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BIODEGRADABLE POLYMERS: *THE OPPORTUNITIES AND CHALLENGES FOR AGRICULTURE*

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As citizens of the global village, the human race will face two crises in the years ahead, and from these crises will come opportunity for agriculture in general and bio-based products in particular.

First, there is an emerging environmental crisis in the form of solid waste management. According to the most recent estimates by WorldWatch Institute, worldwide population is expected to double by the year 2050. Quite obviously, this will result in significant additions to the waste stream and significant withdrawals from the earth's bank of natural resources.

Plastics, despite the many ways in which they improve the quality of life, have become a lightning rod for environmentalists and others concerned about the welfare of this planet. They believe that worldwide consumption of plastics -- about 200 billion pounds annually -- creates a number of environmental problems, including the inability of many plastics to break down and the enormous cost of managing and disposing of plastic waste.

Second, there is an emerging energy crisis. As worldwide population grows, and percapita income increases in industrialized nations, the demand for non-renewable petroleum resources will increase. Currently, the U.S. consumes 4 million barrels per day more for transportation than it produces, and that number will increase to 9 million barrels per day by the year 2010. By then, according to the Energy Information Administration, the transportation sector will consume 14.1 million barrels per day, 60 percent of which will be imported. Obviously, while the world currently is blessed with abundant supplies of cheap oil, at some point in the future this will not be the case.

From these crises comes opportunity for agriculture in the form of biodegradable polymers made from corn and other renewable resources. These products can help address these emerging crises on two fronts. First, biodegradable products can ease some of the pressure on solid waste management systems to dispose of plastic. Second, packaging and other consumable goods made from renewable resources can ease some of the future supply and demand pressure on petroleum, freeing its availability for priority transportation use.

With an aggressive effort, sales of biodegradable polymers could reach 6 billion pounds annually by the year 2010, or about 8 percent of the total commodity polymer market. This would consume 800,000 bushels of corn per day.

Some would say this isn't a lot of corn, considering that a medium-sized corn milling plant can process about the same amount of corn in a week. But it would be a market that does not currently exist, and this market would in turn create the need for new processing facilities and as many as 4,000 primary jobs and 10,000 indirect jobs. And it would be a market that could be supplied with ease. According to the USDA, the U.S. could ramp up corn production by 50 percent over a five-year period without taxing the country's existing collection, transportation, and storage infrastructure.

This opportunity for agriculture could not come at a better time. In the years ahead, U.S. agriculture will face tougher competition for its share of the world marketplace. And, it will face greater pressure to reduce dependence on government and taxpayer assistance. Producers and agribusiness are not blind to the potential impact of these issues. But rather than dwelling on the negatives, they must chart new courses ... courses which will lead to new markets and new opportunities for farm profits.

Realizing the potential of this new technology for agriculture will not be easy, however. Several obstacles stand in the way, and they must be overcome before farmers reap the benefits.

Cargill is one of several companies developing proprietary processes and products in the area of biodegradable polymers. Cargill's product, EcoPLA, is an environmentally engineered material made from polylactic acid, or PLA, which is a product of corn processing.

PLA performs like petroplastic, both from a manufacturing and end-use perspective. It can be used for many applications, from plastic bags to foodservice utensils to horticultural mulch film. And, of course, it is degradable.

It is not, however, a completely new product. Polylactic acid was introduced in 1932 to the textile fiber industry, but poor hydrolytic properties prevented its acceptance.

The 1970s brought renewed interest, however, and these same hydrolytic properties proved to be a virtue for certain biomedical applications such as dissolvable sutures and bone screws. But the high costs of separation, purification and polymerization of lactide prevented its use beyond the medical industry.

In the 1980s, growing concerns about solid waste management brought a new wave of interest in biodegradable plastics as alternatives to petroplastics. This led to the development of a first generation of biodegradable materials. These materials were plagued by production and performance problems, but they nevertheless represented a step forward.

Around 1990, commercial introduction of a second generation of biodegradable polymers emerged in both Western Europe and the United States. These included starch-based polymers and several families of polyesters ... polylactides, polyhydroxybutyrate-valerate, and polycaprolactone, which has been used for more than 20 years but not for biodegradable applications.

Cargill became interested in biodegradable polymers from polylactides in 1987 as a possible new use for corn. It seemed a good fit, since PLA can be produced from the food ingredient lactic acid, which is made from dextrose. Dextrose was readily available from the corn milling business and Cargill was already fermenting citric acid and ethanol from dextrose.

Significant progress has been made. Recently, Cargill developed and patented a continuous process to economically produce PLA from lactic acid. This process is capable of producing a family of polylactide polymers with high purity and high molecular weight at a lower cost than previously possible.

In the spring of 1994, the company established an $8 million pilot facility to make PLA from natural lactic acid. The plant has an annual capacity of 10 million pounds and the company is currently producing and testing a variety of commercial grade products with various physical and rheological properties. Cargill believes many of these products have the potential to be "drop in" replacements for conventional polymers.

So, after many years of significant investments in research and development, Cargill is beginning to market-test a number of product applications of low-cost biodegradable polymers made from renewable resources. While large-scale commercial production is still a few years away, the company is nevertheless pleased with the technological progress made. To date, Cargill has filed more than 25 patents on the processes and products relating to this technology.

CHALLENGES TO COMMERCIALIZATION

Specifically, there are five challenges that must be addressed for biopolymers to reach their full potential.

The first is product performance. Aside from the obvious benefit of degradability, PLA has unique properties that make it a good thermoplastic based on performance alone. It has sufficient toughness for most uses and can be modified to be stronger than polystyrene. It can have equal or better impact resistance than polypropylene. It is resistant to oils and therefore will not craze. It offers good storage stability. And it has a high surface energy that makes it very easy to print.

However, a major challenge for biopolymers is improving functional performance without adversely affecting degradability. Of particular concern are thermo-mechanical properties ranging from softening temperature to flexibility to chemical stability. To address some of these issues, completely new technology must be developed.

Successful introduction of biopolymers is possible only with additional process, product, and applications research, not only for the polymer itself but for a wide range of derivative products, including copolymers, blends, alloys, and filled or reinforced grades.

In addition, the development of renewable resource-based additives must progress on a parallel pace with base polymers. Without these ingredients, property modifications will be challenging and the product category "renewable biopolymers" may not exist. While Cargill is not limiting its research to renewable resource-based materials, from a marketing perspective the company has a strong preference.

Clearing these technological hurdles will be difficult and expensive. Several companies have invested millions of dollars over the past several years, and the market for low-cost biodegradable polymers is only now being commercially tested for the first time. After all, it has taken some 50 years to get conventional polymers to their current state of development.

Developing and commercializing new technologies is becoming increasingly time-intensive and expensive. Few companies these days have pockets deep enough to justify significant investments in R&D projects, especially those that may not be aligned with core businesses or which will not bear fruit for many years. Partnerships within industry, and between industry and government, are critical to maintaining the level of resources necessary to advance these technologies.

While the U.S. initially established a technological leadership position in biodegradable polymers, most of the patents in recent years have gone to Japanese companies. The Japanese Ministry for Trade and Industry has been instrumental in shaping enabling legislation and in helping Japanese companies develop biodegradable polymer technologies.

Cargill is committed to helping the U.S. maintain a technological leadership position in an environment characterized by increasingly stiff competition. All the more reason for Cargill -- and other companies with similar technologies -- to identify government, industry, and special interest partners to help advance these products, not just for the benefit of agriculture but for the competitiveness of the nation. Without broad-based commitment, the investment Cargill and others have made to date may be wasted, and the potential benefits of an emerging industry to the agricultural economy and U.S. competitiveness could be lost to others.

Fortunately, some promising research partnerships are beginning to emerge. Two examples come to mind. The USDA's Alternative Agriculture Research Center has been instrumental in providing funding assistance to new use ventures. And the Advanced Technology Program, ATP, sponsored by the National Institute of Standards & Technology, provides support on a cost-sharing basis to industrial research and development projects with significant potential for stimulating economic growth. Cargill was recently awarded funding from ATP to work on improving some of PLA's material properties.

The second challenge is economics. For commercial success, biopolymers must not only offer functional performance, they must be sold to end-users for little or no premium over competing conventional systems. Solving the aforementioned technical issues will expand the market only if the cost of PLA is in line with competing materials.

Fortunately, due to the nature of Cargill's traditional commodity businesses, achieving cost efficiencies in bioprocessing systems is considered a core competency. The cost of Cargill's PLA is not yet competitive with petroplastics, but it is moving in the right direction and it may be possible to produce EcoPLA for less than one dollar per pound, which would put it in a competitive arena with conventional thermoplastic polymers such as PE, PS and PET.

To achieve wide acceptance, it is critical not only to control the cost of the new materials, but to identify applications in which any premium paid for the polymer is "diluted" by another low-cost material. In the case of PLA-coated paper, for instance, lower grades of paper can be used due to the inherent strength of the polymer.

Finally, economic assessments must consider the total system cost of the polymer, not just its selling price. The system cost includes all costs, including manufacture, delivery, use and disposal. Product disposal costs, energy costs, product responsibility issues -- like the German "Green Dot" laws where the producer of packaging is responsible for the packaging even after the consumer throws the product away -- all are impacting company ingredient purchasing decisions. For many companies, the view of cost has been broadened to include environmental assessment through life cycle analysis.

From a total life cycle cost perspective, PLA looks promising because it has the potential to reduce the amount of non-renewable ingredients used, minimize wasted energy and decrease environmental impact and disposal cost. But these potential economic advantages must be *in addition to* a competitive price at the ingredient level.

Failure to achieve a favorable economic view from all aspects will in effect relegate bioplastics to small-volume specialty markets which will be of little benefit to agriculture as a whole, nor will it take enough pressure off petroleum supplies to help the country achieve a diversified energy policy.

The third challenge is lack of a composting infrastructure. While biopolymers like EcoPLA are compatible with most every type of waste management system, composting allows products to achieve their full potential of converting waste into water and humus for the Earth. Some of the earlier bioplastics did not live up to expectations for degradability, but the new generation of materials is much improved. In laboratory tests, EcoPLA degrades to carbon dioxide and water at about the same rate as cellulose. Hydrolysis converts EcoPLA to lactic acid, which bacteria in turn reduce to carbon dioxide and valuable humus, which can be used to enrich and restore the soil and agricultural and horticultural applications.

It is highly unlikely, however, that biodegradable products will ever realize their full potential without the availability of composting systems. It is also unlikely that the federal government will accept the designation of a material as "biodegradable" unless a disposal pathway is also identified.

In some European countries, as much as 40 percent of municipal solid waste is composted, but in North America the practice is just gaining momentum. Of the nation's 2,500 composting sites, only 1 percent are designed to accept mixed organic wastes. Most are limited to yard and leaf waste.

But government, industry and the environmental community are beginning to understand and accept composting as a "logical next step" to recycling as a way of diverting part of the waste stream away from landfills, and there is increasing interest in establishing more municipal composting sites. While recycling alone is capable of recovering up to 25 percent of the waste stream, recycling in combination with composting can recover up to 70 percent. And about 40 percent of the material normally sent to landfills can be composted. That includes food waste, agricultural waste, non-recyclable paper products, and new, compostable plastics.

Accelerating the development of a composting infrastructure will require changes in technology and regulations.

From a technological perspective, composting on a commercial scale is still in its infancy. Composting has traditionally been considered a low technology venture. Until the composting process is managed like any other manufacturing process, it will be perceived negatively by the uninformed and poorly managed facilities will continue to create odor problems -- and public image problems -- for the rest of the composting community.

Much more work is needed to develop and understand new composting protocols, perhaps using specially adapted bacteria or fungi and greatly improved process controls for the disposal of mixed wastes containing biopolymers. And, there is a need for additional development work alternatives such as the in-vessel composting systems now in limited use in Europe, Canada and Japan.

From a regulatory perspective, the relationship between composting and recycling must be defined. Composting is often characterized as a threat to recycling. And yet nothing could be further from truth. The primary goal of recycling is the diversion of plastic from landfills. There will be applications where biodegradability and compostability enhances the diversion of plastic from landfills and thus accomplishes the same goal as recycling. Some applications -- like soiled food containers and coated paper -- annually account for some 16 billion pounds of U.S. plastic waste which is either technically or economically difficult to recycle. If these products could be composted, the use of degradable polymers would reduce the amount of plastic and other wastes headed for landfills. Unless composting is classified as recycling or allowed to be included in diversion goals, some states will have a difficult time meeting their municipal solid waste objectives.

Recycling and composting are complementary. In fact, biodegradation of renewable resource-based materials through composting can be considered recycling in the fullest sense if the resulting product is used as a soil supplement. It is easy to envision a closed loop system whereby plastic made from corn is returned to the soil to grow more corn. Is this not the embodiment of sustainable agriculture?

It is important for agriculture to enter the composting dialogue, not only because composting will facilitate a market for corn-based products, but because agriculture is part of America's growing waste problem. It is agriculture's responsibility to explore and support sustainable practices that return back to the land what it has removed.

The fourth challenge to renewable resource based polymers are regulatory and legislative disincentives. Currently, there are two regulatory trends which have the potential to negatively influence the development of the renewable biopolymer industry. Like the battle between composting versus recycling, the intent is good but the result is damaging to this developing industry.

The first trend is recycled content mandates. Recycled content mandates impose restrictions by requiring a certain level of recycled material to be contained in an article. The goal is to create or stimulate the market for recycled material. But in many cases, the benefit of degradability will be more appropriate to diverting plastic from landfills.

The second trend is banning or taxing the use of plastic. In this extreme case, the benefits of plastic products are not realized because they are forbidden to be used. And, more important for agriculture, bans and taxes simply reduce the potential market for biopolymers and the demand for corn as a non-food ingredient.

In addition to these regulatory trends, there are legislative issues. Enabling legislation is needed to either discourage the use of non-biodegradables and non-renewables, or encourage -- perhaps through short-term incentives -- the development and commercialization of biodegradable and renewable resource technology. It is imperative that the new Farm Bill address the emergence of new markets for agricultural commodities and the potential benefits of these markets to the nation's economic, environmental and energy goals. It is equally important that the Farm Bill support the establishment of a composting infrastructure, not only as a means of enhancing market development efforts for renewable products but as a sustainable practice from which agriculture can benefit.

For any new technology, the presence of government restrictions and/or the lack of incentives for technological and market development can be crippling. In the case of biopolymers made from renewable resources, it may be necessary *in the short term* for government to help establish U.S. competitiveness in this area. But it will not be necessary *in the long term* for government to provide an artificial propping up of this technology.

Again, agriculture needs to speak with a unified voice to shape the regulatory and legislative debate on new uses, and to educate the new Congress about tomorrow's agriculture ... an agriculture that will not only produce food for the table but will also produce renewable resources which will lead to improved quality of life and energy independence.

The fifth and final challenge is convincing a disinterested and/or skeptical public that this technology is important. Many consumers are generally unaware of the environmental and energy crises that lie ahead as worldwide population continues to soar. On their hierarchy of daily concerns, waste management and the availability of petroleum don't register. Nor does the public give much thought to the "invisible" ingredients -- renewable or non-renewable -- in product packaging or foodservice ware. Until the public demonstrates a high level of understanding and concern for these issues, the benefits of biodegradable polymers made from renewable resources may fall on deaf ears and government will feel much less urgency to encourage further development of this technology and complementary markets and infrastructures.

Achieving awareness is only half the challenge. Undeniably, the public is much more aware of environmental issues than ever before, and they overwhelmingly support -- in concept -- environmentally friendly products and practices. But public attitudes do not always translate into public action. Studies show that while society supports "green" products, it is not yet willing to pay more than a 5 percent premium for such items. Nor is it willing to accept less performance than it has come to expect. Biodegradable products may be held to an even higher standard since claims for earlier products left the American public feeling misled and skeptical.

It's important for agriculture to understand that the development of biodegradable products from renewable resources be accompanied by efforts to educate and motivate the consuming public. Ultimately, consumers have the power to create or stifle demand for both food and non-food products from the farm.

MEETING THE CHALLENGES

Certainly, these hurdles are significant, but they can be overcome. This will require financial resources, perseverance and strategic partnerships.

It is no secret that agriculture does not have the voice it once did. Not since Abraham Lincoln was president has America had so few farms ... now less than 2 million. This means that to successfully develop and commercialize new technology, agriculture must work in closer partnership with government, others in industry and special interest groups which have the ability to advance non-food uses.

This may even mean working side by side with people agriculture has battled in the past. In the past, agriculture has on occasion been at odds with environmentalists, government regulators and the petrochemical industry. And yet today, all of these groups stand to benefit from the development and commercialization of products made from renewable resources. They must, therefore, find ways to work together, focusing on common ground rather than differences.

Collectively, the challenges to successful development and commercialization of biodegradable polymers made from renewable resources can be overcome in the next few years, resulting in a sizable market for corn and continued U.S. competitiveness in emerging "new use" technologies.

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