DISPOSABLE BIOPLASTICS

CONSUMER DISPOSABLES
AGRICULTURAL FILMS

A Market Opportunity Study

April 2008

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UNITED SOYBEAN BOARD

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The demand for bioplastics, both biodegradable and non-biodegradable, makes it one of the fastest growing thermoplastic product types globally. Global demand is expected to reach over one billion pounds by 2012. Currently, the biodegradable segment of bioplastics is the largest segment of the bioplastics category, but it is projected to be displaced by the non-biodegradable bioplastics group of products, which may or may not be 100% derived from biomass. Packaging, disposable food service and fiber applications are major use areas.

In the United States, the growth of bioplastics is estimated to be 19% per annum through 2011, reaching a projected consumption in the U.S. of over 600 million pounds. The growth is driven by several factors: 1) large retailers, such as Wal-Mart and Target, requesting that their suppliers adopt bioplastics for packaging products they stock, 2) the public concern over the depletion of petroleum based raw materials, 3) the desire of manufacturing companies to develop more sustainable raw material sources, 4) the improvement in properties of bioplastics, 5) state and federal government support for biobased products, and 6) the more cost competitive relationship that bioplastics have achieved versus petroleum based plastics.

Polylactic acid polymer (PLA) demand is growing rapidly in both packaging and fiber applications. Demand for starch based polymers, in a modified form or blended with another polymer such as PLA for biodegradability or with a polyolefin such as polypropylene, will continue to grow. Omni Tech estimates that the growth in demand for starch based plastics will be equal to the growth in PLA at about 19% per year through 2011, reaching, conservatively, 180 million pounds.

Among the bioplastic applications, four uses have standout growth opportunities in the immediate future: 1) biodegradable bags/films, 2) biodegradable plastic foam cushioning blocks, 3) bioplastic fibers, degradable and non-degradable, and 4) bioplastic molded products, degradable and non-degradable.

Significant research and development work at several universities on developing biodegradable bioplastics made from soy protein products (meal, flour, concentrate, and isolate) in combination with PLA and other biodegradable plastics is being funded by USB – New Uses, and should continue to be supported. This work is building on past R&D efforts that have laid the technical ground work for these new projects.

Although past research and development work to develop a bioplastic using soy protein as a component has not as yet been commercially successful, new driving forces and biopolymer technology have improved the opportunities for a soy protein containing bioplastic to be developed

Additional projects using soy protein products combined with non-biodegradable biomass plastics and petroleum based plastics and targeted at specific large volume applications in fibers, molded products and films should be encouraged and supported.

PART 2 – AGRICULTURAL FILMS

Photodegradable film use is gone and no commercially proven biodegradable mulch films are yet available in the U.S. The unmet market demand for these films is, however, strong because mulch film disposal costs are escalating and the problem remains unresolved. Two new biodegradable mulch films have been developed using renewable feedstocks that are in the early stages of market introduction.

It is recommended that the USB New Uses Committee consider funding support for future projects involving the development of soy-based biodegradable agricultural mulch films. USB funding support was not recommended in the 2001 market study update. However, demand for biodegradable mulch films has increased considerably since then and the market will now support premium priced biodegradable films if they perform well and eliminate the need for mulch film collection and disposal. An RFP (Request for Proposal) focused on soy protein-based biodegradable mulch films sent to key universities and mulch film manufacturers could stimulate R&D efforts.

DISPOSABLE BIOPLASTICS

PART 1
CONSUMER DISPOSABLE PLASTICS

Phil Sarnacke

INTRODUCTION

The last Omni Tech report on opportunities in the thermoplastic market was in 2001. At that time agricultural films and polyvinyl chloride (PVC) plasticizer segments were the focus of the study. Since that time not only have the customers and soy opportunities changed, but the market prices of many competing petrochemical based plastics have increased dramatically, making soy based plastic more economically competitive.

The study will identify the current market size, market growth, competitive products and opportunities for soy based plastics in the disposable plastics market. This market segment includes biodegradable/compostable plastics and non degradable plastics derived from renewable biomass. Opportunities for soy based plastics exist in both sub classification segments.

OVERVIEW OF NORTH AMERICAN PLASTICS MARKET

In 2006 the US Plastic market demand was 113 billion lbs. Thermoplastics made up 90 billion lbs of the total plastics market. The primary end use applications and the volume of plastics consumed for each of the major market categories are estimated as follows:

Transportation:
Motor vehicles and parts, including: autos, truck and bus bodies; parts for autos and trucks, including engines and electrical ignition systems; truck trailers and containers, including special purpose vehicles (i.e. fire truck) other than military. Also, aircraft and parts; ships and boats; railroad equipment; motorcycles and bicycles; missiles and space vehicles; recreational vehicles including golf carts; military, land, air and marine vehicles. **2006 Demand 4,600 million lbs**.

Packaging:
Bottles, jars, vials; drums, pails, cans, barrels, buckets; caps, closures, aerosol parts; food containers excluding disposable cups; coating for all types of packaging; flexible packaging including bags, household and institutional refuse bags and film; boxes and baskets; personal care packaging products; pallets, crates, spools, reels, bobbins, tape, strapping, twine. **2006 Demand 26,200 million lbs**

Building And Construction:
Pipe, conduit, and fittings including pipelines, drainage and irrigation systems; plumbing fixtures; siding, siding accessories, soffits, fascia, skirts for mobile homes; flooring; insulation materials; roofing materials; partitions, panels; agricultural film; doors, windows, sills; bathroom units, steps, gratings, railings; skylights, countertops, drainage downspouts; air-supported structures. **2006 Demand 15,500 million lbs.**

Electrical And Electronic:
Home and industrial appliances including washers and dryers, air conditioners, lighting fixtures (affixed), freezers and refrigerators; small appliances; radios, TVs, telephones, office machines; electric equipment including electric power equipment, motors and controls, measuring and control equipment, lighting and wiring equipment, current-carrying equipment, non-current-carrying wire devices, pole line hardware; communications equipment; electronic components including tubes, semi-conductors, capacitors, resistors, coils and transformers, magnetic tape and audio, printed circuits, records and tapes, X-ray equipment; batteries, wire and cable. **2006 Demand 2,700 million lbs.**

Furniture And Furnishings:
Rigid furniture including household, case goods, dinettes, lawn/garden furniture, headboards, occasional pieces, also office, institutional, and school furniture; stadium seating; benches for public buildings; churches and restaurant furniture; store fixtures; counter tops; flexible furniture including household upholstered furniture, cushioning, frames, simulated wood components for upholstered furniture, decorative pillows, bedding, bed pillows; carpets and carpet components including backing; curtains, house furnishings, awnings, blinds, household portable lamps and furniture accessories, wall decorations and coverings. **2006 Demand 3,350 million lbs**.

Consumer and Institutional Products:
Disposable food serviceware including cups, dinnerware, tableware, kitchenware, drinking straws; luggage, buttons, hardhats, handbags, apparel; lawn and garden equipment (non-electrical); picnic jugs, ice chests, flower boxes; healthcare, medical products and personal care items including combs, brushes, prosthetic devices, medical tubing, blood packs, syringes, IV bags; toys and sporting goods (not vehicles) including plastic pools, liners, fishing line, life jackets; laboratory supplies; footwear; signs, displays, credit cards, placemats, ashtrays, mats. **2006 Demand 17,700 million lbs**.

Industrial/Machinery:
Engine and turbine parts (except outboard); farm and garden machinery and equipment, construction equipment, mining equipment, oil field equipment, material handling equipment; machine tools (including hand power tools and hardware); industrial equipment; fishing and marine supplies (including commercial buoys and markers); chemical process equipment; ordnance and firearms. **2006 Demand 1,000 million lbs.**

Adhesives - Inks - Coatings:
Adhesives and sealants; paper coating and glazing; printing ink; paints, varnishes, enamels; insulating varnishes and magnet wire enamels; core binder, foundry facing.
2004 Demand 1,110 million lbs.

All Other (Not Elsewhere Classified):
Other sales of resins that cannot be classified under any other major market category. Includes sales to resellers and compounders. **2006 Demand 2,000 million lbs.**

North American Export: 2006 Demand 10,000 million lbs.

Plastic Types

There are over 30 major (large volume) family types of plastics produced commercially today. Two major plastic groupings derived from hydrocarbons (natural gas or oil) are Thermoplastics and Thermoset plastics. The *Thermoplastic polymers* are those polymers that are melted and formed into a net shape article or film. They can be remelted and reformed as well. *Thermoset plastics* are polymers that are usually formed by the mixing of two chemical compounds that react chemically and form a polymer that will not reform on being exposed to heat due to cross linking with the polymer matrix. A smaller third category of thermoplastics exists that are derived from biomass. Most of the products in this family are derivatives of cellulose or modified starch; however recently, two new families of plastics derived from corn, polylactic acid (PLA) and polyhydroxyalkonates, have been developed and are being used to replace hydrocarbon derived thermoplastics in a variety of applications.

Within each family of plastics there can be a dozen or more variants or derivatives off the base polymer type. As an example within the thermoplastics group, the polyethylene family can be divided into several sub groups (high density, low density, linear low density, ultra low density), based on the specific gravity (density) of the polymer. The following is an abbreviated list of major family types of thermoplastics and thermoset plastics produced from petrochemicals and consumed in North America and in the rest of the world:

THERMOPLASTIC FAMILIES

- Polyethylene
- Polypropylene
- Polystyrene
- Polyvinyl Chloride (PVC)
- Polyesters (PET, PBT)
- Engineered Plastics
    - Polycarbonate
    - Nylon
    - Polysulfone
    - ABS

THERMOSET PLASTIC FAMILIES

- Polyurethanes
- Epoxy resins
- Unsaturated Polyesters
- Vinyl Esters
- Phenolic resins
- Silicones

All of these plastics are derived from oil or a natural gas derivative. The remainder of this study will be concerned with the opportunity for bioplastics, specifically derived from renewable biomass. Characterization of these plastics is more difficult due the hybridization of their backbones.

BIOPLASTICS

Thermoset polymers

- Soy polyurethanes
- Unsaturated polyester resins

Thermoplastic polymers

- Polylactic acid
- Modified starch polymers
- Thermoplastic polyesters
- Bio-polyolefins
- Polyhydroxy alkonates (PHA)
- Cellulose ethers

Some but not all of these bio-based thermoplastic polymer families meet the ASTM definitions of biodegradable/compostable. All contain some amount of biomass derived from a renewable resource as part of their macromolecular structure. None of the thermoset plastics meet the ASTM definition of biodegradable/compostable by design.

As a group they still represent relatively small volume of the total volume of plastics produced in the world today. Estimates run from 200 million to 500 million lbs. depending on whether the modified cellulosic polymers are included; however, the growth rate of demand for bioplastics is expected to grow at double digit rates for the next five years.

Disposable Plastic Products

For the purposes of this study, we are focusing on those plastics market segments whose products are usually made from commodity plastics such as polyvinyl chloride (PVC), polystyrene (PS), polypropylene (PP), polyethylene (PE), etc. and fit the following definition:

***Disposable plastics products** are those plastic products that are not designed to last in use for a long period of time. In many cases, mostly packaging, food service and agricultural applications, they represent a onetime only use, followed by disposal. Most applications for disposable plastic products are found in the following market segment categories:*

Consumer and Institutional Products; Disposable food service ware including cups, dinnerware, tableware, kitchenware, drinking straws; luggage, buttons, hardhats, handbags, apparel; picnic jugs, ice chests, flower boxes, plant pots; healthcare, medical products and personal care items including combs, brushes, medical tubing, blood packs, syringes, IV bags; toys and sporting goods (not vehicles) including liners, fishing line; laboratory supplies; footwear; signs, displays, credit cards, placemats, ashtrays, mats.

Packaging: Bottles, jars, vials; drums, pails, cans, barrels, buckets; caps, closures, food containers excluding disposable cups; coating for all types of packaging; flexible packaging including bags, household and institutional refuse bags and film; boxes and baskets; personal care packaging products; pallets, crates, spools, reels, bobbins, tape, strapping, twine

Adhesives - Inks - Coatings: Adhesives and sealants; paper coating and glazing; printing ink; paints, varnishes, enamels; core binder, foundry facing.

Other (Industrial/Construction) : Agricultural mulch, blasting media.

MARKET DEMAND FOR RENEWABLE BIO-BASED THERMOPLASTICS

Background

Thermoplastics produced from renewable agricultural and forest resources (biomass), also called bioplastics, are gaining in importance. For this study, we are investigating the opportunity for biobased thermoplastics in the disposable plastics market segments as opposed to engineering thermoplastics or thermoset plastics/ resins (which have a longer useful like), and will use the terms bioplastics or biobased thermoplastics interchangeably. In point of fact the biodegradable plastics based on bio-renewable raw materials are a subset of the Biobased Plastics category. The bioplastics products we are evaluating may or may not be biodegradable or compostable according to industry and government test protocols. The following two paragraphs further define the differences between the bio-based plastics categories.

Biodegradable/compostable

The term *biodegradable* applied to plastics is used to describe thermoplastic products that are either biodegradable, compostable or photo degradable. There are now specific ASTM tests which can be used to classify the plastic's ultimate fate in the environment. (*ASTM D-6400-99, Standard for Compostable Plastics)*

In order for a bioplastic to be considered ***compostable*** it has to satisfy three criteria (non-technical):

1) Biodegradation – breaks down into carbon dioxide, water and biomass at the same rate as cellulose
2) Disintegration – the plastic is indistinguishable in the compost from other biomass material after a fixed schedule of time
3) Non Toxic – the residual biomass material must not be harmful to animals or plants in final form

Renewable biobased plastic

The term ***renewable biobased*** applied to thermoplastics and thermoset plastic means that some or all of the raw materials used to make the plastic were sourced from a biomass that can be cultivated and harvested on a periodic basis.

Since the 1980's environmental activists have been promoting the concept of degradable plastics along with recycling of trash as the answer to our growing municipal solid waste disposal and litter problems. While recycling is a generally accepted practice in most of North America and Europe (reinforced by legislation), the development and use of degradable bioplastics has been very slow in occurring. Reasons for this lack of adoption of these materials include:

- Cost of the biodegradable polymers (excluding paper) vs. hydrocarbon polymers,
- Lack of physical and thermal properties which meet the end use performance requirements,
- Processing difficulties with the bioplastics (degradable or non-degradable),
- Degradable bioplastics contaminate the current plastic recycle waste streams,
- Realization that biodegradable plastics do not actually degrade under normal landfill conditions found today in most municipal landfills, and
- Lack of government regulation (in the United States) regarding waste.

Current Outlook

In spite of the reasons mentioned in the preceding paragraph, the current demand outlook for the use of degradable plastics based on renewable (biomass) raw materials is more promising due to a number of market, societal and technological developments that favorably impact demand for biodegradable plastic:

- Much higher petrochemical prices leading to higher conventional plastic prices
- Improved synthesis plastic technologies utilizing biomass raw materials
- Global concern over the rapid depletion of petroleum and natural gas resources
    - o Manufacturing corporation's interest in chemicals and plastics raw materials derived from renewable resources
- A burgeoning global population
- Economic growth of developing countries
    - o Global demand for many consumer items and the accompanying packaging of these items
- Improving disposable incomes

- Greater knowledge and awareness of impact of human activity on the global environment
- Government (Federal, State, and Local) support for use of renewable plastics made from biobased raw materials to mitigate the growing waste disposal issues especially in urban areas.

In spite of these favorable factors, the amount of biopolymers being used today in total is small relative to the total market for thermoplastics. One estimate from Chemical Market Associates, reported in Plastic News, places the total consumed in packaging, the largest market for degradable bioplastics, at 90 million pounds worldwide and 35 million pounds in North America.

According to several industry participants (Frederic Sheer, President of Cereplast, Inc, and William Riesbeck, Vice President of Sales and Marketing for Ex-Tech Plastics, Inc.), **bioplastics must meet the cost performance requirements of the petroleum based plastics.** Hurdles to overcome include:

- Minimum heat deflection
- Brittleness
- Processing window sensitivity
- Polymer cost
- Barrier properties

Government Action

The following ordinance went into effect in San Francisco, California:

> **Food Service Waste Reduction Ordinance**
>
> Effective June 1, 2007, the Food Service Waste Reduction Ordinance requires that San Francisco restaurants and food vendors serving food prepared in San Francisco no longer use any polystyrene foam, otherwise known as Styrofoam, as disposable food ware. The ordinance also requires that any disposable food service ware or to-go containers be compostable or recyclable for food prepared and served in San Francisco, unless there is no suitable product that is within 15% of the cost of non-compostable or non-recyclable alternatives

Global Market Size

In spite of the cost performance hurdles mentioned in the preceding list, a recent report by the European Bioplastics association places global production capacity for bioplastics, including both biodegradable and non-biodegradable plastics) at 576 million lbs. in 2007 growing to 3,300 million lbs. in 2011. This growth will occur as a shift occurs among the following three categories (excluding synthetic/non-biodegradable plastics) of plastic materials:

- Synthetic/biodegradable
- Bio-based/biodegradable
- Bio-based/non-biodegradable

The greatest growth is expected to occur in **bio-based/non-biodegradable** materials segment. It is expected that the share of biobased/non-biodegradable bioplastics will reach 40% of total global capacity or 600 million lbs. in 2011 up from 12% share of 69 million lbs/year in 2007.

A Fredonia 2006 market study reports that bio-based/biodegradable plastics will reach 270 million pounds by 2011. Based on other industry reports and OTI sampling of suppliers this number appears to be conservative. Another study of the global biodegradable plastics market by Chemical Market associates states that polylactic acid polymers (PLA) and blends will grow to 450 million lbs in 2011.

TABLE A

GLOBAL MARKET for BIODEGRADABLE POLYMERS*
Million lbs

APPLICATION	2006	2007	2012	CAGR %
Compost Bags	173	242	587	19.4
Loose-fill Packaging	152	161	214	5.7
Other Packaging (1)	51	59	48	23.4
Miscellaneous (2)	33	54	171	25.0
TOTAL	409	516	1,200	17.3

*Data was generated by BCC Research, Wellesley, Massachusetts, in a report entitled Biodegradable Polymers. Published in BioPlastics Magazine Edition 01,2008
(1) Includes medical/hygiene products, agricultural, paper coatings, etc.
(2) Unidentified biodegradable polymers

The rapid predicted change in demand growth of biomaterials is due to the increasing concern over of the earth's hydrocarbon reserves, thus the main driving force behind sustainable plastics in the 21st century is use of annually renewable resources. Biodegradability is an advantage in those countries that have an industrial composting infrastructure in place. However, no biopolymer can sustain a position in the market place without a competitive cost performance profile and for many applications the biodegradability attribute has no added value.

Additionally development work continues in the development of durable plastic products which are usually produced by injection molding and thermoforming processes.

U.S. MARKET DEMAND FOR BIOPLASTIC PRODUCTS

TABLE B

U.S. PROJECTED DEMAND BY BIOBASED PLASTIC TYPE

Million lbs.

	2003	2007	2011	'07-'11 CAGR %
Polylactic acid (PLA)	45	150	300	19
polyhydroxyalkonates (PHA, PHB)	0	< 1	110	49.5
Starch-based	50	100	180	16
bio-Polyester	0	10	50	49%
Cellulosic plastic	NA	NA	NA	NA
Total	95	260	640	25%

The demand for the most common bioplastics is estimated based on public announcements by the companies producing the products, usually in conjunction with an announcement of increased bioplastic production capacity. The high growth rate projection of 25% assumes that the capacity brought on stream this year and next is essentially sold out by 2011.

Polylactic Acid - NatureWorks, the major producer of polylactic acid (PLA) polymers in the U.S., has publicly stated that they will be starting up their second production train in the 2^{nd} half of 2008 which should give them the full production capacity previously announced of 300 million lbs. of PLA produced on two production trains.

Polyhydroxyalkonates - The commercial production of Mirel® polyhydroxyalkonates (PHA) is scheduled to start late in 2008. Telles, a joint venture between Metabolix and Archer Daniels Midland, announced the production capacity to be 110 million lbs. Another potential producer of PHA, Meredian Inc. will begin production in a pilot plant facility in 2009. Capacity is expected to be 30 million lbs. Additional plant capacity of 600 million lbs. of PHA is being planned by Meredian.

Starch Polymers - Starch based polymers will continue to be a large bioplastic product used by itself in a modified form or blended with another polymer such as PLA for biodegradability or with a polyolefin, such as polypropylene. Omni Tech estimates that the growth in demand for starch based plastics will be equal to the growth in PLA at about 19% per year through 2011.

Bio-Polyester - The demand for hybrid bioplastic polyesters (products with both a petrochemical component and a biomass component) in the polymer backbone will also grow. BASF a producer of EcoFlex™, a biodegradable polyester, and Ecovio™, a blend of PLA and EcoFlex™, expects the market for bioplastics to grow at 20% annually for the next 5 years. DuPont has developed a family of non-biodegradable polyesters based on 1,3 propane diol derived from corn syrup.

Cellulosic Plastic – This product category has a long history of use in the plastics market. The products include cellulose esters, cellophane and rayon. They are derived mostly from wood pulp which is reacted with caustic followed by a variety of petrochemical monomers to produce the final products.

Since cellophane is biodegradable, demand for it is again growing in the packaging film market.

Consumer and Institutional Products –Market Demand by End Use

TABLE C

MARKET DEMAND FOR BIO-BASED PLASTICS

	2005[2]	2007[3]	2011[3]	'07-'11 CAGR[3]
Films /Bags	117	200	359	15.8
Ring Carriers[1]	40	42	51	4
Loose fill/Foam	16	17	20	4
Food service	7	17	31	16
Molded	28	46	123	28
Fiber	5	11	50	46
Total	213	333	634	17.5

1) Currently ring carriers are made from a photodegradable polyethylene, it is assumed that this product will switch to a bioplastic that is degradable by 2011.
2) Freedonia Group, Degradable Plastics Demand to 2010
3) Omni Tech estimates, based on industry communications

Demand for bioplastics is accelerating as more supply of all bioplastic types come into production. This will be especially true in the molded products and film/bags markets.

Plastic ring carriers are used for soft drink bottles, cans and for a variety of individual serving containers sold as one unit. We assume that the penetration of ring carries is at saturation and may in fact be losing market share to other unit packaging designs so that growth will be modest until a biodegradable bioplastic is available at a competitive price to the photodegradable polyethylene currently used.

Molded products will show the fastest growth driven by the use of PLA blends, the PHA products and the starch plastic blends with polyolefins.

According to reports in the trade press, PLA fibers are also experiencing rapid growth in clothing and there is even a small amount of soy protein based fiber being imported from China also for use in high end clothing.

Packaging

In spite of this growth, the penetration of biodegradable polymers in packaging applications will still be less than 1% due to the increased production of packaging resins from the relatively low cost Middle East hydrocarbon raw materials (oil and natural gas). According to Innovia Film's marketing manager, a major issue facing the introduction of bio-based films in place of petrochemical based films is their current cost. Additionally, he points out that one of the packaging industries greatest hurdles for adoption of compostable materials is the lack of curb-side collection and municipal compositing facilities (a sentiment echoed by Business Development Director of Heritage Bag, a major producer of biodegradable trash bags).

However, in spite of the hurdles of cost and lack of composting facilities, the growth experienced by the biodegradable packaging suppliers has been very high.

Within packaging applications the following food packaging areas are receiving considerable attention:

- Fresh-food packaging
- Dried snacks and candy
- Bakery goods
- Water and juice bottles
- Meat trays
- Coatings for beverage cups
- Films and card stock

A recent study from Pira Ltd. estimates that in 2006 biodegradable packaging of fresh food was the largest end-use food packaging category at 39.6 million lbs. in the US. The U.S. is the largest single market for biodegradable packaging, where the growth will continue and is estimated to reach 96.9 million lbs. in 2011.

Large potential new applications for bioplastics and especially degradable bio plastics include diaper backing, adult incontinence products and landfill covers.

Another bioplastic film application that is showing considerable growth, despite a cost premium, is the biodegradable plastic bags applications for yard and garden waste and industrial refuse. One supplier of the industrial biodegradable plastic bags told us that their production volumes had been doubling each year for the last 3 years, and was set to double again in 2008. The total bag market, which includes:

- Yard & Garden
- Industrial Refuse
- Kitchen and other

is estimated by Omni Tech to be 150 million lbs. in 2007. It is estimated to be growing at rate of 15% per year through 2011 to 262 million lbs.

Drivers for increased bioplastic degradable bags will depend on an increase in municipal composting facilities and consumer education, and a decrease in cost versus kraft paper and conventional petroleum based plastic bags. Degradable bioplastic bags eliminate the need to separate bags from their contents at compost sites. Most of the biodegradable plastic bags are made from starch blended with polylactic acid (PLA) or a biodegradable polyester.

Protective packaging is also making use of starch based bioplastics that are biodegradable. The products are formed as foam sheets or loose-fill “peanuts”. The major uses are for general impact protection of valuable items such as electronic equipment components, glass items and generally fragile consumer products. Because of their ability to dissipate static charge, they are especially useful in packaging microchips and electronic product susceptible to damage from static electricity. The bioplastics are made mostly from modified starch. Since they will degrade in water as well as compost sites, and are cost competitive with expanded polyethylene foams, the demand for them in growing. The biggest disposal negative comes from the fact that they are considered a contaminate in the petroleum based plastic recycle streams and thus, if not disposed of by composting or dissolution in water will end up in a standard land fill. Waste disposal of loose fill has become an issue for Wal-mart and its supplier base according to one starch packaging company that attended a recent meeting at Wal-mart headquarters. The goal is to eliminate all loose fill including starch based peanuts in favor of “green” protective packaging and space fillers.

Because of the largest retailer in the U.S. is urging its supplier base to drop loose fill we see the demand for these products to be growing at rates of 4-5% annually driven in large part by purchases over the internet and overseas legislation requiring packaging to be compostable or biodegradable. Offsetting these drivers are competition from starch based board stock or planks and inflatable bags.

Food Service

This market segment describes those product used to serve food in a fast-food or causal dinning setting. It includes cutlery, plates, dishes, cups and bowls. Also included are paper products that have a water roof coating made from a renewable plastic such as PLA.

> *At EXPO 2005 Aichi, Japan more than 10 million eating utensils were used at the food and beverage facilities in the food courts at the EXPO site. This represented the first time biodegradable plastics have been used for such a large number of eating utensils at a single event. The disposable utensils were collected by waste disposal companies which composted the waste and utensils.*

Industry contacts by Omni Tech indicated that food service consumed about 17 million pounds. This end use is expected to have U.S. growth rate of 16% CAGR through 2011. At that growth rate, the volume of bioplastics consumed in 2011 would be approximately 31 million lbs. The products used in this application include blends of starch and polylactic acid (PLA), baggase from sugarcane and PLA, polyhydroxyalkonates, and PLA alone. As an example, a Hong Kong company named Roots Biopac, has introduced trays made from sugarcane fibers.

Fibers

Fibers made from the new bioplastics are gaining strength, mostly because they are based on renewable biomass. NatureWorks, the major PLA manufacturer in the U.S., has introduced their fiber grade product call Ingeo® which is being used in clothing. Mazda has introduced a biofabric made of 100% PLA for use in automotive interiors. DuPont’s Bio- PDO™, 1,3 propane diol from corn syrup, is being incorporated into the polymer backbone of a polyester resin named Sorona®, which is being promoted by

DuPont into textile and carpet fiber applications. Even though it is only partially a biobased plastic, it is being accepted as a bioplastic by end users looking for a “green” product. This is another example of the biobased but not biodegradable type of bioplastic that will be reaching the market in large quantities in the future; thus, we see a fast growth rate (46% CAGR) for this category over the immediate future as production of these biopolymers increases.

Molded Products: Construction, Other

This category includes most of the products that would be produced by injection molding, or net shape extrusion. This category is expected to experience very fast growth according to several bioplastic market studies, due to the following:

- General consumer demand for items made from “green” plastics
- Higher end use value because of a longer useful life, even if ultimate disposal by the end user is within 3 years.
- The products made via injection molding or net shape extrusion can be designed to perform a function that will involve physical stress or strain forces during their useful life.

This market segment also lends itself to the use of non-degradable bioplastics which may contain additional components such as inorganic fillers or petroleum based thermoplastic to impart higher performance properties, e.g. higher heat distortion, impact strength or modulus, to meet more demanding applications.

Horticulture / Construction applications in which the product is molded or shaped under pressure and at elevated temperature in the same manner and is intended for temporary use might include:

- Erosion control timbers or stakes
- Concrete forms imbedded in the ground
- Simulated decorative wood products for indoor use
- Cork board
- Sub-flooring and finished parquet flooring tiles
- Disposable trash containers
- Particle board
- Horticultural containers for “square foot gardening”
- Animal feed containers
- Large molded pails

TABLE D

PRICING of Selected Thermoplastic and Bioplastic Polymers

April, 2008

Polymer Type	Price[1] (Cents/lb.)	Comments (>20 million lbs)
Polyethylene	86-104	HD – LD grades volumes.
Polypropylene	92-98	Homopolymer
Polystyrene	85-95	General purpose
Polyester	80-85	PET bottle grade
Polylactic acid	95-110	Very volume dependent
Starch foam	65-75	

[1] various industry sources and trade publications

The pricing of starch based plastic foams and polylactic acid are competitive with estimated pricing of various polyolefin products. Polyhydroxyalkonates are being quoted at $2.50/pound or higher, which would place them in the engineering plastics category with polycarbonate and other high performance plastics. Blends of starch with modified polypropylene have been reported to be cost competitive to polypropylene homopolymer.

CONCLUSIONS and RECOMMENDATIONS

- The bioplastics markets, both bioplastic biodegradable and bioplastic non-biodegradable, are the fastest growing product type categories of plastics globally with an expected demand in 2012 of over a billion pounds.

- Consumption of bioplastics, including biodegradable and non-biodegradable thermoplastics made from biomass, will grow at about a 19% per rate through 2011 reaching a projected consumption in the U.S. of over 600 million pounds.

- Currently, of the product types, the biodegradable segment of bioplastics is the largest segment but is projected to be displaced by the non-biodegradable bioplastics group of products, which may or may not be 100% derived from biomass.

- Starch based polymers will continue to be a large bioplastic product used by itself in a modified form or blended with another polymer such as PLA for biodegradability or with a polyolefin, such as polypropylene. Omni Tech estimates that the growth in demand for starch based plastics will be about 19% per year through 2011 reaching 180 million lbs.

- Polylactic Acid polymer (PLA) demand is growing rapidly in both packaging and fiber applications and will be the largest bioplastic product produced in the U.S. by 2011 at over 300 million pounds. Due to blending with other materials such as starch and polyesters, PLA consumption will be higher.

- Among the bioplastic applications, four have standout growth opportunities, based on interviews with Industry participants:

  - Biodegradable bags/films,
  - Biodegradable plastic foam cushioning blocks,
  - Bioplastic fibers, degradable and non-degradable
  - Bioplastic molded products, degradable and non-degradable

- Several large retailers such as Wal-Mart and Target are actively requesting that their product suppliers use as much biobased packaging as possible while still protecting the products during shipping.

- Biodegradable bioplastics demand, while growing at double digits, is also hampered in the U.S. by several challenges:

  - Small number of commercial composting facilities,
  - Higher cost of the bioproducts versus petroleum based plastics,
  - Contamination of plastics recycling streams,
  - Concern over diversion of grain crops to industrial uses and fuel,
  - Biomass raw materials harvested from genetically modified organism (GMO) crops.

- Past research and development work to develop a bioplastic using soy protein as a component has not as yet been commercially successful, but new driving forces and biopolymer technology have improved the opportunities for soy protein containing bioplastic to be developed.

RECOMMENDATIONS

- Significant development work is now underway, supported by USB New Uses Committee, at several universities with soy protein products (meal, flour, concentrate, and isolate) in combination with PLA and other biodegradable plastics. Support of these efforts should be continued.

- Additional projects using soy protein products combined with non-biodegradable biomass plastics and petroleum based plastics and targeted at specific large volume applications in fibers, molded products and films should be supported.

- Projects that focus on the processing/conversion of soy protein products (meal, flour, concentrate) into water soluble film formers are also needed.

APPENDIX

COMMERCIAL – RENEWABLE/BIO-DEGRADABLE THERMOPLASTIC PRODUCTS

The following tables describe the currently known degradable and non- degradable commercial bio-thermoplastic polymers. Not all are based on 100% renewable biomass.

CHART A

POLYMERS FROM RENEWABLE RESOURCES

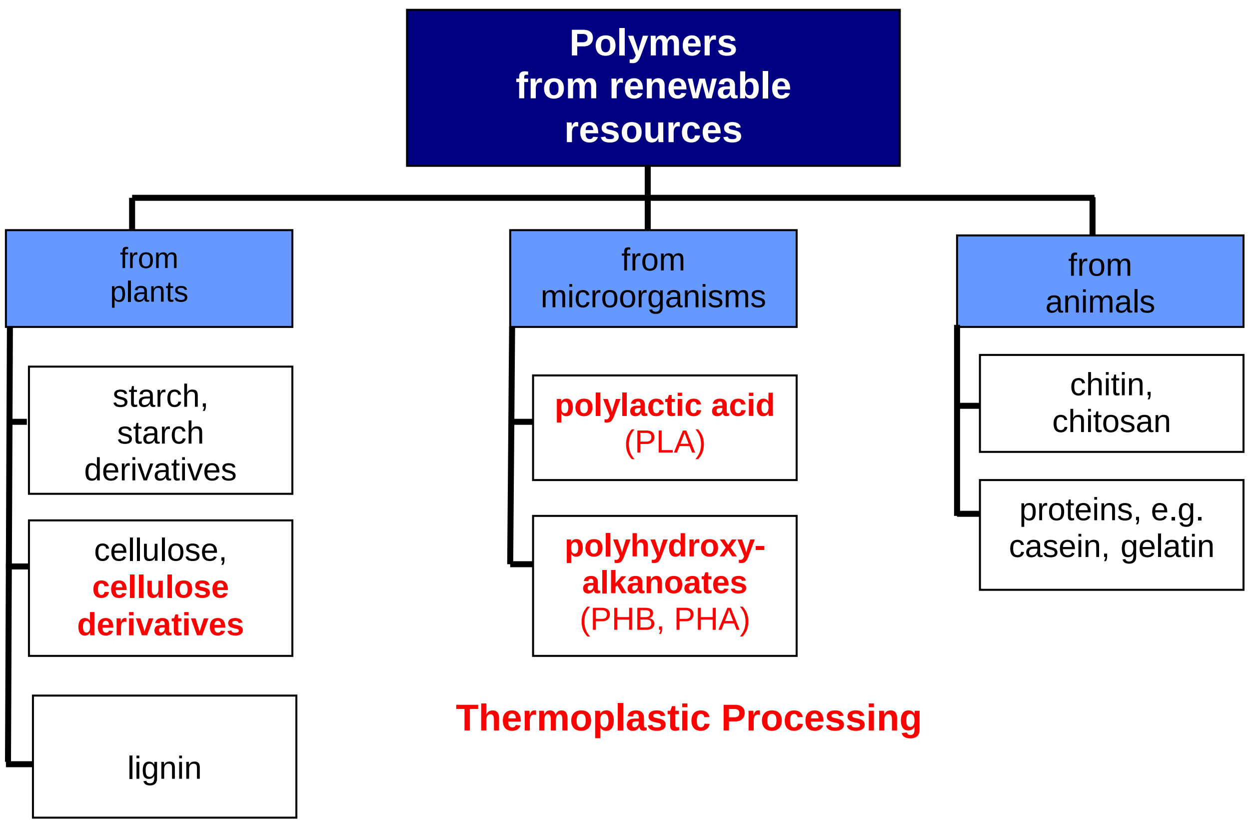

CHART B

BIO-BASED FEEDSTOCKS

BIO-BASED FEEDSTOCKS
Annually Renewable Bio FeedStocks

Cellulosics & Lignocellulosics

Products:
- Cellulose (Cellophane)
- Cellulose Derivatives (CA, CAB)
- Engineered Wood Products

Starches

Examples:
- Corn
- Potato
- Sugar cane

Products:
- Thermoplastic Starch
- Starch Foams
- Starch Graft Copolymers & Reactive

Other Polysaccharides

Examples:
- Pectin
- Chitin
- Levan
- Pullulan

Fats & Oils

Examples:
- Soybean
- Lesquerella
- Rapeseed

Products:
- Biodiesel
- Lubricants
- Polyols – Urethanes
- Plasticizers/Process Aids
- Solvents
- Unsaturated Polyester Resins

Proteins

Examples:
- Zein
- Soy Protein

Biodegradable Thermoplastics

The plastics listed in table D are commercially available to converters/fabricators of plastic products

TABLE E

BIODEGRADABLE / RENEWABLE PLASTICS

Resin Producers	Trade Name	Polymer Family	Biodegrade
Arkema	Rilsan nylon 11		na
BASF	EcoFlex	co-polyester polybutylene succinate/ terephthalate	
Cereplast	Hybrid Resins	modified Starch+ PLA, starch-modified polyolefins	yes
DaniMer Scientific	Seluma	polyester	
DuPont	BIOMAX,(35%) /SORONA EP Cerenol polyol Selar VP (40%) Hytrel RS (25-50%)	polyesters (polytrimethylene terephthalate)/1,3 propanediol(PDO)	
Innovia Films	NatureFlex ™	cellophane	yes
Mitsubishi Chemical	GS Pla®	polybutylene succinate (PBS)	na
National Starch	ECO-Foam	starch	yes
NatureWorks(Cargill)	NatureWorks® PLA / Ingeo	polylactic acid	yes
Novamont	MATER-BI, Eastar Bio Ultra	starch polymer, copolyester	yes
Meredian	Nodax H	poly(3-hydroxybutrate-co-3-hydroxyhexanoate (PHBH))	films, bottles, rigid packaging
Soy Works Corp	SoyPlus™	soy protein	licenses other producers
Telles (ADM-Metabolix jv)	Mirel™	polyhydroxyalkonate (PHA)	yes

STARCH POLYMERS (modified polysaccharides)

These polymers have been under development for some time by Novamont. They have licensed National Starch to be the supplier of resins and technology in North America. The product family is composed of polysaccharides from different sources with various modifications applied. Thus, Novamont offers a variety of products with a range of physical properties. The polymers are processable via injection molding, extrusion and thermoforming and are foamable with water.

Applications for injection molded Mater-Bi™ include cutlery, pencil sharpeners, rulers, cartridges, toys, plant pots and toys for pets, using a starch-based material obtained from cellulose. Combs made of Mater-Bi™ have the additional advantage of being anti-static, eliminating accumulation of electrical charge on conventional combs.

Mater-Bi™ loose fillers are predominantly made of starch, and are expanded using water. It is recommended for packaging pharmaceutical products, laboratory equipment, consumer goods and mail order goods.

They are purported to be completely biodegradable and water-soluble, resilient and anti-static, and have excellent shock-absorbing, elastic properties.

Wave by Mater-Bi™ is starch-based, and is expanded using water, extruded into sheets and then assembled into blocks that can be cut into any shape. Wave by Mater-Bi™ has a robust and resilient closed-cell structure; sheets and blocks are available in different sizes, with densities from 30 to 400 kg/m3.

TABLE F

NOVAMONT'S STARCH POLYMERS

TEST	METHOD	UNIT OF MEASURE	MATER-BI™	PP	PS
MATER-BI™ for INJECTION MOLDING					
MFI	ASTM 1238	g/10 min	6-30	0.9-9	19-24
Breaking load (tensile strength at break)	ASTM D638	MPa	15-35	25-37	31-40
Breaking extension (% elongation at break)	ASTM D638	%	20-150	40-400	1.2-1.6
Young's modulus (modulus of elasticity)	ASTM D638	MPa	600-5000	1000-1600	2900-3200
Linear shrinkage	ASTM D955	%	0.08-1		0.1-0.6
MATER-BI for Extrusion					
MFI	ASTM D1238	g/10 min	8-10		
Breaking load	ASTM D822	MPa	18		
Breaking extension	ASTM D822	%	130		
Young's modulus	ASTM D638	MPa	1400		
MATER-BI for Films				**LDPE**	
MFI	ASTM D1238	g/10 min	2-4	0,1-6	
Breaking load	ASTM D882	MPa	20-50	20-30	
Breaking extension	ASTM D882	%	200-600	150-600	
Young's modulus	ASTM D638	MPa	100-600	150-300	
Start of Tearing	ASTM D1938	N/mm	20-120	70	
- Propagation		N/mm	20-120	70	
Water Vapor Permeability	ASTM E96	gr 30mm/m2 24H	250-1000	15	

POLYLACTIC ACID (PLA)

This polymer based on corn is currently produced in the North America by NatureWorks a joint venture company co-owned by Cargill Inc. and Teijin Ltd. of Japan. The product property profile is similar to polystyrene and polyethylene terephthalate.

TABLE G

POLYLACTIC ACID (PLS)

PROPERTIES	NatureWorks® PLA	Polystyrene General Purpose	Polyethylene terephthalate
Physical properties			
Melt flow rate (g/10 min)			
Density (g/cm^3)	1.24	1.04	1.3-1.4
Haze	2.2		
Amorphous grades	transparent	transparent	
Yellowness index	20-60		
Water absorption			0.16
Mechanical properties			
Tensile strength at yield (MPa)	53	36-52	55-75
Elongation at yield (%)	10-100	1.0-2.2	50-15-
Flexural Modulus (MPa)	350-450	3,150-3,240	
Young's Modulus (MPa)		2800-3100	
Notch Izod (KJ/M^2)			
Thermal Properties			
HDT (˚C)	44-55, 135 (crystalline)	87-97˚C	
Melt Temperature T_m	140-152 ˚C		260 ˚C
Glass Transition Temperature T_g	56.7-57.9 ˚C		75 ˚C
Heat Transfer Coefficient (W/m˚K)			0.24

In addition to being biodegradable, PLA has other properties such as high optical clarity, good mechanical properties, gas and water barrier properties.

Technical hurdles for PLA include a low glass transition temperature of 60 C which might be improved if PLA were composed of both D- and L- lactic acid. This compositional change would probably increase the heat resistance as high as 175 C. Additionally, PLA needs better impact strength, and improved gas barrier properties. Currently, PLA is in short supply, It is estimated by PURAC Biochem that with improvements in PLA supply and quality that the market can grow to over several hundred thousand tons in 10 years.

POLYHYDROXY ALKANOATES

Polyhydroxy alkanoates is the generic term for a family of polyester polymers. Specific members include: poly 3-hydroxybutyrate –co-4- hydroxybutyrate, polydroxy butyrate- co-3- hydroxyvalerate. Metabolix is the major developer of technology for producing polyhydroxyalkonates from bacteria and corn sugar. They have formed a JV with Archer Daniels Midland to produce the biodegradable plastics called Mirel™. Together they are building a production plant in Iowa that will be on stream in late 2008.

Metabolix's Mirel family of plastics range in properties from rigid to tough and highly elastomeric to soft and tacky. They can be made as resins or aqueous dispersions with excellent film forming characteristics. Robust in use yet biodegradable, they offer a renewable and environmentally friendly alternative in many applications now served by synthetic plastics, including fiber, film, molded goods, extruded products, adhesives and coatings.

Applications to date include holiday gift cards sold by Target. According to Metabolix, potential applications include single – use (disposable) items such as coffee cups, dinnerware, containers for cosmetics, food and detergent. Agricultural applications include degradable plant pots, stakes, erosion control netting and mulch film. The companies are expecting to charge a premium for the plastic. Receiving a premium for low value items such as disposable dinnerware or horticultural applications would be very unusual except in those political geographies that are banning non-degradable plastic items.

POLYESTERS

TABLE H

ECOFLEX® – BIODEGRADABLE PLASTIC WITH HIGH FUNCTIONALITY vs LDPE

Typical properties of Ecoflex® F and LDPE

PROPERTY	UNIT	TEST METHOD	ECOFLEX® F	LDPE
Density	g/cm^3	ISO 1183	1.25-1.27	0.922-0.925
Melt viscosity MVR 190 °C, 2.16 kg	ml/10min	ISO 1183	- 2.5-4.5	- 0.8-1.2
Melt point	°C	DSC	110-120	111
Shore D hardness	-	ISO 868	32	48
Vicat VST A/50	°C	ISO 806	80	96

Typical film properties of Ecoflex® F and LDPE at 50 um thickness

PROPERTY	UNIT	TEST METHOD	ECOFLEX® F	LDPE
Transparency	%	ASTM D 1003	82	89
Tensile strength Tensile stress at break Tensile strain at break	N/mm^2 N/mm^2 %	ISO 527 ISO 527 ISO 527	35/44 36/45 560/710	26/20 - 300/600
Fracture energy (Dynatest)	J/mm	DIN 53373	24	5.5
Transmission rates: Oxygen Water vapor	$ml/(m^2d\ bar)$ $g/(m^2d)$	DIN 53380 DIN 53122	1400 170	2900 1.7

Water-vapor transmission (WVT) of Ecoflex® F

	Film thickness um	WVT g/m^2 d 23 °C, 85% r.h 100 um	Tensile strain at break in extrusion direction N/mm^2
Ecoflex® F Ecoflex® F + wax	20 15	85 35	41 39
Ecoflex® F + talc Ecoflex® F + talc, 1:4	32 12	83 48	25 70

The Ecoflex® polyester family was developed as a petrochemical biodegradable plastic. Recently, BASF has modified Ecoflex® so that it could be blended with up to 50% polylactic acid polymers and thus claim a biodegradable plastic having a high biobased content. The new polymer family name is Ecovio®.

The concept of blending of a petrochemical polymer with a biobased polymer to improve properties of the biobased component of the new blended plastic is becoming more common. Other examples of this product trend are the polymer families Sorona® Polymer and Cerenol™ Polymers promoted by DuPont that contain 20-37% biobased component, Bio-PDO™ (1,3 propane diol).

Polyamides
Arkema is planning to launch a complete range of engineering thermoplastic elastomers trade named Pebax® RNew containing from 20-90% renewable content, primarily castor oil.

Cellulose Polymers

Cellulosic polymers are produced by chemical modification of natural cellulose. The main representatives are cellophane, cellulose acetate and regenerated cellulose for fibers, e.g. Viscose rayon. Both cellulose and starch have glucose as their basic monomer unit but the polymers differ in the linkage between the glucose units and in the configuration of their polymer chains. Cellulose's configuration provides an opportunity to form stronger hydrogen bonds as well as a close interaction with other polymeric structures such as lignin, pectin, hemicelluloses and proteins. Because of this mixed polymer morphology, cellulose is more resistant to hydrolysis than is starch.

NatureFlex™ Cellophane

NatureFlex™ films are based on renewable resources (wood-pulp from managed plantations) and use novel heat-seal resins on each side. The films are static free and offer a super wide heat-seal range for outstanding machine performance. The films offer good gas barrier properties and the coatings can be tailored to provide varying degrees of moisture barrier, depending on the needs of the wrapped product.

Soy Protein Thermoplastics

Although no bioplastics currently contain soy protein, several projects supported by the United Soybean Board have as their objective the development of a soy protein containing bioplastic or water soluble polymer. The projects are:

TABLE I

CURRENT USB SOY PROTEIN PROJECTS

USB Project Number	Organization	Description
7426	Univ. of Wisconsin - Madison	Development of Soy Protein blended with modified starch to form a biodegradable plastic
8425	Ford Motor Research	Soy Meal as reactive filler in elastomeric matrices
8476	Washington State University	Development of Soy Protein biodegradable Plastics
8437	Battelle Memorial Inst.	Soy protein polymer as "super absorbent" water soluble polymer
8457	New Jersey Institute of Technology	Soy Protein fiber development
8459	Washington State University	Soy Protein fiber spinning

PART 2
AGRICULTURAL FILMS

STEPHEN G. WILDES

AG FILMS MARKET SUMMARY

Since the last update of this market study in 2001, world use of agricultural films, especially mulch films, has grown significantly. Mulch films will be the focus of this study since biodegradable mulch films appears to present the greatest market opportunity for soybean chemistry.

The world mulch film market has grown but not in the U.S. Mulch film use will continue to grow with increasing demand for more row crop production on limited arable land. U.S. acreage mulched has remained stable but film volume demand has declined due to continued film downgauging and the practice of double cropping. U.S. mulch films are primarily blends of linear low and low density polyethylene (LL/LDPE) and high density polyethylene (HDPE).

Photodegradable film use is gone and no commercially proven biodegradable mulch films are yet available in the U.S. The unmet market demand for these films is, however, strong because mulch film disposal costs are escalating and the problem remains unresolved. Two new biodegradable mulch films have been developed using renewable feedstocks that are in the early stages of market introduction.

Soybean chemistry, probably in the form of soy protein, in biodegradable mulch films is technically feasible. However, no current research work utilizing soy is known. An observation from the 2000 study is still valid – “Such an undertaking would need to be a global effort since the U.S. mulch film market is only 5% of the global area mulched.”

MULCH FILM MARKET – WHAT'S CHANGED SINCE 2000

OVERVIEW

1. World Market – Major growth
2. U.S. Market – Declined but is now static
    - Film downgauging
    - Escalating costs of row crop farming
    - U.S. row crop production lost to Mexico and Latin America
3. Number of U.S. mulch film manufacturers down. Increasing imports.
4. Mulch film product mix:

	2000	**2007**
LDPE	40%	0%
LL/LDPE Blends	10%	60%
HDPE	50%	40%

5. Film disposal – Still an unresolved issue – Recovery cost escalation, reduce landfill availability, very little recycling
6. Biodegradable mulch films
    - Market need higher than ever
    - None commercially available in U.S.
    - Two new films being introduced
        - Novamont, Novara, Italy – Mater Bi™ based on polymerized corn starch
        - Telles (ADM/Metabolix JV), Lowell, MA – Mirel™ based on corn fructose

AGRICULTURAL FILM MARKET - SITUATION ANALYSIS

World demand for agricultural films has grown considerably because of an essential need to improve crop yields on limited arable land that is suitable for cultivation. Additional pressures are challenging the agriculture industry:

- Scarce irrigation water
- Trade subsidy threats
- Demand for ag product sustainability

Plastic films are making a significant contribution to increase crop output in the form of mulch film, greenhouse covers and silage bags with total world demand reaching 7.8 billion pounds in 2007. Demand growth has been especially strong in China, Eastern Europe and Latin America. China represents 60% of world ag film demand.

MULCH FILM MARKET

World mulch film demand has grown strongly from 1.2 billion pounds to 3.2 billion pounds annually with the countries mentioned above leading the way.

U.S. mulch film demand, meanwhile, has decreased in film volume usage from the 90 million pounds reported in 1999 to 60 million pounds in 2007. The acreage mulched has been about the same while film use declined due to the downgauging of mulch film thickness. This was accomplished by the growing use of blends of low and linear low density polyethylene film resins. These films now occupy 60 to 70% of the U.S. mulch film market.

U.S. row crop farmers in large mulching states such as Florida, California and Georgia are experiencing increasing farming costs from higher film, pesticide and fertilizer prices that raises the difficulty of competing with other countries especially Mexico and Central America.

AGRICULTURAL FILMS - WORLD DEMAND 2007

GLOBAL AGRICULTURAL CHALLENGES

- Food security
  - Populations are growing and individual calorie intake rising
    - Arable farm land in cultivation is static
    - Improved yields are essential
      - In 1950 one hectare fed 2 people
      - In 1995 one hectare fed 4 people
      - In 2025 one hectare will feed 5 people
- Water scarcity
- Move to reduce trade subsidies

PLASTICS AND AGRICULTURE - THE STORY SO FAR…

- Plastics have made a substantial contribution to the increased production in agricultural output in the last 50 years
  - Films
    - Greenhouse
    - Mulch
    - Silage
  - Pipes
  - Containers
- Global plastics demand for agricultural uses in the film area was 7.8 billion pounds in 2007

CHART C

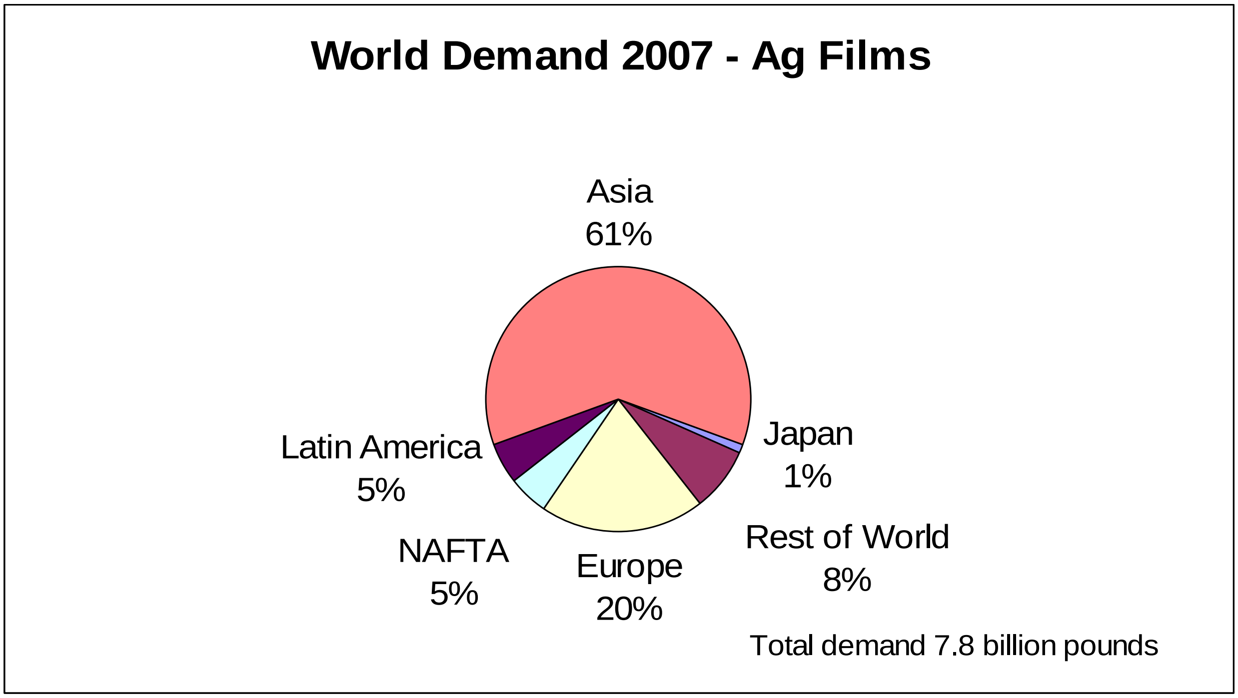

CHART D

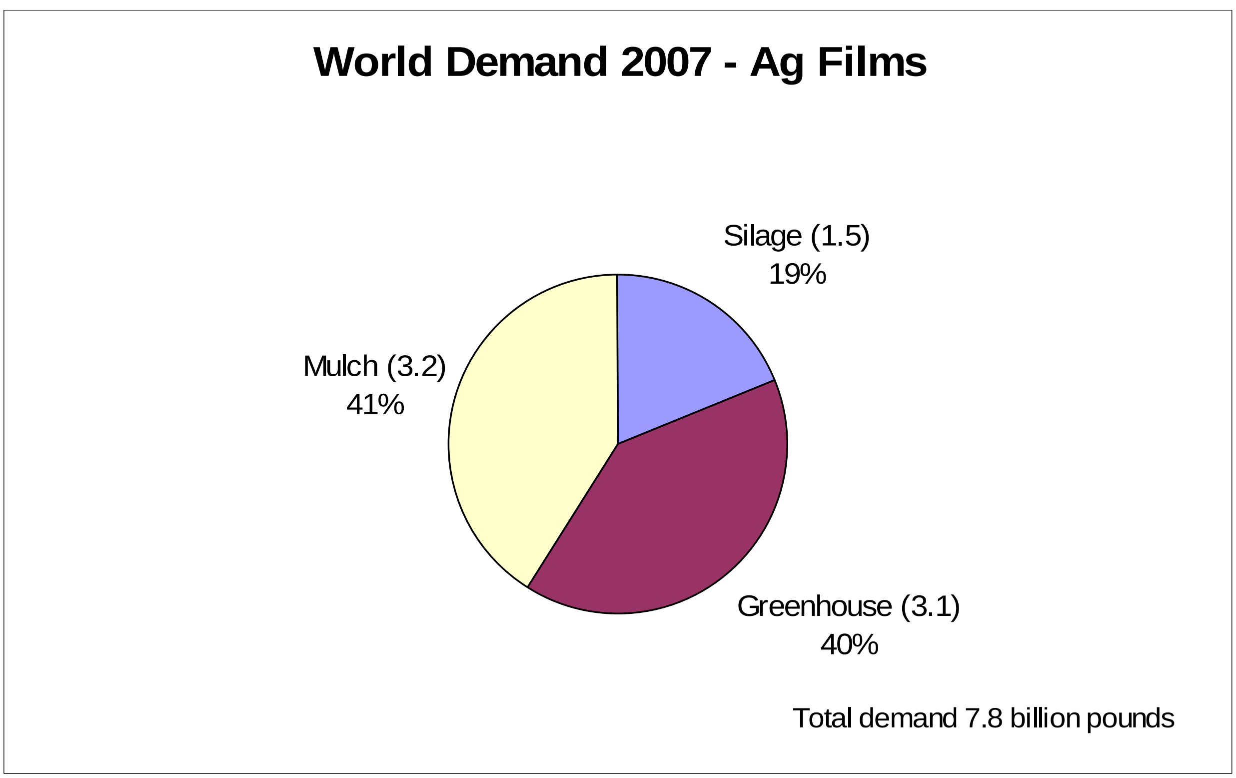

CHART E

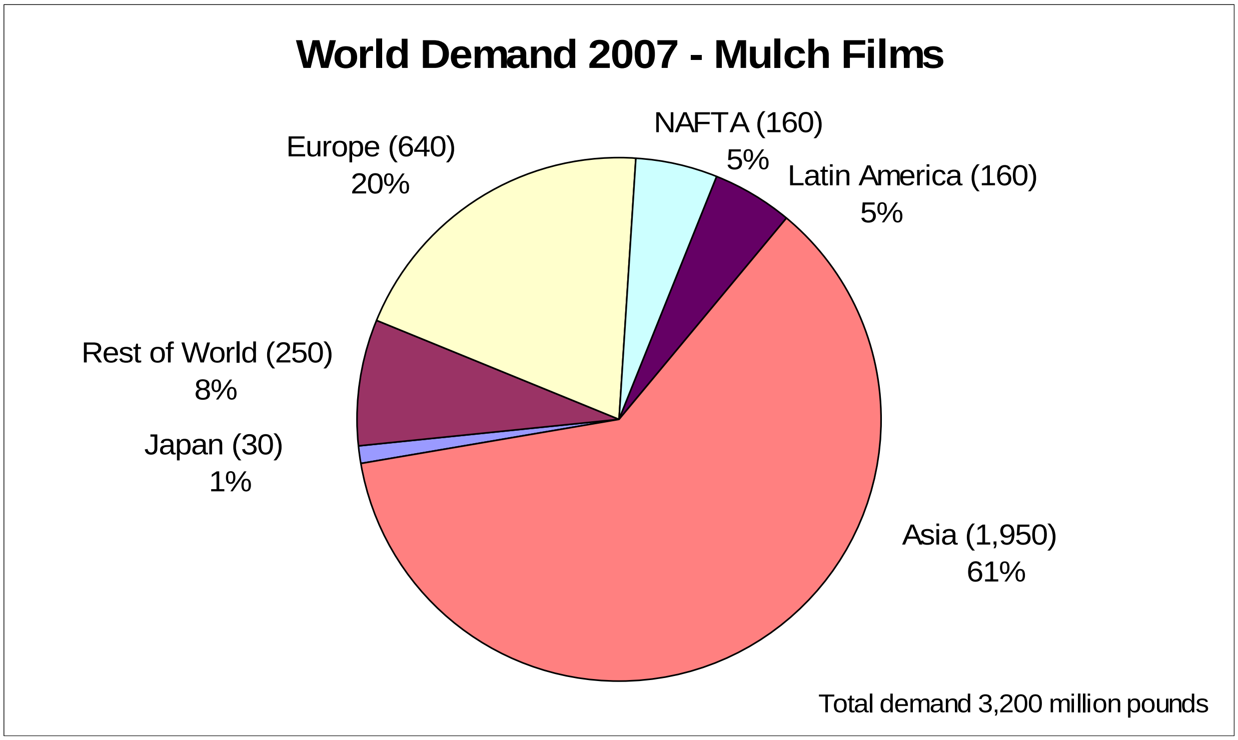

TABLE J

WORLD MULCH FILM MARKET
Million Pounds

AREA	1999		2007	
North America	150		160	
U.S.		90		60
Mexico		60		100
Latin America	90		160	
Europe	410		640	
Spain				70
Italy				60
Germany				50
France				50
Others				100
E. Europe				310
China	850		1,950	
Rest of World	200		290	
TOTALS	1,220		3,200	

MULCH FILM PRODUCTS (U.S.)

Mulch film use in the U.S. since year 2000 has changed markedly. At that time, LDPE film was dominant, LL/LDPE blends were coming in to the market but downgauged HDPE film was growing fastest. In 2007, the market dynamics have changed radically. LDPE film is no longer used, HDPE film use is about 40% of the market and LL/LDPE blends are dominant at 60% of the market and growing.

Specialty films – embossed, barrier, metalized and coextruded films are widely used while photodegradable films have disappeared. There are still no commercially available biodegradable mulch films although interest and demand potential is high because of escalating film disposal costs.

Fumigation films are blown rather than extruded resin blends that are heavier gauge -1.25 mils - and wider - 13 feet vs. 5.3 feet - mulch films. There is no need for in-situ biodegradability since the primary function is as a barrier film with a short 1-4 day use life. Fumigation appears to offer little opportunity for soy protein-based biodegradable films.

COMMERCIAL MULCH FILMS

- LD/LLDPE Blends:
  Gauge – 0.9 - 1.0 mils
  Width – 64”
  Roll – 4,000 ft, 102 lbs/roll
  Pricing - $1.25 - $1.30/lb, $127/roll
- HDPE:
  Gauge – 0.6 - 0.7 mils
  Width – 64”
  Roll – 7,000 ft, 107 lbs/roll
  Pricing - $1.50 - $1.70/lb, $180/roll
- Specialty Films:
  Embossed, barrier, metalized and coextruded versions of above films at premium prices. Film colors – black, white, clear, silver, red, blue, green, yellow

Typical Film use:

> 1 roll/acre, 200 lbs. of film/acre
> LL/LDPE Blends – 240 lbs/acre
> HDPE – 170 lbs/acre

Mulch film costs per acre have increased from $80/acre to $170/acre since 2000.

U.S. MULCH FILMS

TABLE K

PRODUCT	GAUGE (mils)		PRICE/LB		MARKET SHARE	
	2000	2007	2000	2007	2000	2007
LL/LDPE Blends	1.0	0.9-1.0	$0.75	$1.25-1.30	10%	60%
HDPE	0.7	0.6-0.7	$1.00	$1.50-1.80	50%	40%
LDPE	1.25		$0.55		40%	0%
Barrier – LLDPE/HDPE				$1.60-2.10		
Metalized – LLDPE/HDPE				$1.60-2.85		
Embossed – LLDPE/HDPE				$1.25-1.80		

The use of LD/LLDPE blend mulch film is growing and becoming dominant. The use of LLDPE imparts additional stretch and strength to the film. HDPE film is stronger than LDPE and can be downgauged further but it does not stretch. Mulch film is typically stretched when applied in the field. Too weak a film will tear under the tension necessary for its application.

MULCH FILM MANUFACTURERS (U.S.)

TABLE L

2000

LDPE
LD/LLDPE BLENDS

Clarke Ag Plastics – Greenwood, VA
First Film Extruding – Des Plaines, IL
Green-Tek Inc. – Edgerton, WI
Holland Transplanter – Holland, MI
Huntsman Packaging – Newport News, VA
Ken-Bar Inc. – Reading, MA
Sunoco Products Co. – Hartsville, SC
Treessentials Co. – Mendota Heights, MN
Tyco Plastics – City of Industry, CA

HDPE

Sunoco Products - Hartsville, SC

2007

LD/LLDPE BLENDS

Pliant Corp. – Chicago, IL
Olefinas – Guatemala
Ginegar – Israel
TRM – Los Angeles, CA
EPA – Mexico
Climagro – Montreal, Canada

HDPE

Hilex Poly Co. – Hartsville, SC
(purchased Sunoco products)

MULCH FILM PERFORMANCE REQUIREMENTS

Physical property performance for any new film must meet the requirements described below and be thoroughly proven in field testing. Biodegradable and photodegradable films have been introduced over the years and been unsuccessful making the farmer skeptical and wary of new product claims.

- Gauge thickness – 1.25 mils or less
- High elasticity to allow field stretching
- Toughness – good tear resistance
- Chemically resistant to pesticides
- Ultra-violet (UV) stable to last the growing season
- Film fabrication capability
    - On existing high speed casting or extrusion equipment
    - Coextrusion, embossing, metalizing
    - Colors - black, white, clear, silver, red, blue, green, yellow
- Biodegradability - Predictable biodegradation rates of 90 days and 180 days. Two defined rates for different row crops.
- Cost – A significant film cost premium of 50% or more is feasible if film removal and disposal can be eliminated
- New film quality standards – “The NF Mark”

This is a new European voluntary industrial quality standard that includes plastic films for agricultural use. It covers product specifications for mulching and silage films and includes ISO 9002 standards.

ECONOMICS

The cost of row crop farming has increased significantly since 2000. Price escalation of ag films, pesticides and fertilizers has occurred due to petrochemical feedstock price inflation – crude oil and natural gas. Prices of mulch films have risen 70% since 2000. Typical mulching costs have increased from $130 per acre to $200 per acre since 2000.

Mulch film disposal costs for field collection (labor), trucking and disposal (landfill tipping fees) have, concurrently, increased from $50 to $100 per acre on an average depending on location.

Film disposal remains an unresolved and costly problem. Landfilling waste film is a declining alternative as landfill space becomes less available. Film recycling has been attempted but it was not cost-effective. In Florida, the largest mulch film user state, film is typically burned in the field. This practice will not be allowed much longer.

The obvious unmet market need is for an effective biodegradable mulch film that will meet standard performance requirements at a price not to exceed film disposal costs. To date, no commercial biodegradable mulch film is available in the U.S. However, two companies have been developing these films and one of them is being marketed in Italy and eastern Canada. These films will be described later in this study in the "State of the Art" section.

MARKET OUTLOOK

The use of plastic mulch films will continue to grow globally, especially in the intensive cultivation of high value row crops such as tomatoes, strawberries and tobacco. External conditions will continue to challenge the farmer and accelerate the use of mulch films.

FARMER CHALLENGES

- Irrigation water scarcity
- Increasing food demand by a growing world population
- Limited arable land
- A shortage of plant nutrients requiring more efficient fertilizers
- Increasing environmental pressure on pesticide use
- Mulch film disposal, a growing and costly problem

Demand for cost-effective biodegradable mulch films would be strong across most world row crop markets. Farmers would probably be willing to pay a significant price premium for biodegradable films to eliminate the film disposal problem. Biodegradable films could reinvigorate the U.S. market and help make the American farmer more competitive.

A successful biodegradable mulch film could also create additional market opportunities beyond fruits, vegetables and tobacco.

- Trash and yard waste bags
- Forestry seedlings
- Cotton

STATE OF THE ART – BIODEGRADABLE MULCH FILMS

Although no commercial biodegradable mulch films are yet available in the U.S., a new Novamont product is being marketed in Italy and has recently been introduced in Canada. A second film has been developed by Metabolix Inc. and will be marketed by Telles of Lowell, Massachusetts, a joint venture of ADM and Metabolix Inc.

Novamont S.p.A., Novara, Italy

Mater - Bi™

- Polymerized corn starch modified with sunflower and rapeseed lipids
- Italian plant – 132 million pound capacity – onstream 2007
- Sales mostly in Italy but introduced in Canada by Dubois Agrinovation, Montreal (BioTeloAgni™)
- Dubois having difficulty getting product approval in the U.S.
- Successfully field tested by Cornell University
- Two grades available for 4 and 6 month biodegradation
- Pricing – 2-2.5 times LL/LDPE blend films – $2.60-$3.00 per pound

Telles, Lowell, MA

Metabolix, Inc. & ADM Joint Venture

Mirel™

- Made from corn fructose and vegetable oils
- Clinton, Iowa resin plant – 110 million pounds start up scheduled for late 2008
- Resin samples from pilot plant available for evaluation by fabricators
- Pricing – Expected to be 2.5 to 3 times LL/LDPE blend films - $3.00 - $3.50 per pound

Polylactic acid (PLA) – Manufactures – Nature Works (Cargill) and Purac.
Ag films have and can be produced but are brittle, do not stretch well and require performance additives that make them cost prohibitive.

Additional research on biodegradable mulch films is active by various chemical firms and universities but most approaches involve modified polyester films that are said to perform marginally.

MARKET OPPORTUNITY

U.S. market is 60 million pounds, 5% of a global market of 3.2 billion pounds. This market has stabilized after declining due to film downgauging and the loss of some crop farming to Mexico. The U.S. market is poised to resume growth with the availability of higher performance mulch films. World market demand, meanwhile, continues to increase significantly. While some countries could not afford premium priced films, Europe definitely could.

BIODEGRADABLE MULCH FILMS

Two new biodegradable mulch films – Novamont's Mater'Bi™ and Telles' Mirel™ have been developed and are in early market introduction. They are based on corn starch and corn fructose respectively as described in the "State of the Art" section of this report. Mention has been made by these companies that each film resins contains "vegetable oils". This will be investigated further to determine if soybean oil and derivatives are and can be utilized.

Development of soy protein-based films will require considerable cost and time. Earlier research at Iowa State University demonstrated that such films are feasible. An invitation for development was presented to the American Society for Plasticulture at their recent Congress on March 9, 2008.

RECOMMENDATIONS

Omni Tech International, Ltd. recommends that the USB New Uses Committee consider funding support for future projects involving the development of soy-based biodegradable agricultural mulch films. USB funding support was not recommended in the 2000 market study update. However, demand for biodegradable mulch films has increased considerably since then and the market will now support premium priced biodegradable films if they perform well and eliminate the need for mulch film collection and disposal. An RFP (Request for Proposal) focused on soy protein-based biodegradable mulch films sent to key universities and mulch film manufacturers could stimulate R&D efforts.