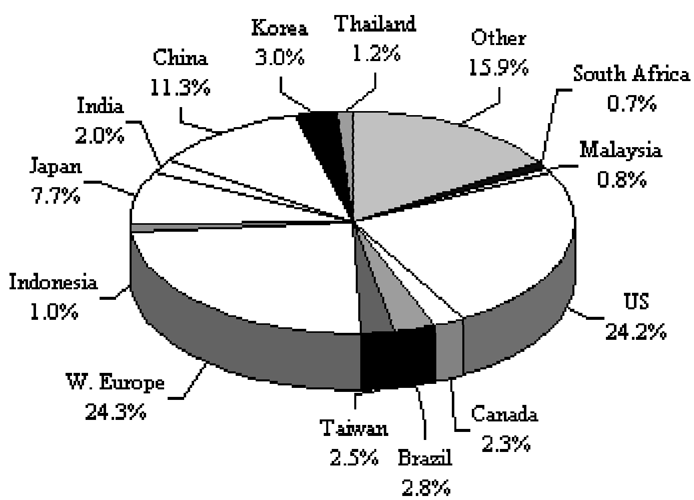


**Figure 2:** World Consumption of Selected Thermoplastics [MIN04]

Clear, rigid plastic packaging serves valuable needs in the market: it is inexpensive, lightweight, clear (so the packaged item is visible to the consumer), and relatively impermeable to liquids, oils, and odors. Rigid plastic is nearly unbreakable and protects items from damage during shipping and handling. Cargill Dow's NatureWorks™ PLA performs the same functions as clear petroleum-based plastic in terms of strength, permeability, and weight. It can be used for cold and room temperature foods, but its melting point is currently about 114°F.

Currently, PLA resins are 20% to 30% more expensive than petroleum-based resins, and for the end user, NatureWorks™ can be twice the cost per piece [STA04, AND04]. The market may be waiting for a breakthrough in cost, or function (e.g. a PLA package for hot foods, or a microwavable package). However, as sales and recognition of the product grow, and additional production efficiencies are achieved, the cost per unit is expected to become competitive with petroleum-based plastics.

Another significant barrier to market penetration for NatureWorks™ is like many other products new to the market retailers are skeptical of the performance. Because PLA packaging is a new product, there are adoption barriers along the value chain. Switching costs also cause some companies to be reluctant to switch to a PLA-based product—particularly where new product is more expensive. Cargill Dow is tackling this challenge by marketing to the top 50 or so supermarket chains to generate demand and "pull the product through the chain" instead of "pushing" the more expensive product through the packaging makers [RID04].

Another, less easily surmountable obstacle waiting in the future is the "all or nothing" food packaging barrier. When sufficient compostable polymers get in to the market, the difficulty of separating them from mainstream traditional plastic containers will arise. Our society is already set up around recycling, so this will be confusing for the consumer [GIO04].

Additional market development efforts, at both the retail and wholesale levels, will also be critical. For about 145 million adult consumers in the U.S. price and quality are the major drivers of purchasing decisions. The U.S. “mainstream” consumer market is made up of two large sub-groups, the “Modernists” and “Traditionalists.” Modernists tend to believe that progress is measured in terms of technological advance and material wealth; Traditionalists, as the name suggests, believe that economic and moral structures of the past represent the best solution to current problems [COO04]. These consumer groups are more likely to shop at large grocery chains such as Safeway or Alberston’s. If PLA plastic can become more cost-competitive with traditional plastic, then mainstream consumers will be more likely to respond to appeals such as the use of a bio-based product for contact with fresh foods such as salads, cut fruit, and deli items.

The fastest growing segment of the consumer market is the approximately 44 million “Cultural Creative” consumers in the U.S. Cultural Creatives tend to consider social and environmental impacts of their purchasing decisions [RAY97]. A sub-group (about 5-10%) of the Cultural Creatives, the “True Greens,” will often “pay more and go out of their way to buy what they perceive to be environmentally-responsible products” [HAR96]. Both groups have other needs beyond functionality, price, and quality for the products they purchase. They like to feel that their purchases are making a difference in helping to address environmental issues [STR99]. Biopolymers offer the promise that “closed-loop” solution that plastics from renewable resources can be recycled back in to compost for agriculture. Despite the concern some have to genetically modified organisms (GMOs), the concern regarding the use of genetically-modified corn to produce NatureWorks™ PLA does not seem to be of great concern to Wild Oats customers in the Portland-area stores [STA04]. However, it may be a significant consideration for many “True Green” consumers. For example, PCC Natural Markets in Seattle refuses to use PLA products because it promotes GMO usage.

Their customers are part of the vocal lobby that successfully backed strict USDA Organics standards [THO04].

NatureWorks™ PLA packaging now meets market needs in terms of functionality and seems to meet "environmentally friendly" market standards as well, particularly for "green" consumers. Yet despite the attributes and environmental advantages of NatureWorks™, overall consumer awareness of the product (at least in the Seattle market) seems low.

## 3.2 Market Drivers and Timing

### 3.2.1 The Oil Industry

The oil industry has become a driving force in biopolymer technology. Fluctuations in the price of petroleum impact the plastic industry heavily. Manufacturers who use oil for polymer production largely have to absorb the rising costs of oil in their margin [LEV04]. Because PLA is produced from agricultural products, products made with PLA could be more price stable over the long term if supply disruptions in petroleum occur. Current increases in petroleum prices are driving renewed interest in large-scale production of biopolymers for markets such as food packaging and clothing.

Overall oil to crop price ratios have been steadily declining since the OPEC crisis of the early 1970s [MIC04]. This trend reflects the overall decrease in real prices of petroleum, but also the increase in production efficiency of farmers. As scarcity inevitably increases in the petroleum market, biopolymers will become more cost-competitive. Cargill Dow currently projects that within the "next few years," PLA will be a competitive polymer platform with hydrocarbon based polymers and that PLA will be produced in "numerous, world-scale production facilities" by 2010 [CAR04].

### 3.2.2 Landfill Space and the Waste Industry

As landfill costs continue to rise, and per capita disposal rates also increase in the major industrial economies, a further advantage of compostable polymers is that they can be diverted from disposal to commercial composting facilities, resulting in significant avoided costs of disposal. The discrepancy in landfill costs (and available space for siting landfills) between Japan, the European Union (E.U.) and the U.S. is a major factor driving the market for biopolymers. The Japanese and E.U. governments have offered early and active support of biopolymer technology research and development, partly due to higher waste disposal costs, as opposed to the more hands-off and entrepreneurial approach taken in the U.S. [LEN95].

### 3.2.3 Environmental Movement and Recycling Efforts

The environmental movement in the E.U. and the U.S. has raised awareness of the environmental issues associated with disposable packaging. The efforts to educate the public have led to growing recognition that petroleum-based plastics are "over-engineered" for many food packaging applications: most consumers now recognize that their potato salad container does not need to last for 10,000 years. While recycling efforts were the first step in addressing the social and environmental costs of a "throwaway society," even recyclable petroleum-based polymers have a limited "heat history," and may be recycled only a few times before the polymer must be "down-cycled," often to lower-value uses [STG04]. In addition, recycling is not always an economical option, particularly when the costs of the raw materials are so low [AME01].

### 3.3 Estimated Market Size and Longevity:

The traditional plastic market value in the U.S. increased by 4.7% in 2002 to $138 billion, as the market bounced back from a difficult year in 2001. The unsupported film and sheet sector, which is used primarily for packaging applications, remained the largest in the plastic products industry in 2002, accounting for $20.9 billion, nearly 15.1% of total value sales. [APC04]

The plastics market in industrialized nations is a mature market, and manufacturers realize that they must introduce sophisticated new technologies in order to achieve sales growth and acquire market share. This presents a growth opportunity for biopolymer-based "green plastic" in the sense that certain consumers can differentiate it from hydrocarbon based plastic. For example, packaging made from agricultural materials should appeal to consumers in the growing organic foods market segment.

Some analysts estimate that the market for biodegradable plastics could grow by 30 percent per year over the next decade. By 2010, biopolymers could capture between 1.5 percent and 4.8 percent of the total plastics market [MIC04]. Eventually biodegradables might capture 10 to 20 percent of the overall plastics market [EPI01]. Even given these encouraging growth estimates, most sources agree that biodegradables lack the overall versatility (and longevity) of hydrocarbon-based plastic, given the current state of technology, which could limit the overall market share biodegradables may capture. Nonetheless, a 20 percent share of the U.S. plastic market is extremely lucrative, and creates a significant inroad for a sustainable product.

Ultimately, the market size and longevity for NatureWorks™ will depend on how quickly it is adopted through the value chain, prices of petroleum relative to agricultural products, and the pace of innovation in biopolymer research. If consumer awareness can be raised about the benefits of the product, demand should grow rapidly for the next ten years.

# 4 PLA AND COMPETING TECHNOLOGIES

### 4.1 Introduction to Biopolymer Technology

There are two elements that make the alternatives to traditional plastics "green". Based on a literature survey, polymers are considered "green" if they are (1) developed from renewable resources such as crops or biomass, or (2) are compostable. These two conditions are not dependent upon each other. A polymer can be made from renewable resources and not be compostable; just the same, a polymer can be made from petroleum products and be compostable. There are two types of polymer feedstocks: natural and synthetic. Natural polymers are largely based on renewable resources such as starch and cellulose (e.g. seaweed, corn, and wheat straw) and synthetic polymers are based on petroleum products. Figure 3 shows the different types of biobased polymers.

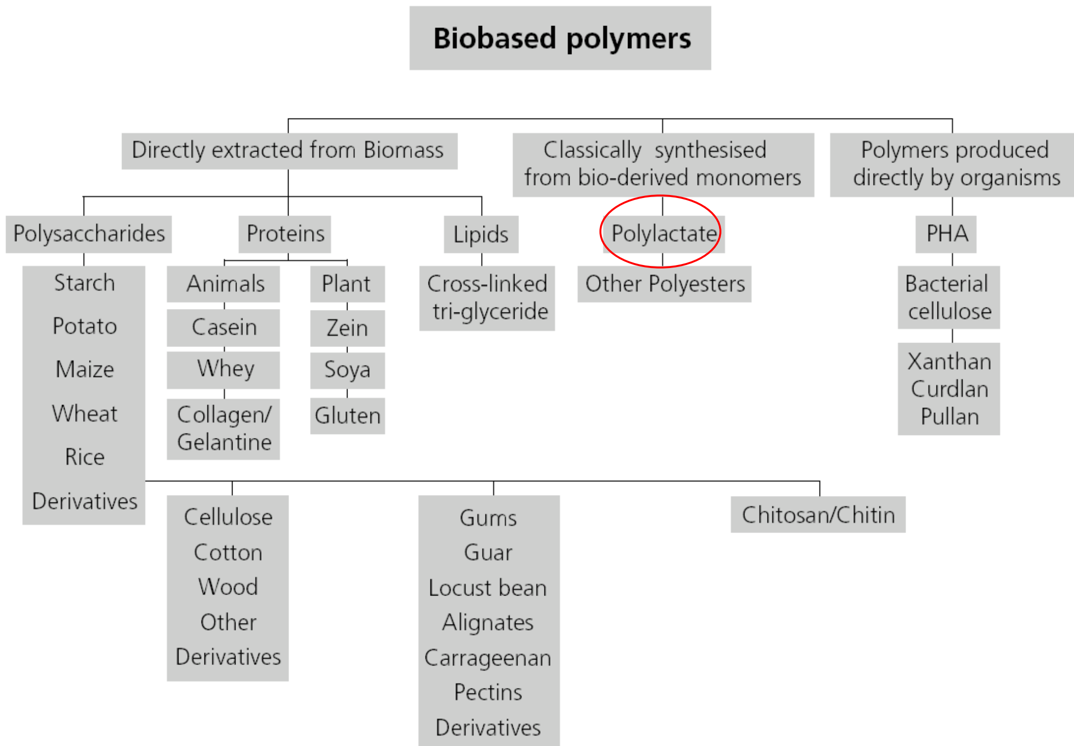


**Figure 3**: Biopolymer categories [WEB00]. PLA, the baseline technology, is circled.

Within each of these categories the polymers can either be compostable or not. Synthetic compostable polymers have additives that break down the polymer under certain conditions at the end of its useful life. Natural compostable polymers don't need a chemical additive to break down.

By segmenting the materials in this way there are four major categories of polymers: (a) Synthetic, non-biodegradable polymers, (b) Synthetic, biodegradable polymers, (c) Natural, non-biodegradable polymers, and (d) Natural, biodegradable polymers.

The baseline technology for this study, Cargill Dow's PLA (polylactic acid), is one type of natural, compostable polymer. Other types of natural, compostable and biodegradable polymer technologies will also be examined as competing technologies.

## 4.2 PLA

PLA produced by Cargill Dow uses corn starch as a feedstock. Corn is milled, which separates starch from the raw material. Unrefined dextrose is then processed from the starch. Dextrose is turned into lactic acid using fermentation, similar to that used by beer and wine producers. Through a chemical process called condensation, two lactic acid molecules are converted into one cyclic molecule called a lactide. This lactide is purified through vacuum distillation. A solvent-free melt process causes the ring-shaped lactide polymers to open and join end-to-end to form long chain polymers. A wide range of products that vary in molecular weight and crystallinity can be produced, allowing the PLA to be modified for a variety of applications. Figure 4 shows the production process. [CAR04, GRU00]

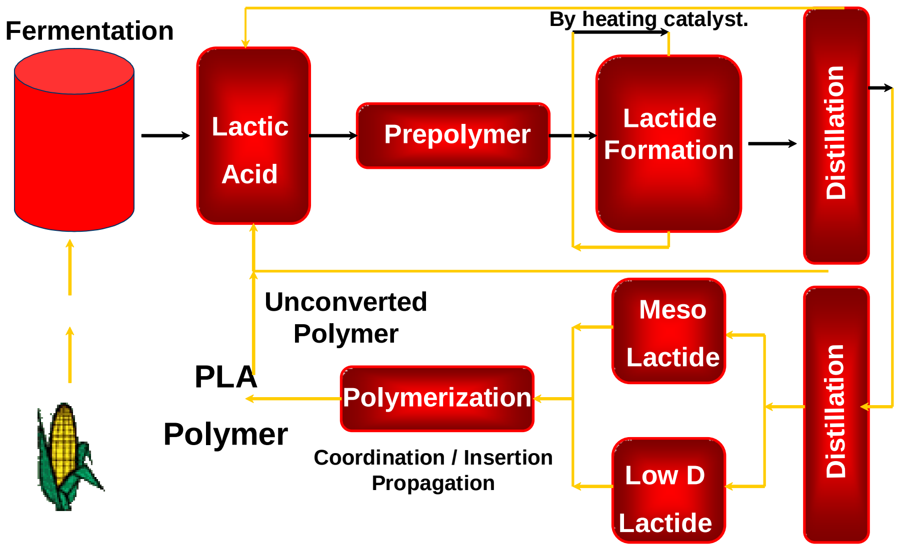


**Figure 4**: Cargill Dow LLC Process.[GRU00]

The polymer is produced in loose-fill pellets from the plant and is then sold to production companies as a feedstock for packaging production. It is then processed using conventional processing methods to create the end product. There are some complications with the use of conventional processing methods, however many of these issues can be easily resolved on a plant by plant basis. After its useful life PLA can be disposed of, composted, or recycled.

Polylactic acid polymers are fully compostable in commercial composting facilities and are recyclable with proper equipment. PLA can also be converted back to monomer, which then can be converted back into polymers to create a new product. However, PLA cannot be composted in backyard composts and will not biodegrade in landfills; therefore, PLA will face the same fate as traditional plastics if disposed of as traditional solid waste.

Despite the many environmental advantages of PLA, there are still some technical aspects that need to be resolved. For example, because starch is very reactive with water, many of the physical properties of PLA depend on relative humidity. This means that one of the biggest plastic packaging markets, the bottling industry, cannot currently be tapped with PLA. Another issue with PLA plastics is the useful temperature range. The maximum useful temperature is 114°F. The product will melt if this temperature is exceeded.

## 4.3 PHA

Poly(hydroxyalkanoates) or PHAs are another promising biopolymer. This polymer is currently being researched in many area as a replacement for traditional plastics. Biologists have known of the existence of PHAs since 1925 when they were found to exist in bacterial cells. Many types of PHAs can be synthesized using different carbon sources, microorganisms, and processing conditions.

There are two different ways to synthesize PHAs. Processing by fermentation was the original technology that was used to develop PHAs. Processing by fermentation includes growing the plant source such as corn, harvesting the plant source, transporting the plants, extracting the glucose from the plant, fermentation of the glucose into cells containing PHA using microorganisms, washing and spinning the cells twice to release the PHA in the cells and finally concentrating and drying the PHA into a powder form.

Processing by growth of PHA in plant cells is the technology that is currently being pursued. This process resembles the process described above except the fermentation step has been eliminated. It was thought that by eliminating this step the energy requirements for production would be reduced; however, after eliminating this step it was determined that extracting and collecting the plastic from the plant would require large amounts of solvent, which would have to be recovered after use. Because of this, the energy requirement was actually increased. The figure below shows a comparison of the energy requirements for the two types of PHA production in addition the energy requirements for some petrochemical products and PLA are shown. This comparison assumes (1) that all plastics will be sent to a landfill at the end of life and (2) all energy is supplied by fossil fuels. Different energy sources such as use of leftover plant products for steam and electricity production and different end-of-life scenarios could change the results [GER00, PAT04].

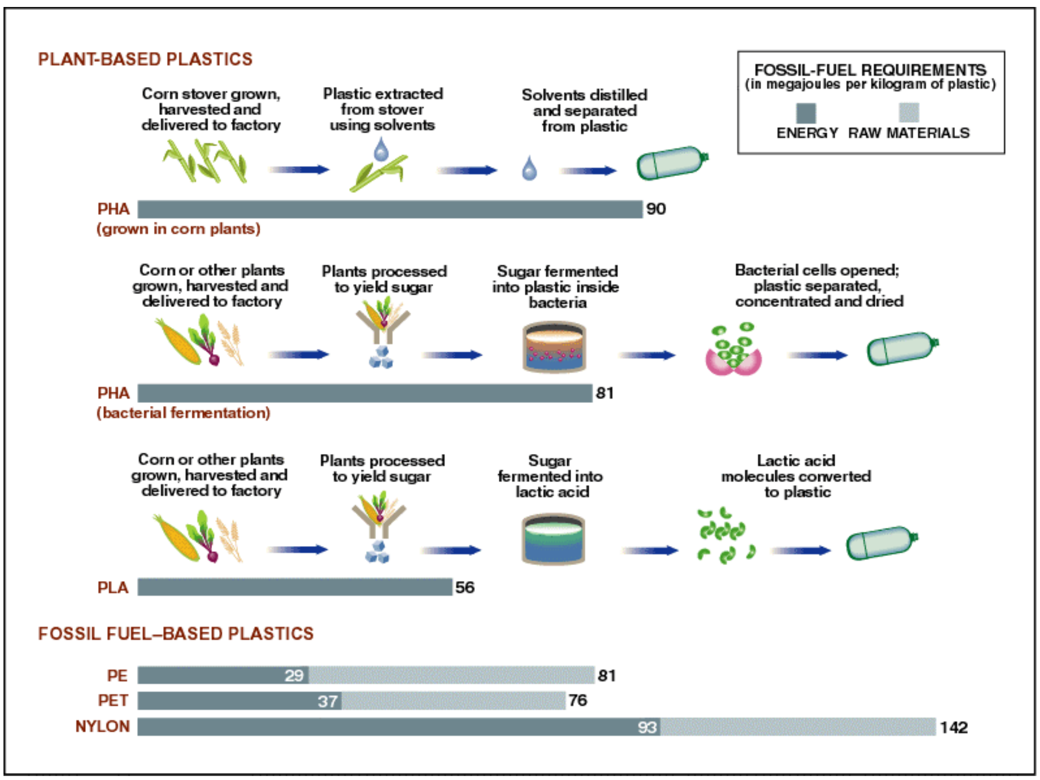

**Figure 5**: Fossil Fuel Requirements from [GER00]

One obvious advantage that PHA has over PLA is that PHA polymers are fully compostable and biodegradable in many environments. PHA will biodegrade in water or soil, and compost under aerobic and anaerobic conditions. When exposed to natural organisms, PHA will rapidly decompose into carbon dioxide and water. This gives PHA a marketing advantage in some applications [MET04].

## 4.4 Thermoplastic Starches

Thermoplastic starches (TPS) have also gained much momentum in the biopolymer industry. These polymers are made from starches such as corn, potatoes, and wheat. At first glance, it is difficult to determine the difference between TPS polymers and polymers such as PHA and PLA; however, the difference is that TPS polymers do not have to be fermented. TPS polymers use the polymer created in the starch source directly and a baking technology to thermally treat the starch.

To obtain plastic-like properties, TPS polymers are mixed with synthetic materials. TPS polymers can contain between 10 and 90% starch but must have at least 60% starch content before significant material breakdown occurs. The higher the starch content the better the material will breakdown and the less residue is left.

There are several different types of TPS polymers, including thermoplastic starch products and blends of starch and various polymers (synthetic and natural). Blending TPS and other polymers lead to a significant reduction in cost, a difference of about $2.50/kg. Starch and PBS or PBSA blends are used to produce most of the TPS polymers in the packaging industry.

## 4.5 Biopolymer Processing Techniques

Biopolymers can be processed essentially the same way as traditional plastics. PLA in particular can be processed by most melt fabrication techniques including thermoforming, sheet and film extrusion, blown film processing, fiber spinning and injection molding. Appendix C describes plastic processing techniques and their applications.

## 4.6 The Future of Biopolymers

### 4.6.2. Biomass

Currently, biopolymers are produced using agricultural products such as corn and potatoes; however, in the future our ability to provide these products for uses other than human consumption might be strained. The world population is still growing and food production is maxing out. Even with all of the advances in biotechnology and GMOs, the planet's ability to provide food for the population will soon fall short. For these reasons, and the public concern over GMOs, much research has been done into using other feedstock sources such as waste biomass (i.e. food wastes, corn stalks, rice hulls, etc.) to produce more sustainable polymers. There are many issues and benefits of using waste biomass as a feedstock in the production of biopolymers.

Corn is often the feedstock of choice because it is readily available (feed corn is overproduced by 10% annually in the United States [STA04]) and is the cheapest and most homogeneous source of glucose available. In addition, the infrastructure to use the corn is already in place. The "wet-milling" process used in the production of corn and corn products has been perfected for the last 150 years [COR04]. To convert to a different feedstock would require new knowledge, technologies, and infrastructure.

There have been many studies on using waste biomass as a feedstock for the production of green polymers. One of the most promising is a study completed by Sakai, et al. which uses municipal food waste as a feedstock. Figure 6 shows the processing of food waste into PLA.

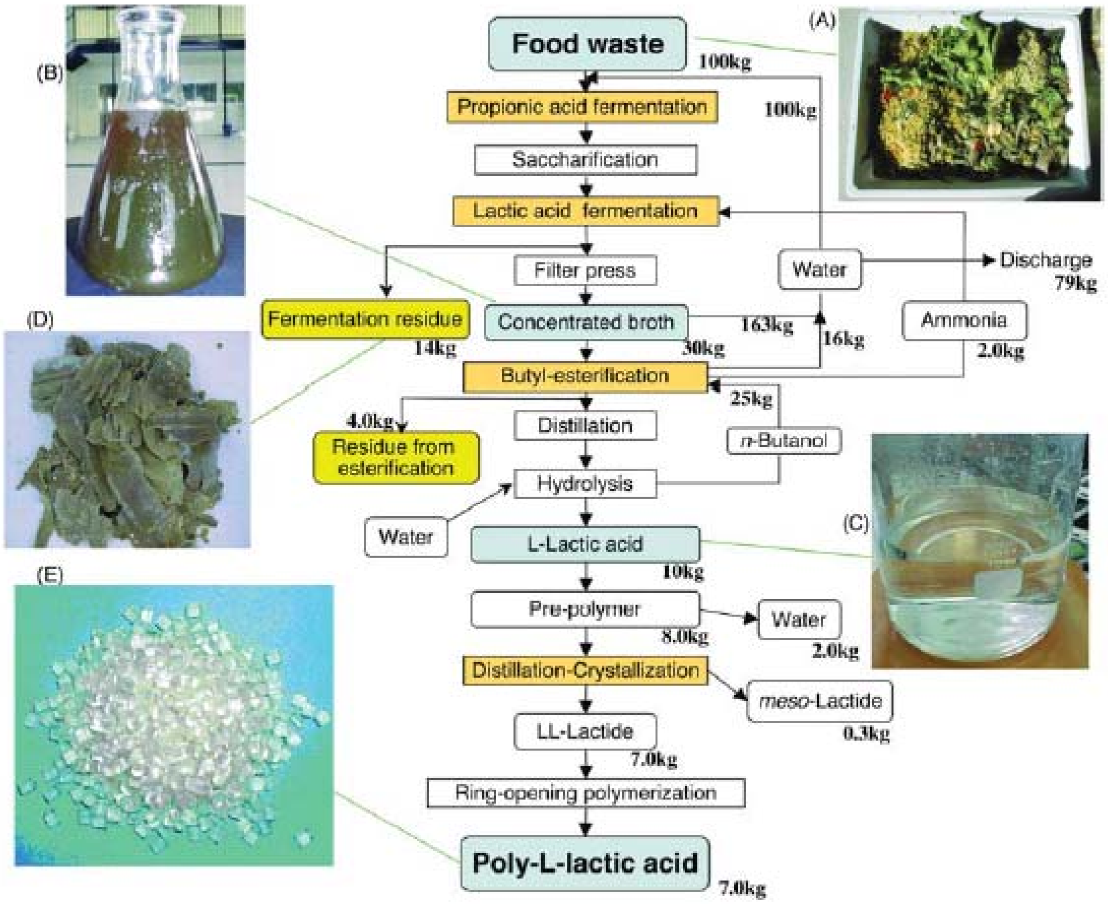


**Figure 6**: Process outline of PLA production from food waste. Photos adjacent to the figure show food waste (A), concentrated broth after lactic acid fermentation (B), purified L-lactic acid (C), fermentation residue (D), and pellets of PLA (E). Average amounts of intermediates and products yielded from 100 kg food waste are also included. [SAK04]

The authors of this article in the Journal of Industrial Ecology claim that 68.8 grams of PLA can be produced from 1 kg of wet food waste and only uses 44.4 MJ of processing energy per kg, which is not much more than the energy use claimed by Cargill Dow (39.5 MJ/kg).

Food wastes are readily available in any major city making the use of them as a feedstock a technically viable option. For example, in Kitakyushu City, Japan alone over 60 tons of food waste is produced per day. This could lead to a PLA production volume of $1.2 \times 10^3$ tons/year.

Despite some of the drawbacks of using waste biomass as a feedstock such as inhomogeneity, lack of commercial infrastructure (i.e. collection, transportation, processing, etc.), difficulty separating usable portions, and added costs; there are also many benefits of using waste biomass [HOL04]. For example, by using waste biomass there is a reduction the amount of wastes that are landfilled or incinerated, and in turn there is a reduction in greenhouse gas emissions.

### 4.6.2. Modified Atmosphere/Controlled Atmosphere Packaging

Modified Atmosphere/Controlled Atmosphere Packaging (MAP/CAP) is anther sector of the packaging industry that is rapidly growing. MAP/CAP allows foods to stay fresh longer, which allows perishable to be shipped further and stay on the shelf longer, and in turn allows the product to reach the consumer in optimum condition. Each product has its own "ideal atmosphere" which is achieved by high barrier packaging and controlling the level of nitrogen, oxygen, and carbon dioxide. Currently, the biopolymer industry has not offered a compostable alternative to traditional plastics in this application; however, more research into improving the barrier properties of compostable plastics might make breaking into this market a possibility.

## 4.7 Life Cycle Analysis and Environmental Performance of Biopolymers

### 4.7.1 Introduction to LCA

The overall environmental performance of the different biopolymers has been highly criticized by competitors, consumers, and the media due to unclear performance parameters. Over the years many frameworks have emerged to help clarify these parameters and create a standardized evaluation method. One of the most widely recognized frameworks is the Life Cycle Assessment (LCA) methodology. LCA is a technique for assessing the environmental aspects of technologies from various points in their life cycle: from raw materials acquisition through production, use, and disposal.

### 4.7.2 Biopolymer LCA Results and Comparison

Many LCAs have been completed on biopolymers. The results of these studies vary due to different goals and scopes. Some report that certain biopolymers are no better than the synthetic alterative and actually increase fossil fuel use by as much as 700%. Others claim that biopolymers reduce fossil fuel use by as much as 50%. These discrepancies are due to different process technologies, processing energy sources (i.e. fossil fuels or renewable energies), and end-of-life options.

Table 1 is a combination of the results of many LCAs from different sources. This table compares petroleum based plastics to bioplastics on the basis of cost, non-renewable energy consumption from the beginning of the production process to the final product, "cradle-to-gate", and greenhouse gas emissions. It can be seen in almost every case the bio-based plastics require less fossil fuel than the petrochemical polymers. The only exception is PHA. The energy requirements for PHA vary greatly and depend on the process and the type of energy (renewable vs. non-renewable) used in production. However, it must be noted that in some cases PHA might still be a viable alternative to some petrochemicals.

When comparing the different polymers, it must be kept in mind that the LCAs provided are from different sources and therefore the results have imbedded in them different assumptions and boundaries. This means that one should not draw firm conclusions as to whether or not bio-based polymers are better than their petrochemical counterparts. For more information and detail please see Patel, et al [PAT01].

**Table 1**: LCA and Cost Comparisons [PAT01]

| Polymer | Impact compared to conventional polymers (in %) | | |
|---|---|---|---|
| | Fossil energy | GHG emissions | Cost/lb |
| **TPS** | -25% to -70% | -30% to -80% | ~150% to 300% |
| **PLA** | -30% to -40% | -20% | ~200% to 1000% |
| **PHA** | -30% to +700% | n/a | ~150% to 700% |

# 5 COMPETITORS

## 5.1 Biopolymer Competitors

There are several major firms moving from the research and development to the production phase of biopolymers. Cargill Dow is one of the largest biopolymer producers in the United States. They have recently opened a new PLA production plant in Blair, Nebraska. This plant will be built as an addition to an existing wet-milling plant owned by Cargill.

Despite Cargill Dow's success, TPS polymers currently hold the largest market share in biopolymers. In the packaging sector, Novamont Corporation, based in Italy, is one of the largest producers of TPS polymer blends, which has been highly successful in the E.U. and has captured a significant market share.

These blends, like PLA, are compostable as long as the starch content is greater than 60%. Novamont claims that their products will compost in as little as 10 to 15 days under good conditions. Novamont also claims that their products will compost in a backyard compost, which is not currently a property of pure PLA polymers [GIO04]. However, Cargill Dow considers Novamont to be a customer, not a competitor [STA04].

In addition to PLA and TPS polymers, PHA is also a promising biopolymer. Matabolix-BASF AG is currently the only company producing PHA. Matabolix-BASF AG, is a partnership between Cambridge, MA based Metabolix, and the German multinational BASF AG. Despite the findings from Gerngross, 2001 [GER01], they continue to believe that PHA can be used for a wider variety of applications than PLA, including biodegradable single-use cutlery, plastic films, cups and plates. Metabolix states that the melting point of PHA is up to 200°F, which is superior to PLA and may offer a wider variety of applications where heat resistance is a factor. In addition, Metabolix' PHA products are biodegradable under most circumstances; and do not require the high heat of a commercial composting operation, as does NatureWorks™ PLA.

In November, 2003 Metabolix/BASF AG was awarded a contract from Defense Supply Center Section of Defense Logistics Agency (DLA*)* to create a prototype molding of PHA for cutlery and other biodegradables products for the Navy [MET04]. The company is the sole provider of biodegradable single-use products to the federal government.

Biopolymer research and development is still an emerging field. While production of new chemicals from synthetics and petrochemical has stalled in the 1990's, with very few new molecular building blocks being developed biopolymers have the potential to be the next wave of polymer platforms for a sustainable century.

## 5.2 Traditional Plastic Industry as a Competitor

The main competitor of the biopolymer industry is the traditional plastic industry, particularly PET, polystyrene, and polypropylene [LEV04]. These materials have the vast majority of the market share in food packaging. The advantages of traditional plastics are that they are *well accepted*, *widely distributed*, and *inexpensive*. In addition, the infrastructure already exists for recycling, and the public has been educated about recyclability labeling (e.g. industry codes 1-7). Composting infrastructure and education lag far behind in the U.S.

Traditional plastic is not as taxing to the environment as many environmentally-conscious consumers often suppose. Because plastic is strong and light weight, in many cases using plastic reduces the amount of material used for packaging and the overall product weight, and therefore the amount of fuel used to transport the product, as well as the amount of waste sent to a landfill. Plastic manufacturing has evolved over the past several decades to be fairly efficient in its use of energy and resources [LEV04]. In the U.S., 60-70% of plastics are made from natural gas (the "cleanest of all the fossil fuels" [NAT04]), and the manufacture of *all* plastics uses only 4% of U.S. energy resources each year [KRE04]. While some rigid plastic food packaging is recyclable or reusable, much of it cannot be recycled due to food contamination. Recycling also often costs more than manufacturing virgin resin [AME01]. So most of this type of packaging ends up in the landfill. Engineered to last the consumer for hours, days, or months, in the landfill it will last for centuries. Nothing biodegrades in modern landfills, so bioplastic products do not reduce landfill content unless they are removed from the waste stream and composted.

# 6 FORGEIN MARKETS

Europe is said to be 10 years ahead of the U.S. where biopolymers are concerned [GIO04]. The rapidly developing market for biopolymers outside of the U.S. is driven by a combination of consumer demand and waste-reduction policies. Several criteria should be considered when deciding which foreign countries will be most receptive to biopolymer food packaging products.

The most important criteria involve money and the market. First, the country should have a strong and growing economy. Because biopolymer food packaging products are currently more expensive than traditional plastic packaging, consumers must be willing and able to pay more for the product. Second, the country should already have a well-developed market for plastic food packaging. It is easier to switch from using traditional plastics to biopolymers than to convert from not using packaging or using packaging made from a different material. Also, the market estimated for biopolymers should not already be saturated by a competitor's bio-based products.

An additional key criterion for evaluating foreign markets is the country's environmental policies, particularly those relevant to packaging. Although policies in themselves are not likely to be sufficient to guarantee marketability of biopolymer products, policies (or the lack of them) act as an important indicator of a society's priorities. It may also be beneficial to consider the country's landfill situation and the availability of composting for the average consumer. The country's potential for growing agricultural feedstock for biopolymer production, consistent with expected demand, is a lesser, but still important consideration. Finally, the short and long-term political stability of the country will influence the business climate there.

Several countries, particularly in the E.U. and Asia have some potential for the production and sale of biopolymers. Appendix A contains the preliminary analysis of the following countries according to the criteria described above: Japan, the U.K., France, Sweden, Germany, China, India, and Brazil. Japan and the U.K. currently have the greatest potential as markets for biopolymer packaging for food. They are discussed in detail in the following sub-sections, while the countries not selected for immediate market entry are briefly described in Appendix A.

## 6.1 Market Entry in Japan

Japan has a huge market for plastic packaging of non-food items, and it has a culture of individually packaging food items (although traditionally foods are wrapped in paper). Japan is home to several manufacturers of biopolymer for non-packaging applications, which shows the Japanese acceptance of and desire for bioplastics. As of late 2003, biopolymers accounted for less than 0.1% of the annual production of plastic in Japan, but the market is expected to expand dramatically (by 400% according to some reports) in the next few years [TRE03a].

At this time, there are several manufacturers of bioplastics in Japan, but none yet manufacture food packaging. NEC Corporation is making bioplastic for personal computer cases, and Toyota is manufacturing it for automobile interiors.

Because landfill space is limited and expensive, Japan has several packaging waste reduction and take-back laws that make it a favorable location for compostable packaging. The Food Recycling Law, enacted in 2001, requires businesses producing food waste (e.g. hotels, supermarkets, and even companies with cafeterias) to treat organic waste separately, keeping it out of landfills. Many cities already require citizens to sort their garbage into burnable, unburnable and recyclable waste [TRE03a]. Businesses are also responsible for recycling or reusing discarded packaging. Officials should favor biopolymer food packaging because it can either be put into the "burnable" garbage, where it will burn cleanly, or into the composting waste stream. Some public education may be required.

Good marketing targets in Japan include cafeterias of large businesses (e.g. Toyota) and supermarkets (for salad bars and other take-away foods). A smaller, but apparently growing market might be major hotels that have an upscale take-out business [TRE03b]. Some of these hotels may wish to distinguish themselves from others by offering biopolymer packaging.

The best way to entering this market is through existing packaging companies. They can receive their PLA from Cargill Dow's Japanese affiliate Mitsui Chemicals.

## 6.2 Market Entry in the United Kingdom

The U.K. has aggressive landfill waste-reduction targets, and organic waste is banned in landfills [GIO04]. The U.K. it is a party to the E.U. Packaging Waste Directive, which requires E.U. nations to recapture 50% of packaging waste by either recycling or incinerating for energy, but incineration is unpopular due to air-quality concerns. The public is very aware of the solid waste issues.

Since 2001, the U.K. Department for Environment, Food and Rural Affairs has been working on a Food Industry Sustainability Strategy, a joint venture between the government and producers, wholesalers, caterers and retailers [DEF03]. No concrete actions have appeared as a result yet, but it is a sizable movement, drawn from many sectors, including the government and food and farming industries. This movement could be drawn upon to mobilize around new sustainable packaging products.

There are several manufacturers of biopolymers in Europe, including the Italian Novamont, which makes Mater-Bi, a starch-based biopolymer mix. Throughout Europe Mater-bi is used in food packaging, as well as such diverse applications as grocery bags, diapers, cutlery, foams, additives for tires, and agricultural uses [GIO04]. In the U.K., J. Sainsbury's Co. has been using a biopolymer tray for organic vegetables since 2002, made by Eastman's Eastar Bio® biodegradable copolymer [PAC02].

The U.K. has a sizable market for plastic food packaging. The market is similar to the U.S. market, and should be approached in similar ways, starting with high-end natural food stores (particularly those with in-store cafes) and organic products. In the U.K., chains such as supermarkets have more influence over their suppliers than in the U.S. [PAC02], so convincing retail chains to switch to biopolymer packaging will have a ripple effect. Some examples of outlets to start with include Sainsbury's, Fresh and Wild (associated with Whole Foods), the Better Food Company in Bristol, Highland Organics in London, and Eighth Day Co-op in Manchester.

In order to provide the packaging for these stores, the U.K. market should also be approached via existing packaging companies. Europackaging, for example, is currently using Cargill Dow's PLA in grocery bag and rigid packaging products [STA04].

# 7 CONCLUSIONS AND RECOMMENDATIONS

## 7.1 Policy

Possible future policies that will spur interest in bioplastics include:

- legislation distinguishing recyclable from biodegradable materials;
- legislation requiring a certain percentage of packaging be biodegradable/compostable;
- taxes on energy use, higher landfill/disposal costs;
- creation of "ecolabel" based on life-cycle impact of a product (including raw materials, energy consumption, emissions from manufacture and use, and waste disposal) [STE02]

Challenges include public education/awareness about biopolymers and infrastructure set-up. The U.S. public has largely been trained to recycle plastics, but they will need to re-learn how to deal with compostable plastic packaging [GIO04]. As biopolymer packaging becomes more common, consumers will need to learn which packaging items they can put with their organic waste (if separation is available) and which to recycle (where applicable). Eventually separate collection and recycling of biopolymers may become feasible [STA04], but this will require a long time to set up adequate infrastructure and education, and it may not make sense economically. Fostering relationships with NGOs is one way to better re-educate the public and to raise awareness.

## 7.2 Market

Because PLA food-packaging products have similar material properties to polystyrene, neither has an overwhelming advantage in the properties of the product. Instead, PLA has perceived "value-added" benefits that do not affect the consumer directly, and thus will not be advantages to every consumer. In addition to compostability, the advantages of PLA over traditional plastics are that it is made from rapidly renewable resources, and it is not made with chemicals harmful to humans (that could be released into the ground water in a landfill or into the air upon incineration [STA04]). Currently, higher cost is one of the disadvantages of PLA food packaging. At this time, it makes the most sense to compete with PET on a cost basis [STA04]. Perhaps a larger obstacle than cost, however, is its relatively unknown status, even among the most favorable "green" market segments.

Packaging made from PLA won't replace traditional plastics any time soon. In the coming years, production of PLA will increase while production of traditional plastic may decrease. As fossil fuel resources decline, the cost of traditional plastic packaging will rise [STA04].

Some major market drivers for biodegradable and compostable polymers are:

- Strong environmental movements in the E.U., Japan, and U.S. – Concerns about sustainability, global climate change and waste disposal options have created a market opportunity for "natural" compostable biopolymers.
- Agricultural surpluses in U.S. and E.U. – Surplus corn was inexpensive enough that Cargill Dow decided to use it with commercial production of NatureWorks™ PLA.
- Increasing landfill costs – Real costs of disposal and per capita disposal rates continue to increase in industrialized nations.
- Increasing petroleum costs – Crude oil prices per barrel have reached record highs in the last month.
- Technology breakthroughs – Process for using fermentation to produce a compostable biopolymer that could be used for multiple end-uses (packaging, fiber, etc.) put Cargill Dow in market leader position.

Market trends for PLA and other biopolymers suggest that the public sector (including the military, government agencies, schools and universities at all levels) has the potential to become a very large promoter/user of biopolymers, especially food packaging and utensils, plates, and cups. Because public institutions are under intense scrutiny for the sustainability of their practices, efforts to promote the use of sustainable products often focus on the public sector. Through environmental purchasing programs (EPP) and pollution prevention (P2) edicts and orders, public agencies can drive the market for compostable biopolymers for all available applications. For example, the federal government currently purchases half a billion single-use plastic items each year. The U.S military has increased efforts to deal with the 14,000 tons of waste it generates from the 47 million operational rations consumed annually. For the Navy, important attributes in food service items are barrier properties to prevent food-borne illness on ships and submarines and biodegradability in the marine environment [MET04].

Markets where waste disposal is a problem due to space limitations for landfills and/or environmental concerns with solid waste incineration will continue to be good markets for compostable biopolymers. Island nations such as Japan, Taiwan, and the U.K., as well as other countries with high populations and limited space (Korea, Southeast Asia, Indonesia) will be likely to move to compostable polymers for many disposable products. A rigid, temperature resistant biopolymer would have wide application potential in packaging (e.g., microwavable frozen foods), as well as very large markets in automotive applications, building materials, and electronics.

As plastic packaging is the highest-value segment in the hydrocarbon-based plastic industry, Cargill Dow's decision to focus on plastic packaging makes sense. As the prices of petroleum and natural gas rise, and PLA production costs fall, many users of plastic packaging will make the switch to PLA.

Modified Atmosphere Packaging/Controlled Atmosphere Packaging (MAP/CAP) is another rapidly growing segment in the plastic packaging industry [IFT04]: tuna, milk, and fruit juices and other perishables are increasingly packaged in these packages that extend shelf life. Monterey Pasta Company currently uses MAP for its fresh pastas. A representative from the company said they have considered using biodegradable packaging, but this packaging does not have the necessary oxygen and moisture barrier properties for MAP [JOH04]. Cargill Dow has focused on packaging for short shelf-life applications, but this shelf-stable system may quickly become one of the highest value segments when production costs for MAP/CAP packaging begin to decrease.

## 7.3 Technology and Competitors

Continued innovation in PHA-based products could capture market share from NatureWorks™. Metabolix-BASF AG's efforts to refine PHA production could provide a breakthrough in the near future which could enable PHA to be produced from less expensive biomass feedstocks such as corn stover, rice straw, or hybrid poplar. Metobolix is currently researching the use of PHBV (polyhydroxybutyrate valerate) for films, coatings, molded durable goods [MET04]. Metabolix continues to research in-plant production of PHA coupled with biomass energy production using a prairie switchgrass. This research is funded in part through a grant from the U.S. Department of Energy.

We are entering and era of multiple, competing technologies that will drive a "next wave" of "white biotechnology." The third "color" of biotechnology, white biotechnology refers to biopolymer process innovation and movement away from fossil-fuel based polymers and solvents in the industrial chemistry arena; "green biotechnology" refers to the earlier innovations in transgenic mutation of agricultural crops for increased production and disease resistance, while “red biotechnology” describes the explosive growth of biotech applications in drug research and the pharmaceutical industry in the 1990s [MIR04]. While it is impossible to predict the trajectory of biopolymer development, competition in process innovation and real-world applications will continue to drive research in this promising area.

## 7.4 Technical Recommendations for Cargill Dow

The plastics market is a multi-faceted one. For Cargill Dow to continue to grow, they must be able to compete in the strongest existing segments, and also within the “green” segment they are helping to define. To this end, we have several recommendations from the preceding analysis. We strongly recommend accelerating efforts to produce PLA from biomass (and therefore decrease usage of GMO corn) as well as breaking into the MAP/CAP market segment. Our additional suggestions are to research ways to make PLA microwavable/heat resistant and biodegradable in a greater range of conditions.

- ***Biomass/GMOs***
  Looking through the 21st century and beyond, the pressures of population growth and climate change contribute to increasing uncertainty in available agricultural output. To truly become a sustainable business under these conditions, it may become necessary to use agricultural or even household-type organic waste as feedstock for PLA production. We recommend devoting substantial resource and development time and funds now to ensure an economically smooth transition. This has the added benefit of circumventing future tensions about the issue of using GMO crops.
  Although the GMO issue is not a top priority for many Americans [STA04, PRI04], others in the U.S. and elsewhere are less tolerant, and this vocal minority is growing [THO04].
- ***Modified-Atmosphere/Controlled-Atmosphere packaging (MAP/CAP)***
  This is a rapidly growing segment of the plastics market, and one that has the potential to be useful for fresh-food producers who want to extend the shelf life, and therefore distribution capabilities, of their products. This is particularly useful for fresh organic produce (e.g. herbs) and products like fresh pastas.
- ***Microwavable/heat resistance***
  A large market segment could be reached if the product could be used for hot-food take-out and re-heatable meals. Containers made with PHA may soon become more used for these applications in the “natural” market segment.
- ***Biodegradability (disappearing litter)***
  Again, PHA-based packaging currently has the advantage in this area. Of course there is a trade-off between having the packaging behave like traditional plastic (engineered to last for a long time) and rapid biodegradability. It would be desirable to have different polymer formulations for different applications, ensuring that the lifetime of the packaging is better tailored to the expected lifetime of the product.

## 7.5 Recommendations for Market Entry

Cargill Dow and its partners (e.g. Wilkinson Manufacturing) have done a remarkable job searching out and penetrating the market for plastic food packaging [STA04, CAR04]. We approve of their strategy and offer the following suggestions, reiterations and additions. Several of our sources felt most of the interest in biopolymers in the U.S. is currently on the west coast [PRI04, KRE04].

***High-end groceries/short shelf-life products***

- In-store packaged fruits, vegetables (especially organics), bakery items in stores such as Whole Foods, Kroger-affiliated stores, and others with large "natural food" selections.
- Organic fruit and vegetable growers
- "Natural" or organic fresh pastas that are not currently packaged in MAP/CAP [LAR04].
- "Natural" or organic dried fruits, trail mixes, bulk nuts and chocolate (e.g. nSpired Natural Foods and Just Tomatoes, etc. [COX04]). These are distributed to many stores.
- Food/snack items for children (especially organic, emphasize natural packaging)
- Fresh or organic pet food items (e.g. Three Dog Bakery in Madison, WI, Kansas City, MO, Seattle, WA, and Indianapolis, IN)

***Institutions***

- College campuses – cafeterias, eateries, etc. – especially "green" college campuses (e.g. Bastyr, Carlton, Evergreen, UBC, Williams). Universities might also have composting facilities. To take full advantage of a university's commitment to sustainability, it might be advantageous to work with a distributor of bioplastic utensils, cups, plates, etc. to sell it as a "package deal."
- Private schools in "green" areas (West Coast).
- Big corporations (with cafeterias, etc) that are publicly committed to sustainability (e.g. Ford, Dow, 3M?)
- Institutions that are already composting food waste (e.g. hospitals, prisons, Disney World [GIO04])
- National/state parks food service. (Earthshell products are already used in several national parks.) In addition to the environmental benefit, this could potentially expose millions of nature-inclined visitors to biopolymer packaging.

***Marketing/Public relations***

- Take advantage of product and trade shows, as well as food shows in regions where PLA products are or will soon be available (e.g. Bite of Seattle, Vegfest in Seattle, Taste of Washington).
- Earned media - generate continuing earned media on benefits of sustainable and compostable packaging. Foster relationships with NGOs (e.g. National Research Defense Council, Union of Concerned Scientists, Environmental Defense Fund, Greenpeace, Nature Conservancy, etc.), which have enormous distribution lists. They could send out information about packaging alternatives.
- In-store promotions - e.g. giveaways "buy 1 get 1 free" organic strawberries, etc.
- Education/public awareness – Develop school lesson plans and programs around composting and sustainability (Novamont has a few). Work with natural food grocery stores with PLA products to promote and distribute these to local schools.

***Service***

- PLA packaging performs as well as traditional-polymer packaging, but it is made from renewable resources and does not need to end its life in the landfill. Many potential customers are “sold” on the idea before they even place their hands on the product, despite its high cost. Yet potential customers know that in order to run a more sustainable business, they have to stay in business. They universally asserted that not only did they have high product-performance expectations, but it is imperative that their supplier also meets the highest standards of reliability and responsiveness.

# 8 REFERENCES


AME01 American Plastics Council, October 2001, "2000 Post-consumer polystyrene recycling statistics summary."

AND04 Andrews, Ted, Herbco International, Personal Communication, Tel: (425) 788-7903, E-mail: herbco@msn.com May 13, 2004

APC04 "Total U.S. Sales and Captive Use of Selected Thermoplastic Resins by Major Market," www.americanplasticscouncil.org

BRO04 Broydo, Leora. March/April 1998. "Vinyl Analysis." http://www.motherjones.com/news/outfront/1998/03/homeplanet.html. April 5, 2004.

CAR04 Cargill Dow. "Company Website." Internet. (2004) Accessed May 2004 www.cargilldow.com

COO04 "Forty-four Million Americans can't be Wrong: the Market is Ready for Socially Responsible Businesses," http://www.coopamerica.org/business/B44million.htm, accessed 2/27/04

COR02 Corn Refiners Association, "The Corn Refining Process", Accessed May 2004, http://www.corn.org/web/process.htm

COX04 Karen Cox, owner Just Tomatoes, etc., Personal Communication. (209) 894 5371, karen@justtomatoes.com. 27 May 2004.

DEF03 DEFRA (U.K. Department for Environment, Food and Rural Affairs), 7 March 2003. "Food and drink industry to join sustainability drive." http://www.defra.gov.uk/news/2003/030307a.htm. May 20, 2004.

DUN03 Marvin Duncan, U.S. Federal Initiatives to Support Biomass Research and Development, The Journal of Industrial Ecology Volume 7, Issue 3-4 / 2003

ECK98 Angela Eckhardt "Paper Waste: Why Portland's Ban on Polystyrene Foam

EDF97 Denison, R.A., 1997. "Something to Hide: The Sorry State of Plastics Recycling." http://www.edf.org/documents/1889_SomethingtoHide.pdf. April 22, 2004.

ELW96 Elway Research 1996 " City of Seattle, 1995 Home Organics Waste Management Survey" http://www.ci.seattle.wa.us/util/solidwaste/docs/reports/1995HomeOrganicsSurvey.PDF May 23, 2004

EPI01 “New Wave of Biodegradable Plastics Captures Niche Markets,” Environment and Plastics Industry Council, Canadian Plastics Industry Association, May 2001,

FAI04 Faint, Martin, “A-maizing bags to defuse eco timebomb.” Birmingham Post. March 26, 2004.

GEM00 Tillman U. Gerngross and Steven C. Slater, “How Green are Green Plastics?” Scientific American, August 20, 2000.

GER01 Gerngross, et al., “Greenhouse Gas Profile of a Plastic Material Derived from a Genetically Modified Plant”, Journal of Industrial Ecology, Vol 4, Number 3, 2001

GIO04 Tony Gioffre, Novamont N.A., Personal Communication, P.O. Box 1039 Ridgefield, CT 06877, Tel.: (203) 438-5904, Fax: (203) 431-0451, E-mail: gioffre@materbi.com. May 18, 2004.

GRU00 PR Gruber, RE Drumright, DE Henton: “Polylactic acid technology.” Advanced Materials 12 (2000) 1841-46.

HAR96 The Hartman Group. *The Hartman Report, Food and the Environment: A Consumer's Perspective, Phase I*. Bellevue, WA. 1996. from www.coopamerica.org/business/B44million.htm, accessed 3/1/04

HOL04 Holladay, Johnathan, Pacific Northwest National Laboratories, Personal Communication, 902 Battelle Boulevard, P.O. Box 999, MSIN: K2-12, Richland, WA 99352, Tel: (509) 375-2025, Cell: 509-528-1762, E-mail: john.holladay@pnl.gov, May 24, 2004

http://www.cascadepolicy.org/growth/poly.pdf May 23, 2004

IPC01 IPCC (Intergovernmental Panel on Climate Change) 2001. “Climate Change 2001: The Scientific Basis.” Cambridge University Press.

ISO97 International Organization for Standardization (ISO). ISO 14040: Environmental Management - Life Cycle Assessment - Principles and Framework. (1997).

ISO98 International Organization for Standardization (ISO). ISO 14041: Environmental Management - Life Cycle Assessment - Goal and Scope Definition and Inventory Analysis. (1998).

KRE04 Robert Krebs, Director of Communications, American Plastics Council, Personal Communication, 703 741 5626, Robert_Krebs@americanchemistry.com. 30 April 2004.

LAR04 Anna Lee Larimore, Nettles Farm, Personal Communication. (360) 778 0153, hans@nas.com. 31 May 2004.

LEA03 Robert Leaversuch, "Lots of Ferment in Biopolymers," Plastics Technology, June, 2003, Vol. 49, Iss. 6

LEN95 Lenz, Robert W., "Biodegradable Plastics and Polymers in Japan: Research, Development and Applications," International Technology Research Institute, March 1995.

LEV04 Michael Levy, Polystyrene Packaging Council, Personal Communication, 703 741 5647, Mike_Levy@plastics.org. May 24, 2004.

LIP93 Brian Lipsett, "The McToxics Victory", 1993, http://www.mcspotlight.org/campaigns/countries/usa/usa_toxics.html, Accessed May 27, 2004

MAZ02 Patrick Mazza, The New Federal Farm Bill: Opportunities for Northwest Rural Clean Energy Development, Oct. 2002. http://www.harvestcleanenergy.org/enews/enews_1002/enews_1002_Farm_Bill.html May 23, 2004

MCD02 William McDonough and Michael Braungart, Cradle to Cradle: Remaking the Way We Make Things, c. 2002, p. 104

MET04 Metabolix, Company Website, Internet (2004), Accessed May 2004, www.metabolix.com

MIC04 Michael, David, "Biopolymers from Crops: Their Potential to Improve the Environment," www.wondu.com

MIN04 Mindfully.org, " Plastics Growth in California, U.S., and World." www.mindfully.org/Plastic/Growth-World-US-CA.htm. April 1, 2004.

MIR04 Feliza Mirasol, "Industry Gears Up for Industrial Biotechnology Wave," Chemical Market Reporter, April 5, 2004

MOJ01 Mojo, Steven A., "What's Next for Biodegradable and Compostable Plastics?", ATSM Standardization News, April 2001

NAR04 Narajan, Ramani, "Drivers and Rationale for Use of Biobased Materials Based on Life Cycle Assessment (LCA)", www.msu.edu/user/Narajan

NAR99 Narayan, Ramani and Charles A. Pettigrew, "ASTM Standards Help Define and Grow a New Biodegradable Plastics Industry," ASTM Standardization News, February 1999

NAT04 “Natural gas and the environment.” http://www.naturalgas.org/environment/naturalgas.asp. May 23, 2004.

NOL02 Nolan-ITU Pty Ltd., “Biodegradable Plastics – Developments and Environmental Impacts, Australian Government, Department of the Environment and Heritage, October 2002, Accessed May 2004, http://www.deh.gov.au/industry/waste/biodegradable/index.html

PAC02 Packaging World, May 2002. “U.S., U.K. progress in biodegradables.” http://www.packworld.com/cds_print.html?rec_id=14472. May 23, 2004.

PAT01 Patel, Dr. Martin, “Review of Life Cycle Assessments for Bioplastics,” Department of Science, Technology and Society, Utrecht University, Netherlands, November 2001

PAT04 Patel, Dr. Martin, Department of Science, Technology and Society, Utrecht University, Personal Communication, Email: m.k.patel@chem.uu.nl, Netherlands, November 2001

Products has Been a Costly Failure” Oct, 1998

RAY97 Paul H. Ray, “The Emerging Culture,” American Demographics, Feb. 1997, accessed 2/27/04 through www.coopamerica.org

RID04 Knight Ridder, “Company struggles to ignite U.S. market for biodegradable plastic.” St. Paul, Minnesota. Jan 8, 2004. http://www.theplasticsexchange.com/Public/News_Template.aspx?Buffer=&ID=52347858

ROW95 Rowlands, “Assessing the Political Influence of Global Environmental NGOs”, 1995, http://www.kun.nl/milieubeleid/staf/arts/POWER.doc, Accessed May 23, 2004

SAK04 Sakai, et al., “Making Plastics from Garbage – A Novel Process for Poly-L-Lactate Production from Municipal Food Waste”, Journal of Industrial Ecology, Vol 7, Number 3-4, 2004

SCA01 Lynn Scarlett and Robert Anex , “Packaging, Recycling, and Solid Waste,” June 1997, http://www.rppi.org/ps223.pdf , Accessed May 25, 2004.

STA04 David Stanton and Nicole Whiteman, Cargill Dow, Personal Communication, 952-742-0587 (phone), 952-221-5990 (cell), 952-931-1505 (fax), david_stanton@cargilldow.com. May 20, 2004.

STE02 Stevens, E.S., 2002. Green Plastics: An introduction to the new science of biodegradable plastics. Princeton University Press, Princeton, NJ.

STG04 St. George, Gary, Intec Alliance, Personal Communication, Tel: Mfgr Plant in MN 866 468 3200 (toll free), Cell: 805 236 5150, May 20, 2004

STR99 Robert D. Straughan and James A. Roberts, “Environmental segmentation alternatives: A look at green consumer behavior in the new millennium,” Journal of Consumer Marketing, Vol. 16, no. 6, 1999, p. 562

THO04 Jan Thompson, Deli Merchandise Manager, and Lori Ross – Sustainability Director, Puget Consumer Coop (PCC) Natural Foods, Personal Communication. 25 May 2004.

TRE03a Trends in Japan, December 16, 2003. “BIOPLASTIC: Eco-Friendly Material Has a Bright Future” http://web-japan.org/trends/science/sci031212.html. May 18, 2004.

TRE03b Trends in Japan, January 16, 2003. “Posh Food to Go: First-Class Hotels Enter the Takeout Business.” http://web-japan.org/trends01/article/030116soc.html. May 20, 2004.

WEB00 Weber, Claus J, “Biobased Packaging Materials for the Food Industry: Status and Perspectives.”, Food Biopack Project, EU Directorate 12, November 2000.

YAR04 Yardley, Jim, “China Races to Reverse Its Falling Production of Grain.” New York Times, New York, New York. May 2, 2004.

# APPENDICIES

# APPENDIX A. FOREGIN COUNTRY ANALYSIS

| Criteria | Weighting Factor | Japan | U.K. | France | Sweden | Germany | China | India | Brazil |
|---|---|---|---|---|---|---|---|---|---|
| Economy (high GDP) | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 1 |
| Social awareness (eco-friendly policies) | 3 | 2.5 | 2 | 2 | 3 | 3 | 2 | 1 | 1 |
| Plastic Food Packaging Market | 3 | 2 | 2 | 2 | 0.5 | 1 | 3 | 1.5 | 1.5 |
| Market Access/Unsaturated green plastic market | 3 | 2 | 2.5 | 2 | 2 | 0.5 | 2 | 3 | 3 |
| Little landfill space | 2 | 3 | 2.5 | 2 | 3 | 3 | 1 | 1.5 | 1.5 |
| Access to composting | 1 | 2 | 2 | 2 | 3 | 3 | 1 | 2 | 1 |
| Availability of corn/other plant products | 1 | 1 | 1 | 2 | 0.5 | 2 | 3 | 3 | 2 |
| Political Stability | 1 | 3 | 3 | 3 | 3 | 3 | 2.5 | 2.8 | 1.5 |
| **TOTAL** | | **40.5** | **39.5** | **38** | **38** | **36.5** | **35.5** | **33.3** | **27** |

| | China | India | Germany | Japan | United Kingdom | France | Brazil | Sweden |
|---|---|---|---|---|---|---|---|---|
| **Economy (high GDP)** | **2003. The National Bureau of Statistics (NBS) said gross domestic product was 5.7 trillion dollars, up 9.1 percent. Per capita gross domestic product was US$1,090.<br>Population: 1,287,000,000** | **2003. 7.3 percent growing, 2.66 trillion GDP<br>Per capita gross domestic product was US$545<br>Population: 1,049,701,000** | **GDP US$2.16 trillion<br>Population ~ 82,400,000** | **Per capita GDP US$28000<br>Population ~ 127,200,000** | **GDP US$1.53 trillion<br>Population ~ 60,000,000<br><br>The UK, also with a 2003 pop. Of about 60 million, has a per capita GDP of US$ 26,513. 10% of GDP is generated by energy production; the UK has large coal, natural gas and oil reserves. The UK is the 3rd largest economy in the EU, after Germany and France. The UK is ranked 12th on the UN HDI.** | **GDP US$1.56 trillion<br>Population ~ 60,000,000<br><br>France, with a population of 60 million, is a leading industrial/agricurtural economy in the E.U. The per capita GDP in 2002 was US $24,228. 68 % of GDP is generated by the service sector, and 24% by industry. France is ranked 13th on the UN Human Development Index, which averages economic and social conditions across countries to describe standard of living** | **Per capita GDP US$ 7600<br>Population ~ 182,000,000** | **GDP US$231 billion<br>GDP per capita US$25,985<br>Population 8,878,085** |
| **Market for food packaging** | **Lots of exports yields big market** | **Not yet plastic-centric.** | **Some cities have policies discouraging packaging** | **Cultural tendency to individually package food items, often in paper** | **Lots of plastic packaging** | **Less than UK more than Germany** | **Not yet plastic-centric.** | **Information sketchy, but presence of strong packaging reduction act indicates there is probably a small, tight market for plastic packaging. However, to the extent that plastic food packaging is used, bioplastics are likely to be popular.** |
| **Availability to corn/other plant products** | **Because of the growing population, both countries face agriculture pressure.<br>Both countries are looking carefully at the potential of genetically-modified (GM) crops to boost output, but are developing them warily.** | | **22nd in world for cropland<br>Not a major exporter** | **Imports > exports<br>44th country in world for cropland** | **39th in world for cropland, not a major exporter<br><br>England produces primarily wheat and barley as grain crops** | **16th in world for cropland<br><br>Corn, wheat, and other sugar and starch Bearing plants are produced in large Quantities in France.** | **Exports slightly larger than imports, 5th country in world for cropland** | **71st in the world in arable & permanent cropland<br>main agricultural products:** |

| | China | India | Germany | Japan | United Kingdom | France | Brazil | Sweden |
|---|---|---|---|---|---|---|---|---|
| | | | | | **(62% wheat and 28% barley of total metric tones produced); all corn is imported. (http://www.hgca.com/default.asp?InitialPage=/main_page.asp)** | **France is the largest grain producer in the E.U.; although France is a net exporter of wheat, it is a net importer of corn.** | | **barley, wheat, sugar beets; meat, milk** |
| | **China is producing GM cotton in key growing areas and a leading biotech company is conducting field tests on corn, but the government is cautious over producing corn commercially because of anti-GM feeling abroad. Genetically-altered rice might be grown in China in the next two to three years.**<br><br>**3rd in world for cropland** | **In India, recently the country would not permit the use of biotechnology that goes against the interests of farmers. India needed to develop a suitable system to protect plant breeder's rights, plant varieties and patenting, he said. Any crop variety likely to affect the environment or health would not be allowed, but at the same time transgenic crops with the potential to enhance productivity, profitability and nutritional value should not be ignored.**<br><br>**2nd in world for cropland** | | | | | | |
| **Political Stability** | **China will have great difficulty in continuing with economic freedom but not allowing political freedom, in keeping politics centralized** | **India with its federalism and democracy will have the advantage.** | **Stable** | **Stable** | **Very similar to France with stable political system, with Labor and Conservative parties operating much like two party system in U.S.** | **France has a very stable democratic political system, with power changing hands between socialist and conservatives in the National Assembly** | **Questionable. US State Dept says situation is fairly stable for a South American country, but warns Americans the situation could become unstable at any time** | **(80% turnout in last parliamentary election)** |
| **Eco-friendly policies** | ***Effectiveness of Environmental policy and Environmental Management System (EMS)* may not be apparent unless they** | **An assessment of India's environmental management system suggests that weaknesses are evident at every administrative** | **LOTS AND LOTS** | **Many. E.g. Packaging waste law requires municipalities to collect, sort, wash waste packaging;** | **The UK has active solid waste recycling policies: by 2005 the government aims to reduce the amount of industrial and** | **France incinerates over 60% of its MSW and this percentage is rising. France recovers 33% of plastic, but this includes post-consumer plastics** | **Some policies, but much resistance due to economic situation.** | **Packaging reduction laws (extended producer responsibility) since 1993.** |

| | China | India | Germany | Japan | United Kingdom | France | Brazil | Sweden |
|---|---|---|---|---|---|---|---|---|
| | **are properly integrated with other corporate policies/systems.<br><br>Major changes in National Packaging Policy; Chinese Urged to Make Eco-Friendly Products; More Polluting Factories Closed in China; Shanghai to Spend 70 Billion Yuan on Environment; Shanghai Opens Huge Solar Plant** | **level ate the center, state and district. The ministry of environment linked to state-level implementation agencies have proved to be largely unsuccessful in effectively managing the protection of the environment.** | | **packaging manufacturers required to take back and recycle waste packaging.** | **commercial waste disposed of in landfill sites to 85% of 1998 levels and to recycle or compost at least 25% of household waste, increasing to 33% by 2015; between 1998-99 and 1999-2000, household recycling increased from 8.8% to 10.3%** | **that are burned. 1 in 10 Parisians derive electric heat from garbage incineration. France tends to view incineration of some forms of plastic as preferable to recycling in some cases. However, receptacles for recyclable items are present in major urban hubs. France has very aggressive targets for recycling and management of agricultural wastes, but less emphasize on MSW recycling. France is second only to Sweden on overall reliance on nuclear energy.** | | **Deposit fees for single-use packages.** |
| **Little landfill space** | **landfill disposal is the most popular in China, with more than 85% of the country's household waste ending up in landfills. China's capabilities are far too inadequate to handle the amount of solid waste it generates and the speed of its growth** | **Nearly all of the waste generated is typically disposed in landfills. (Although referred to as landfills, all disposal sites in India are open dumps rather than sanitary landfills.) Increased urbanization, lack of space, and a cultural shift toward disposable plastics have all decreased household waste segregation.** | **Very conscious of amout of landfill space, decreasing space** | **Very little landfill space. Most garbage is incinerated.** | **Solid waste per capita increased 21.4 percent in the United Kingdom between 1980 and 19 95, The United Kingdom disposes of over 70 percent of its waste in landfills<br><br>The UK is disposing of 27million tonnes of municipal solid waste per year and it is estimated that the current capacity of landfill space will run out in 9-15 years. The UK waste stream is growing at around 3% per year: partly due to increased population and partly due to the average UK household producing 8kg kg of waste per day.** | **France has little landfill space, and has built state-of-the art incinerators for an increasing percentage of the solid waste stream.** | **Becoming a problem, but is not critical yet.** | **National goal to reduce landfill waste 50-70% by 2005** |
| **Access to composting** | **Regulations in China require farmers to** | **The current rules emphasize the need for** | | **Becoming more common,** | **Composting in United Kingdom (UK)** | **Commercial residential yard and food waste** | **Some interest, little or no** | **20-25% of household** |

| | China | India | Germany | Japan | United Kingdom | France | Brazil | Sweden |
|---|---|---|---|---|---|---|---|---|
| | **compost the waste first, but this is often not done.** | **composting by requiring that biodegradable waste be biologically processed. The rules also require that new landfill sites either be located near composting facilities or have composting facilities on site. Educational campaigns are being conducted throughout India to encourage composting at both household and municipal levels.** | | **infrastructure in place.** | **continues to grow rapidly. Material composted during the year 2000 increased by around 23% to 1 Mio. t from the previous year. The majority of current facilities are small-scale low technology, processing predominantly green waste. Planned new facilities are likely to include a significantly higher proportion of enclosed hall and in-vessel systems for composting catering wastes and animal by-products in combination with source separated plant wastes.**<br><br>**Separate collection of garden waste or garden and kitchen waste is expected to increase. A total number of 161 kerbside collection projects were operational by the end of 1999.** | **infrastructure is in place and operating well in France: in 2000, 50% of 3.1 million metric tons of separated organic materials was composted.** | **infrastructure.** | **waste separated (incl compost) in some municipalities, 15% of households nationally** |
| **Unsaturated green plastic market** | **A study, carried out by the Trade Development Council (TDC) released today (12 March 2004), notes that the demand is being prompted by stricter environmental controls on the mainland and growing overseas discrimination against products that damage the** | **Unsaturated market** | | **Several manufacturers of green plastic, but not food packaging yet.**<br><br>**How would Cargill Dow deal with competitors? Would they buy the competitors?** | **Bioplastics with small market foothold (Cadbury-Schweppes candy) but market share not available.** | **Bio-plastics such as Mater-Bi are available in France, but good data on market share is not available** | **None yet.** | **Biodegradable cutlery in McDonald's since 1967!** |

| | China | India | Germany | Japan | United Kingdom | France | Brazil | Sweden |
|---|---|---|---|---|---|---|---|---|
| | **environment.**<br><br>**The survey, conducted by TDC's Assistant Chief Economist Daniel Poon, advises "green" product suppliers and service providers to look out for the next round of concessions by Cepa, the Closer Economic Partnership Arrangement between the Chinese mainland and Hong Kong.** | | | | | | | |
| | **In Asia, countries such as China, India, Japan, Korea, Malaysia, Singapore and Thailand have already established their own green label schemes** | | | | | | | |

***Extended discussion of countries not chosen:***

France, Sweden and Germany are not perceived to have as much opportunity in biopolymer food packaging as the U.K. at the moment. While these countries have impressive municipal composting availability, France still incinerates most of its garbage without widespread public complaint, and Germany was not found to have as large a market for plastic food packaging. With only 9 million people, Sweden is a small, if willing, market. These countries and the rest of the E.U. bear future investment consideration for food and non food-packaging applications.

China is a potentially enormous market, which should also be considered for the future. The barriers to entry in this market make it potentially less worthwhile in the short term. In the medium to long-term, China may require more and more of its grain crops for food because production has been falling in recent years, while population continues to increase [e.g. YAR04]. This will force grain prices to rise and may make biopolymer production from agricultural crops less competitive. At this point, production of biopolymers from agricultural waste such as corn stover or rice hulls would likely become more economically viable.

India and Brazil are additional countries to watch for future entry. At present, neither has a particularly strong economy or plastic packaging market, and neither can afford additional environmental policies regarding packaging.

In developing nations, substitution from traditional materials such as paper, glass and wood will lead to dramatic growth in per capita plastic consumption [MIC04]. Cargill Dow has an opportunity to “leap frog” traditional plastic in these developing nations by rolling out NatureWorks™ in these markets when it becomes somewhat more cost-competitive.

# APPENDIX B. INTERVIEW NOTES

| Team member | Interviewee | Phone | E-mail | Date | Phone/In person |
|---|---|---|---|---|---|
| Kim | • Rob Krebs, American Plastics Council<br>• Michael Levy - Polystyrene Packaging Council<br>• Gordon Johnson, Monterey Pasta Company<br>• Karen Cox, Just Tomatoes<br>• Anna Lee Larimore, Nettles Farm | (703) 741-5626<br>(703) 741-5647<br>(831) 753-6262<br>(209) 894 5371<br>(360) 778 0153 | robert_krebs@americanchemistry.com<br>mike_levy@plastics.org<br>karen@justtomatoes.com<br>hans@nas.com | 4/30<br>5/24<br>Friday 5/21<br>5/31 | phone<br>phone<br>Phone<br>phone<br>phone<br>phone |
| Yun | • Kinley Deller-King County Solid Waste | (206) 296-4409 | Kinley.Deller@metrokc.gov | Tuesday | email |
| Dan | • Gary St. John, InTec Alliance<br>• Jan Thompson, Lori Ross, PCC Markets | (866)468-3200<br>(206) 547-1222 | garys@intec-alliance.com | Thursday 5/20<br>Friday 5/28 | phone<br>phone<br>phone |
| Christina | • John Nevling - Earthshell<br>• Nicole Carey - Willis Mktg.<br>• Johnathan Holladay – PNNL | (410) 847-9420<br>(253) 307-7883<br>(509) 375-2025 | ncarey@willismarketing.com<br>John.Holladay@pnl.gov | Friday 5/7<br>Friday 5/7<br>Monday 5/24 | phone<br>phone<br>phone |
| Group | • Ted Andrews-Herbco International<br>• David Stanton/Nicole Whiteman – Cargill - Dow<br>• Brad Price - Simply Biodegradable<br>• Tony Gioffre – Novamont | (425) 788-7903<br>(952) 742-0587<br>(509) 586-1360<br>(203) 438-5904 | david_stanton@cargilldow.com<br>brad@simplybiodegradable.com<br>gioffre@materbi.com | Thurs. 5/13<br>Thurs. 5/20<br>Thurs. 4/29<br>Tuesday 5/18 | In person<br>phone<br>Phone<br>Phone (Christina & Kim) |

# APPENDIX C. PLASTIC PROCESSING TECHNIQUES

Processing of Plastics [http://homepages.enterprise.net/caistorg/Main_p.html#p_thermo]

| **Process** | **Applications** |
|---|---|
| **Compression Molding** | Compression molding is the process that moulds molten plastic, through **compression**, into the desired shape of the molding. The animation below shows a separable mould used to form a large pot for gardening.<br>Compression molding is the only plastic molding process that can mould **thermosetting** plastics because due to their cross-linked structure, preheating as used in other molding processes would make the product assume the wrong final shape, by 'curing' earlier in the process. Thermosetting plastics possess excellent electrically insulative properties because they can not burn, only decompose.<br>Familiar products manufactured by compression molding include: 3-pin mains plugs, electrical switches, sockets and ashtrays.<br><br>The plastics that are used in compression molding include: urea formaldehyde, urea formaldehyde resin, melamine formaldehyde and polypropylene (**PP**). |
| **Injection Molding** | Most thermoplastics can be processed by Injection Molding. Injection molding is the process that moulds plastic through heat and pressure, by injecting molten plastic polymer into the desired mould.<br><br>Injection molding is the most commonly used process for molding plastics because it gives a good surface finish and can be used for very complex moldings. Injection molding, although requiring a substantial capital investment, becomes very economically viable in mass production and gives a very low unit production cost. Injection molded plastics are invariably thermoplastics because thermosetting plastics assume their final shape through heat and so can not be molded with this process.<br><br>Familiar products manufactured by injection molding include: computer enclosures, milk crates, CD cases and mobile phones.<br><br>The plastics that are used in injection molding include: polythene, low density polyethylene (LDPE), high density polyethylene (HDPE), polystyrene (PS), polypropylene (PP) and acrylonitrilebutadienestyrene (ABS). |
| **Thermoforming** | Thermoforming is the process that moulds sheet plastic into the desired shape through the pressing of formers into the warmed plastic.<br><br>Thermoforming is used primarily in low-cost applications for the simple embossing of thin plastic sheet and cannot be used to form as rigid shapes as vacuum forming is capable of. Thermoformed plastics are invariably thermoplastics because thermosetting plastics assume their final shape through heat and so can not be molded with this process.<br><br>Familiar products manufactured by thermoforming include: yoghurt pots and simple trays. The plastics that are used in thermoforming include: acrylic, low density polyethylene (LDPE) and crystalline polyester (CPET). |
| **Blow Molding** | Blow molding is the process that takes an extruded pipe of plastic and introduces air into it, once sealed at both ends. This causes the pipe to rapidly inflate and assume the shape of the mould surrounding it. The mould is opened, and the molded item is removed, with a new constant circular profile.<br><br>Blow molding produces a fairly good surface finish so for many items there is no further surface finishing necessary. Blow molded products have a constant thickness of polymer at every point of the shell, and can be large in size. Blow molded plastics are invariably thermoplastics because thermosetting plastics assume their final shape through heat and so can not be molded with this process. |

| Process | Applications |
| --- | --- |
| | Familiar products manufactured by blow molding include: drinks bottles, shampoo bottles, water drums and plastic barrels.<br><br>The plastics that are used in blow molding include: low density polyethylene (LDPE), high density polyethylene (HDPE) and polypropylene (PP). |
| **Vacuum Forming** | Vacuum forming is the process that moulds sheet plastic into the desired shape through vacuum suction of the warmed plastic onto a mold.<br><br>Vacuum forming can be used for many thicknesses of plastic sheet and can provide great strength in its finished moldings. Fairly complex moldings can be achieved with vacuum forming. Vacuum formed plastics are invariably thermoplastics because thermosetting plastics assume their final shape through heat and so can not be molded with this process.<br><br>Familiar products manufactured by vacuum forming include: baths and trays.The plastics that are used in vacuum forming include: acrylic, low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP) and crystalline polyester (CPET). |
| **Extrusion** | Extrusion is the process that moulds plastic into a form with constant cross-section, usually a pipe. This is achieved by passing molten plastic polymer through a metal die.<br><br>Extrusion is sometimes coupled with another process, blow molding, in order to inflate the extruded part. Extruded plastics are invariably thermoplastics because thermosetting plastics assume their final shape through heat and so can not be molded with this process.<br><br>Familiar products manufactured by extrusion include: pipes, guttering, window sills and insulation on wires.<br><br>The plastics that are used in extrusion include: poly vinyl chloride (PVC), low density polyethylene (LDPE), high density polyethylene (HDPE) and polypropylene (PP). |
| **Blown Film** | Blown film molding is the process that blows plastic polymer using an air jet into a blown film of circular cross-section. Once the plastic has been blown out, rollers flatten it into a sheet of double-thickness film and it is automatically cut to length.<br><br>Blown film molding is a very efficient plastic molding process because little polymer needs to be used for a large production of film. Blown film plastics are usually thermoplastics because it would be a waste of expensive thermosetting plastic polymer and none of the special thermosetting properties are required.<br><br>Familiar products manufactured by blown film molding include: carrier bags andthin plastic sheeting.<br><br>The plastics that are used in blown film molding include: polythene. |
| **Rotational Molding** | Rotational molding differs from all other processing methods in that the heating, melting, shaping, and cooling stages all occur after the polymer is placed in the mould, and no external pressure is applied during forming. |