The Effects of Expanding Biodegradable Polymer Production on the Farm Sector

by

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Abstract: *This article develops two sets of estimates of the probable growth of biodegradable polymer output to the year 2000. These estimates are then used to simulate possible impacts on the farm sector. The results suggest that net farm income will increase slightly and total government deficiency payments will decrease slightly. However, farm output will be largely unaffected.*

While increased production of corn-starch based biopolymers may represent a valuable new niche market for corn and other starch crops, such uses by themselves probably will not cause major increases in the market prices of agricultural commodities. Agriculturally based biopolymers will need to be combined with other new uses--such as for ethanol and as a feedstock for basic industrial chemicals--to help support market prices over the long term. The results here do suggest that increased support of biodegradable polymer research, development, and commercialization would decrease government outlays and increase net farm income.

Keywords: New uses, biodegradable polymers, government commodity programs.

The overall economic impact of biodegradable polymer production needs to be evaluated on an integrated scale. Impacts on farmers and farm subsidies, waste and litter management, national employment, plastic consumers, and investment should be considered. Many of these are beyond the scope of this article. However, the article does examine the environmental consequences of increased biodegradable polymer use, and develops estimates of the effects of increased biopolymer production on farmers and farm subsidies.

Estimates vary widely on the potential impacts of starch-based biopolymer production on farmers. For example, the National Corn Growers Association estimates that the use of corn to produce biodegradable polymers could require between 150 million and 300 million bushels of corn per year. According to earlier USDA estimates, this would increase the price of corn by 6 to 18 cents a bushel and decrease farm-program costs by $300 million to $900 million. However, others have estimated that corn-based biopolymer production could actually increase farm program costs [3]. Most others found a small, yet significant decrease in farm subsidies as a result of starch-based biopolymer production [7, 9].

What is Recycling and How Do Biodegradable Polymers Fit In?

Mounting environmental concerns have focused attention on designing materials from "cradle to grave." This requires that recyclability and/or degradability features be incorporated into all materials, while still retaining performance characteristics. Two distinct types of recycling are called for:

- *Materials recycling* requires processing and remanufacture, and is what we typically think of as recycling. However, there are technical limits to how many times materials can be recycled and still exhibit the desired physical properties; and
- *Waste Recycling* includes composting, and is the conversion of solid waste into useful products. This is appropriate when materials recycling is not practical or feasible.

According to many groups and the Environmental Protection Agency (EPA), composting is a means of recycling. It is efficient, cost-effective, and environmentally responsible. Now, 23 States have laws requiring that landscape and yard wastes be composted by 1995.

Biodegradable polymers, along with other organic materials that are to be disposed of in the environment, should be designed to become an integral part of the carbon cycle. Use of biodegradable polymers in place of petroleum-based plastics slows the introduction of fossil-fuel-derived carbon dioxide into the atmosphere. That is because incineration or biological digestion of renewable biomass simply recycles carbon dioxide--leaving it at current levels. Many believe that integrated waste management practices--which include recy-cling, source reduction of packaging materials, off-landfill composting of biodegradable wastes, barring of toxic colorants, and incineration--may bring waste disposal under control [5].

What Does Degradable Mean and What Are Biodegradable Polymers?

The American Society for Testing and Materials is finalizing the technical definition of a degradable plastic. Now, there are basically two types of degradable polymers that have achieved some market success: photodegradables and biodegradables.

Photodegradable plastic resins are made by introducing a sensitizing group which absorbs radiation, generally a vinyl ketone, into the structure of the plastic. The vinyl ketone monomer is stable in photochemically incandescent light but degrades in the natural sunlight of the outdoor environment.

Examples in the marketplace include Ecolyte plastic resins that are made by copolymerizing ketone-containing comonomers with ethylene, styrene, and other commercial plastics. The use of Ecolyte in food packaging is promising because the ketone monomers are nontoxic and they remain a permanent part of the polymer chain. But, during degradation, these types of polymers leave small fragments of petroleum-based plastics which must be disposed of in a landfill or incinerated.

In comparison, biodegradable polymers degrade primarily through the action of microorganisms such as bacteria, fungi, algae, and/or yeasts. Two key steps occur in the biodegradation process:

- Depolymerization or chain cleavage--occurs outside the microorganism due to the size of the polymer chain and the insoluble nature of many of the polymers; and

- Mineralization--occurs once the fragments are sufficiently small, so they can be transported into the cell to be mineralized. At this stage, the cell usually derives metabolic energy from the mineralization process leaving behind carbon dioxide, methane, nitrogen, water, salts, minerals, and biomass.

Therefore, biodegradation relies on microbes and their enzymes to convert organic matter to water, carbon dioxide, cellular material, and mineral salts.

For waste recycling, even small amounts of nonbiodegradable synthetic substances in the starting substrate are unacceptable. These materials should not be used in soil amendments because continuous application of any material that includes an inert substance, like petroleum-based plastics, would slowly build up, and decrease soil fertility and productivity. Because several biodegradable polymers are 100-percent degradable, they are being scrutinized by the Department of Defense (DOD) so that its packaging can be properly disposed of at sea.

Composting Is Needed For 100-Percent Degradable Polymers

No material, including 100-percent degradable polymers, will appreciably degrade in modern landfills. As a result, replacing petroleum-based plastics with biodegradable polymers will probably not reduce perceptibly the volume of trash in the municipal solid waste stream. So, from an environmental standpoint, the future of biodegradable polymers relies on building a composting infrastructure to transform these wastes into carbon-rich soil additives. Composting systems are designed to accelerate the degradation of organic materials through the actions of microbial organisms in a moist, warm, aerobic environment.

In the United States, composting has a large potential for achieving waste reduction goals. Industry analysts estimate that up to 40 percent of the municipal solid wastestream can be composted. Compost-amended soil can increase organic carbon, water, and nutrient retention; reduce chemical inputs; and suppress plant diseases. Professor Hoitink, at Ohio State University, has patented a composted material which suppresses four deadly microorganisms found in nurseries. Growers who had routinely lost 25 to 75 percent of their crop now lose only 1 percent, without applying a single fungicide.

A recent study by EPA addressed the economics of leaf composting in eight areas across the United States. The programs studied showed that composting costs (excluding revenues) ranged from $11 to $102 per ton and avoided disposal costs of $5 to $137 per ton. In several cases, revenues of up to $25 per ton were generated through sale of the finished product. In other cases, costs were avoided by using the finished compost for landfill cover or private use [13]. As landfill space becomes more costly, composting makes more environmental and economic sense.

Nevertheless, there are some problems with composting. In a 1992 telephone survey by the Roper Organization, more than two-thirds of the 201 solid waste experts surveyed mentioned the following as significant problems jeopardizing the future of composting: insufficient standards for compost quality, cost of separate collection of organic materials, uncertainty of future regulation, difficulty of separation in plants, lack of capital to build facilities, odor, and lack of markets for composted products. For the top 10 disadvantages, 8 in 10 of the people surveyed were at least somewhat optimistic that solutions would be found.

How Are Biodegradable Polymers Used Now?

The main use of degradable plastic has been for items where disintegration after use is a direct benefit. Examples include: agricultural mulch films, planting containers and protectors, hay twine, surgical stitching, medicine capsules, and composting bags [4, 6]. Agricultural pesticide firms are also examining the use of starch-based polymers to encapsulate products. Encapsulated pesticides offer several advantages over traditional pesticides:

- Reduced runoff and groundwater contamination,

- Greater safety in handling,

- Extended activity,

- Reduced volatility losses,

- Reduced degradative losses, and

- Reduced application rates.

Additionally, encapsulation shows promise for significantly increasing the environmental stability and pest-control efficiency of entomopathogens such as *Bacillus thuringiensis* (Bt) [1].

As biodegradable polymers expand into new markets, there are several challenges that must be met. The primary one is to design polymers that work when needed, but self-destruct after use. Moreover, performance must meet public expectations and provide value relative to paper and plastic substitutes.

Another challenge is to determine the environmental impact of biopolymer degradation, both in its intended disposal method and in litter. The promise of 100-percent biodegradability does not lessen the need for increased environmental fate studies on all forms of polymers. The EPA feels that there are too many unanswered questions regarding the impact of biodegradable polymers on different environments and is opposing recent legislation which promotes increased use of these products [10]. More specifically, questions must be answered on:

- Whether a polymer is degradable and, if so, under what conditions and in what time frame,
- The potential environmental impact of increased degradation products and additives from a degrading polymer,
- The potential impact of small pieces of degrading polymers in terrestrial and aquatic ecosystems, and
- The potential impact of degradable polymers on recycling programs.

Provided that manufacturers continue to use biodegradable polymers and natural biodegradable additives, the answers should favor many of these products.

Promising Technologies Ahead

Polylactic acid polymers look very promising. They are generally derived by fermenting carbohydrate crops, such as corn, wheat, barley, cassava, and sugar cane. These polymers can also be made from cheese whey and potato wastes. Commodity giants like Archer Daniels Midland and Cargill produce lactic acid as a byproduct of corn wet milling.

Battelle Memorial Institute's Senior Research Chemist, Dr. Richard Sinclair, describes polylactic acid polymers as "nice well behaved thermoplastics which can, in its various compositions, mimic all the physical properties of conventional packaging plastics" [2]. Moreover, polylactic acid polymers degrade back to lactic acid--a natural, harmless product. While properties of these polymers are excellent, full realization of its potential will depend on improved preparation and recovery of the basic fermentation chemicals. To improve the economics, better technology is required to readily recover lactic acid from the fermentation broth.

To date, the relatively high price of polylactic acid polymers, compared to petroleum-based plastics, has restricted their commercial application. Polylactic acid polymers have achieved some success in the high-priced medical field. Producers of polylactic acid polymers include Cargill, and joint ventures between DuPont and ConAgra, plus Battelle Memorial Institute and Argonne National Laboratories.

A second technology which has received a great deal of attention is the poly-hydroxybutyrate/valerate (PHBV) copolymers developed by International Chemicals, Inc. (ICI). ICI has developed a process where bacteria act on a controlled feedstock of organic acid and sugar to produce PHBV, which can be harvested. The production technology is similar to the bacterial fermentation of corn to ethanol. PHBV completely biodegrades in a microbially active environment, such as a composting facility or a sewage plant [11].

Like polylactic acid polymers, the relatively high cost of PHBV, compared to petroleum-based resins, has prevented it from significantly penetrating the plastics market. Companies that have product agreements with ICI generally pay $8 to $10 per pound of resin. ICI officials expect the price to drop to $4 per pound by the mid-1990's. Market successes include injection-molded bottles used by Wella for its Sanara brand shampoo, and by Brocato International for a new line of hair care products called Evanesce.

The final technology is receiving the most attention at USDA. Starch-based biopolymers begin with starch that is relatively inexpensive (cornstarch is approximately 7 cents per pound), can be thermoprocessed using conventional plastic processing equipment, and is available as a surplus raw material from agricultural production. However, polymers with improved water resistance require specialty starches, which are more expensive than other starches. Another advantage of starch-based polymers is that they are biodegradable on land and at sea.

Starch readily gelatinizes (or disperses) in hot water to form a paste that can be cast into film. Unfortunately, the films are sensitive to water and become quite brittle upon drying. To alter these properties, starch is generally blended with biodegradable plasticizers and additives. The basic problem with starch biopolymers centers around the influence of water during processing and the post-processing stability of materials when the water content changes.

NOVON Products, a division of the Warner Lambert Company, has been able to overcome many of these difficulties by blending specialty starches from potatoes and/or corn, in a patented process with other completely biodegradable additives. Like polylactic acid and PHBV polymers, NOVON resins are relatively more expensive than petroleum-based resins [11]. Nevertheless, NOVON has obtained some market success:

- Jafra Cosmetics uses biodegradable starch-based loose-fill cushioning made from NOVON polymers to ship its mail-order cosmetics and personal-care products,
- Storopack Inc., uses NOVON resins to manufacture a water-dispersible loose-fill that can replace polystyrene "peanuts,"

- Terraform Company uses NOVON resins to produce golf tees now stocked by K-mart,
- Biku-Form uses NOVON resins to manufacture votive candle cups, and
- Bio-Bags and Film uses NOVON resins to make film bags for composting.

The properties, costs, and producers of biodegradable polymers currently on the market are in appendix table 1.

Where Do Biodegradable Polymers Fit in the Plastics Industry?

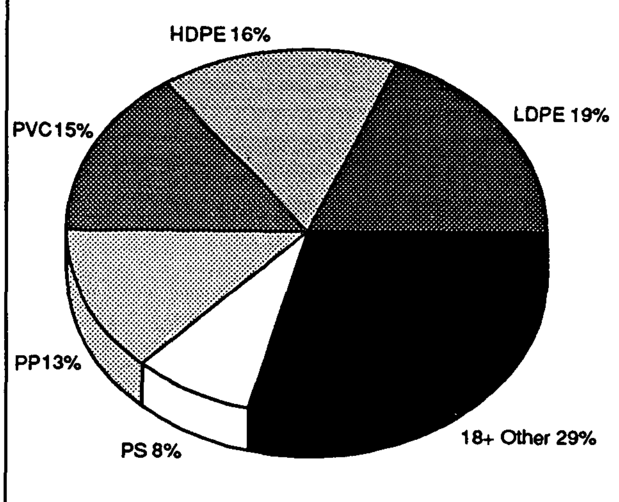
Biodegradable polymers compete in the plastic materials and resins markets. The output from this industry includes commodity resins such as high-, low-, and linear-low-density polyethylene; polypropylene; polystyrene; polyvinyl chloride; and polyethylene terephthalate. Between 1987 and 1992, the value of shipments for the overall industry grew from $26.2 billion to an estimated $31.4 billion. Based on constant 1987 dollars, this translates into a 4.6-percent real annual increase [14].

Approximately 65.4 billion pounds of resins were produced in 1992. Low-density polyethylene (LDPE) captured 19 percent of the 1992 market; high-density polyethylene (HDPE), 16 percent; polyvinyl chloride (PVC), 15 percent; polypropylene (PP), 13 percent; polystyrene (PS), 8 percent; and more than 18 additional materials account for the remaining 29 percent (figure A-1). Of the remaining 29 percent, degradable polymers have captured less than 5 million pounds of the resins market.

Plastic's durability and indestructibility make it best for many applications. Nevertheless, environmental concerns, both of pollution from production processes and of solid waste disposal of end-use products, have forced the plastics industry to look for raw material substitutes and for improvements in the recyclability and biodegradability of end-use products.

Figure A-1

U.S. Plastic Sales, 1992



Source: Modern Plastics, January 1993.

The bottom line is that recycling should be done whenever possible. However, in those cases where recycling is ineffective or impossible, biodegradability becomes an issue. Four markets are targeted for biodegradable polymer applications: food packaging, nonfood packaging, personal and health care, and other disposables. Degradable food packaging will not be addressed in this article because the Food and Drug Administration (FDA) has not yet established guidelines for its use. For that reason, nonfood packaging will be taken as the key market.

How Big Is the Potential Market?

The single-use items slated for replacement are manufactured from a few classes of commodity resins. These include high- and low-density polyethylene, polypropylene, polystyrene, polyethylene terephthalate, and polyvinyl chloride. Of the 16.5 billion pounds of plastics used in packaging in 1992, various forms of polyethylene and polystyrene accounted for 62.4 percent or 10.3 billion pounds.

In 1992, total sales of low-density polyethylene (LDPE) reached 6.9 billion pounds (table A-1). If one assumes that half the miscellaneous packaging market represents nonfood packaging, then the total LDPE nonfood packaging market is 2.68 billion pounds. In addition, the trash bag market, a major target for biodegradable polymers, accounted for 1.4 billion pounds. Smaller markets for which some penetration might be possible include diaper backing, 0.24 billion pounds, and agriculture, 0.22 billion pounds.

In comparison, total 1992 sales of high-density polyethylene (HDPE) were 10.4 billion pounds. HDPE is used to produce durable products and so is not as amenable to biodegradable polymers as the LDPE market. However, there are some potential applications: nonfood bottles, films and sheeting, and consumer packaging (table A-2) [7]. Therefore, if biodegradable polymers were to replace low-density polyethylene and high-density polyethylene in selected nonfood packaging uses, the potential market would be approximately 8 billion pounds annually.

Table A-1--Low-density polyethylene use, 1992

Market	Million pounds
Nonfood packaging	2,439
Trash bags	1,432
Food packaging	1,158
Miscellaneous packaging	563
Miscellaneous nonpackaging	354
Industrial sheeting	245
Diaper backing	242
Agricultural	221
Household wrapping	183
Nonwoven disposables	57
Total	6,894

Source: Modern Plastics, selected years.

How Will Biodegradable Polymers Affect the Farm Sector?

In 1992, biodegradable polymer resins captured less than 5 million pounds or roughly .08 percent of the resins market. Provided that Congress does not mandate increased biodegradable polymer use, market penetration into the 8-billion-pound, single-use plastics market described above will likely be slow. Consequently, this analysis uses conservative scenarios.

The low-growth scenario is based on estimates from the Institute for Local Self-Reliance (ILSR). ILSR expects the demand for biodegradable polymers to double between 1991 and 1995. This would put total demand at roughly 8.4 million pounds of resin in 1995. The moderate-growth scenario is based on projections by the Business Communications Company (BCC) of Norwalk, CT. BCC expects natural plastic use to reach 1.2 billion pounds by 2002. Table A-3 shows the yearly demand for biodegradable polymers starting from a base of 5 million pounds in 1992, and applying these two growth scenarios.

How will higher biopolymer production increase the demand for agricultural commodities? The analysis explicitly assumes that cornstarch technologies will capture the lion's-share of this market. This simplifies the analysis, recognizing that all of the technologies mentioned above use or could use corn, wheat, or potato starch for production. Furthermore, since many of the inputs used to produce biodegradable polymers are highly substitutable, there would be positive feedback effects in each related market. So, the choice of substrate is not crucial.

Wet milling corn yields 33 to 35 pounds of starch per 56-pound bushel of corn. Multiplying the number of pounds of resin by the percentage of cornstarch used in a particular technology gives an estimate of the number of pounds of cornstarch needed. Then, dividing the number of pounds of cornstarch by 34 gives an estimate of the number of bushels of corn used. Table A-4 translates the resin projections in table A-3 into bushels of corn, assuming technologies that use, on average, 25-, 50-, and 75-percent cornstarch.

The final step simulates the effect of increased biopolymer producion on farmers and farm subsidies. The Food and Agricultural Policy Simulator (FAPSIM) has been developed and refined at ERS for over 10 years, simulating the effects of various farm policy decisions on farmers and farm subsidies. FAPSIM estimates a simultaneous price-quantity equilibrium solution for a set of individual commodity models developed for beef, pork, dairy, chickens, eggs, turkeys, corn, oats, barley, grain sorghum, wheat, rice, soybeans, and cotton. FAPSIM also endogenously determines farm production expenses, cash receipts, net farm income, government deficiency payments and reserve storage payments, plus farmer participation in government commodity programs [12].

FAPSIM includes the level of farmer participation in government commodity programs to develop acreage response equations for corn, wheat, and other program crops. Therefore, the acreage response relationships contained in FAPSIM reflect the relative profitability of either participating or not participating in a government commodity program. Here, the model's estimates can be used to determine how increased biopolymer production will affect overall farm profitability and government program payments.

Based on industry estimates of starch-loading between 25 and 90 percent, this analysis simulates the 50 percent loading scenario. The FAPSIM simulations measure the difference between the baseline projection for each year, given the 1990 Farm Bill, against the low- and moderate-growth scenarios. The only thing changed between the baseline projection and the FAPSIM simulations is the introduction of increased production of cornstarch-based biodegradable polymers.

Table A-2--High-density polyethylene use, 1992

Market	Million pounds
Nonfood bottles	1,447
Film and sheeting	1,187
Consumer packaging	905
Total	3,539

Source: Modern Plastics, selected years.

Table A-3--Two market scenarios of biodegradable polymer growth, 1993-2000

Year	Low growth	Moderate growth
	--Million pounds of resin--	
1993	5.9	8.6
1994	7.1	14.9
1995	8.4	25.8
1996	10.0	44.7
1997	11.9	77.3
1998	14.1	133.6
1999	16.8	231.0
2000	20.0	399.3

Table A-4--Corn utilization, 1994-2000, with two biopolymer growth scenarios

Year	Percent starch loading 25	50	75
	--1,000 bushels of corn--		
Low growth scenario			
1994	51.98	103.95	155.93
1996	73.48	146.96	220.43
1998	103.88	207.76	311.63
2000	146.85	293.71	440.56
Moderate growth scenario			
1994	109.91	219.81	329.72
1996	328.56	657.11	985.67
1998	982.20	1,964.41	2,946.61
2000	2,936.24	5,872.47	8,808.71

As shown in appendix table 2, an increase in cornstarch-based biodegradable polymers has little effect. Total feed grain and corn supplies increase marginally. Industrial uses for feed grains and corn reflect primarily the increased use of corn for biopolymer production, however some substitution between grains appears to exist. Also, the average market price for corn does not change in the low-growth scenario, and changes slightly in the moderate-growth scenario.

Under both scenarios, corn deficiency payments go down and total deficiency payments, including corn payments, decrease further. This suggests that there is some substitutability in the starch market, so the choice of substrate is probably not critical from a policy perspective. Finally, in both scenarios, net farm income increased, reflecting primarily the higher cash receipts associated with higher corn prices.

References

1. Bartelt, R. B., M. R. McGuire, and B.S. Shasha. "Feeding Stimulants for the European Corn Borer: Additives to a Starch-Based Formulation for *B. thuriniensis*." *Environmental Entomology*, 19(February 1990):182-189.

2. Biggs/Gilmore and Associates. *Situation Analysis for Degradable Plastics*. Prepared for the National Corn Growers Association, July 1988.

3. Coble, Chang, McCarl, and Eddleman. "Assessing Economic Implications of New Technology: The Case of Cornstarch-Based Biodegradable Plastics." *The Review of Agricultural Economics*, 14(January 1992):33-43.

4. Doane, William M. "Promising New Products and Processes From Corn." In the 1990 Proceedings of *Outlook '91: Annual Agricultural Outlook Conference*. USDA, November 1990.

5. Doane, W. M., C. L. Swanson, and G. F. Fanta. "Emerging Polymeric Materials Based on Starch." *Materials and Chemicals from Biomass*, American Chemical Society, (1992):197-230.

6. Environmental Resources Ltd. *Feasibility Study on Degradable Containers and Packaging*. Ireland; Office for the Protection of the Environment, September 1991.

7. Francke, Thompson, and Ekart. *The Market Potential for the Use of Cornstarch in Biodegradable Waste Products: A U.S. and Kansas Projection*. Prepared for the Kansas Corn, Grain Sorghum, and Soybean Commission, December 1989.

8. Kaplan, D. L., J. M. Mayer, D. Ball, J. McCassie, A. L. Allen, and P. Stenhouse. "Fundamentals of Biodegradable Polymers." Natick, MA; U.S. Army Natick Research, Development and Engineering Center, Biotechnology Division. Presented at the Biodegradable Materials and Packaging Symposium, Natick MA, June 1992.

9. Leeds, Rob and Carl Zulauf. "Corn Based Plastics: Wave of the Future or Ripple that Degrades?" In *Exploratory Conference on Farm Income Enhancement: Concept Paper Series*. The Ohio State University, supported by USDA Cooperative State Research Service, April 10-11, 1989.

10. Mayer, J. M. and D. L. Kaplan. "Biodegradable Materials and Packaging: Environmental Test Methods and Needs." Natick, MA; U.S. Army Natick Research, Development and Engineering Center, Biotechnology Division. Presented at the Biodegradable Materials and Packaging Symposium, Natick MA, June 1992.

11. Morris, David and Irshad Ahmed. *The Carbohydrate Economy: Making Chemicals and Industrial Materials from Plant Matter*. Washington, DC; The Institute for Local Self-Reliance, 1992.

12. Salathe, L. E., J. M. Price, and K. E. Gadson. "The Food and Agricultural Policy Simulator (FAPSIM)." *Agricultural Economics Research*, 34(April 1982):1-15.

13. Taylor, A. C. and R. M. Kashmanian. "Overview of EPA Composting Study." *Biocycle*, September 1989:36-39.

14. U.S. Department of Commerce. *U.S. Industrial Outlook: 1993*. Washington, DC; 1993.

Appendix table 1. Some properties and producers of biodegradable polymers 1/

Company (plastic type)	Price per lb. of resin	Maximum use temperature (centigrade)	Specific gravity (times heavier or lighter than water)	Base properties	Applications	Bio-degradability
NOVON resins (starch-based)	$1.50-3.00	170-200	1.40-1.45	Water soluble, suitable for injection molding.	Pharmaceutical capsules, packaging materials like "peanuts," golf tees, candle stands, fast-food cutlery, films.	Very high
ICI resins (sugar-based PHBV)	$8.00-10.00	110-180	1.25	Good shelf stability, suitable for injection and blow molding.	Shampoo bottles, disposable razors, injection-molded articles.	High
Battelle polymers (polylactic acid)	$1.00-2.00	120-170	1.20-1.40	Excellent molding properties. Copolymerized with glycolic acid and other plant-based polymers.	Commodity plastics for molding applications, controlled release of agrichemicals and drugs.	Very high
FLEXEL cellulose resins (cellulose films)	$2.40-3.60	60-100	1.10-1.30	Excellent film-forming properties. Flexible. Good mechanical strength.	Sandwich bags, packaging films, uncoated clear films.	High
Mater-Bi Novamont/Feruzzi	$1.60-2.50	150-200	1.32-1.45	Contains at least 60% starch and other biodegradable materials. Excellent molding and film-extrusion properties.	Disposable diapers, high heat-aging resistant films, moldable article applications.	High
Ecochem (polylactides)	$2.00-2.50	130-150	1.20-1.40	Recyclable polylactide. Completely compostable. Good extrusion properties and film formation.	Packaging film and sheets.	High

1/ Source: Morris, David and Irshad Ahmed. *The Carbohydrate Economy: Making Chemicals and Industrial Materials from Plant Matter.* Washington, DC; The Institute for Local Self-Reliance, 1992.

Appendix table 2: FAPSIM difference from baseline projections

			Low-growth scenario		Moderate-growth scenario	
			Sum	Average	Sum	Average
Total feed grains						
	Total supply	Mil. metric tons	0.007	0.001	0.065	0.008
		% change[1]	0.001	0.000	0.020	0.003
	Industrial use	Mil. metric tons	0.032	0.004	0.325	0.041
		% change	0.065	0.008	0.623	0.078
Corn						
	Total supply	Mil. bushels	0.291	0.036	2.313	0.289
		% change	0.001	0.000	0.021	0.003
	Industrial use	Mil. bushels	1.298	0.162	12.793	1.599
		% change	0.074	0.009	0.715	0.089
	Average market price	Dollars/bushel	0.000	0.000	0.012	0.002
		% change	0.000	0.000	0.487	0.061
Corn income factors						
	Value of production	Mil. dollars	10.995	1.374	116.002	14.500
		% change	0.052	0.007	0.524	0.066
	Deficiency payments	Mil. dollars	-5.000	-0.625	-45.03	-5.629
		% change	-0.221	-0.028	-2.120	-0.265
Total deficiency payments[2]		Mil. dollars	-5.819	-0.727	-51.528	-6.441
		% change	-0.103	-0.013	-0.954	-0.119
Net farm income		Mil. dollars	6.000	0.750	30.00	3.750
		% change	0.010	0.001	0.054	0.007

[1]The percentage change numbers are a non-weighted cumulative average. This gives a rough approximation of the percentage change over the simulation period, 1993-2000.

[2]Deficiency payments for all other crops in Federal programs either went down or did not change.