Natureworks: Green Chemistry's Contribution to Biotechnology Innovation, Commercialization, and Strategic Positioning

In 2002, a 10-year joint venture between U.S. agricultural giant Cargill Inc. and Dow Chemical received the prestigious Presidential Green Chemistry Challenge Award from the U.S. Environmental Protection Agency for its development of the first synthetic polymer class to be produced from renewable resources—specifically, from corn grown in the American Midwest. The product was biomass material and held the potential to substitute a renewable feedstock (raw material) for petroleum-based polymers. At the Green Chemistry and Engineering Conference and awards ceremony in Washington, D.C., attended by the president of the United States National Academy of Sciences, the White House science advisor, and other dignitaries from the National Academies and the American Chemical Society, the award recognized the company's innovative direction. In January 2005, Cargill chose to acquire Dow's share of the venture. Now, the fledgling company had to learn to fly.

NatureWorks' bio-based plastic resins were named and trademarked NatureWorks PLA for the polylactic acid that comprises the base plant sugars. In addition to replacing petroleum as the material feedstock, PLA resins have the added benefit of being compostable (safely biodegraded) or even infinitely recyclable, which means they can be reprocessed into the same product again and again. That feature provides a distinct environmental advantage over recycling ("downcycling") post-consumer or post-industrial materials into lower-quality products, which merely slows material flow to landfills by one or two product life cycles. Additional life-cycle environmental and health benefits have been identified by a thorough life-cycle analysis (LCA) from corn to pellets. PLA resins, virgin or post-consumer, can then be processed into a variety of end-uses.

This case was prepared by Research Associates Alia Anderson and Karen O'Brien under the supervision of Associate Professor Andrea Larson at the Darden School of Business at the University of Virginia. It is intended to serve as a basis for class discussion rather than to illustrate the effective or ineffective handling of an administrative situation. These materials were developed through a cooperative effort of the American Chemical Society's Green Chemistry Institute and the U.S. Environmental Protection Agency (EPA) Office of Pollution Prevention and Toxics' Design for the Environment Program. Partial funding was provided by the EPA through Cooperative Agreement #X8-83077701-0. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the EPA. Any mention of trade names does not imply endorsement by the EPA.

By early 2005, CEO Kathleen Bader and Chief Technical Officer Pat Gruber were wrestling with a number of questions. NatureWorks' challenges were both operational and strategic:

1. How to take the successful product to high-volume production
2. How to market the unique resin in a mature plastics market

With Cargill's January 2005 decision to acquire Dow's share of the venture, they also raised questions about the structure of NatureWorks going forward.

CEO Kathleen Bader had been at Dow for 30 years before joining NatureWorks in 2004. She managed Dow's Styrenics and Engineered Products, a $4 billion business, between 1999 and 2003. She also led Dow's Six Sigma program implementation. As a NatureWorks board member who had long championed the technology, Bader was confident about its future and supported it from her budget at Dow; she was a logical fit at the helm. One of her first decisions involved selecting a retail alliance partner and narrowing a list of prospective customers. Limited resources constrained her choices.

Other issues included application challenges when converting PLA resins to different plastic forms, the controversy over genetically modified organisms (GMOs), and appropriate market positioning for a "sustainable" product—still a vague concept to many. Many executives in the company knew all too well that positioning its new product would take far more than simply getting the technology right.

In spring 2005, NatureWorks employed 230 people, split almost equally between headquarters (labs and management offices), the plant, and the international division. International consisted primarily of the European Union; the Hong Kong representative who worked with the Japanese market was brought back to headquarters in early 2004. As a joint venture, the enterprise consumed close to $750 million dollars in capital and was not yet profitable, but it promised tremendous growth that could transform a wide range of markets worldwide. In 2005, NatureWorks was still the only company in the world capable of producing large-scale, bio-based resins that exhibited standard performance traits such as durability, flexibility, and strength, all at a competitive market price.

The Plastics Industry

In 2001, the plastics industry was the fourth-largest manufacturing segment in the United States, behind motor vehicles, electronics, and petroleum refining. That year, the United States produced 101.1 million pounds of resins from oil and shipped $45.5 billion in plastic products.[1] Both the oil and chemical industries were mature and relied on commodities sold on thin margins. The combined efforts of a large-scale chemical company in Dow and an agricultural processor giant in Cargill suggested Cargill Dow—

[1] Plastic Materials and Resins, Industry Profile for SIC Code 2821, 2001.

now NatureWorks—was in some ways well-suited for the mammoth task of challenging oil feedstocks. But could the small company grow beyond the market share that usually limited environmental products, considered somewhere between 2 to 5 percent of the market? And for that matter, should PLA be considered an “environmental product?”

Wave of Change

The rising wave of interest and activity in biomaterials pushed industrial biotechnology into the economic mainstream by 2005. Projects to convert renewable resources into industrial chemicals proliferated, funded by government, corporate, and private capital. Major agricultural companies and chemical giants teamed up to produce carpeting, paint, inks, solvents, automobile panels, and roofing material made from plants. Production of plant-derived fuels, such as ethanol and biodiesel, was growing. Advocates described the advantages of these products: less polluting, equally dependable and lower-cost feedstocks; more environmentally friendly products, and processes with fewer toxic byproducts; reduced reliance on imported oil; and a smaller environmental footprint.

McKinsey & Co. (Zurich) estimated the 5 percent market share represented by biotechnology products in 2004 could jump to 10 to 20 percent by 2010, with the biggest shift occurring in biotech processes to make bulk chemicals, polymers, and specialty chemicals. Developments in enzymatic biocatalysis already allowed for the production of new materials with improved properties compared to existing products. Bioprocesses enabled production of existing chemicals at lower cost. The textiles, energy, chemical, and pharmaceuticals industries were all transforming in the face of biotechnology advances. Within this larger dynamic, polylactic acid (PLA) was just one of many “platform” materials available to be converted into a range of derivative products.

NatureWorks was contributing to creating, and being carried forward by, this wave of biotechnology innovation. Factors converged to create new markets worldwide. According to *Fortune* magazine (July 2003):

> Sales that large [$280 billion by 2012] would displace a notable quantity of oil, freeing it up for other uses and helping keep prices down. It would also shift the source of industrial chemicals from foreign countries to farm fields nearer the markets where the end-products will be consumed. That would cut transportation costs and conceivably reduce dependence on foreign oil.

Pat Gruber, chief technology officer for NatureWorks LLC, knew of biotechnology innovation’s potential since his graduate school days in biochemistry. Gruber’s interest in environmental issues had a long history, going back to high school, where he enjoyed and showed an aptitude for biology and chemistry. He always liked crossing over between the systems perspective of biology and the molecular building-block orientation of chemistry.

In the same year that NatureWorks' achievements were recognized by the Green Chemistry Innovation Award, the company brought online a plant with a capacity of 300 million pounds (140,000 metric tons) that promised to turn his team's breakthroughs into a viable and very large business. In 2003, the business won the United Kingdom's prestigious Kirkpatrick Award for Chemical Engineering Achievement for "bringing to market a technology that allows abundant, annually renewable resources to replace finite petroleum, to make consumer goods without sacrificing performance or price."

NatureWorks Pre-2005: The Cargill Dow Joint Venture (CD)

Cargill, the largest privately held company in the United States, also was the largest agricultural processor in the country, with 2004 revenues of $63 billion. The company served the food processing, food service, and retail food industries. The origins of NatureWorks went back to 1988, when Pat Gruber joined Cargill after graduate school. Sponsorship by Cargill's corn milling division launched what was then a small research project. During the 1990s, Gruber and his team built up considerable biomaterials and bioprocessing expertise, but Cargill sought a polymer partner that would bring plastic processing and application knowledge as well as market know-how. Cargill processed and sold high-volume meats, corn, and other agricultural products to large customers such as Wal-Mart and McDonald's, but it knew little about resin converters, thermomolding lines, or polymer science applications—traditional domains of the plastics industry. As a Cargill employee summed up in the early 1990s, "We know food, we don't know chemicals." On the chemicals side, in the early 1990s, experts in the chemical industry generally did not believe it was possible to create plastics from carbohydrate feedstocks (plant-based starches and sugars) that would perform the same as, and be cost-competitive with, petroleum-originated plastics.

Ultimately, Cargill found an interested partner in Dow Chemical, a $40 billion commodity chemical and plastics manufacturer. Dow was active in oil-based raw materials, plastics, additives, processing aids, and solvents applied across multiple industries. In 2004, Dow expressed its commitment to its oil-based plastics with plans to site large-scale plastics feedstock production facilities next to oil wells in the Arabian Peninsula. Dow also had major commitments to polypropolene (made from natural gas released in oil drilling) and polyethelene. Although Dow had considerable plastics science expertise, at the time it did not make polyethylene terephthalate (PET), the material PLA most likely would replace.

In 1995, the working partnership officially became a joint venture, a 50–50 undertaking between the two parent companies, Cargill and Dow. Though small, the enterprise was monitored closely because costs would show in red on the budgets of units within both companies. The initial $100 million investment carried the assumption that Cargill, primarily an agricultural commodity trading company, would contribute its corn and biological process expertise, while Dow would bring polymer science, process control methods, and plastic supply-chain marketing knowledge from its commodity plastic polymer businesses. Dow also had a large biotech effort in its pharmaceutical intermediates business that could provide complementary knowledge for chemical production. The agreement between the two industry giants seemed ideal, since the structure of the plastics industry—dominated by large companies generating high-volume, low-margin, mature commodity plastics through established supply chains—virtually ensured that small players with limited capital would not last.

Board communications issues, the turnover of three CEOs between 1997 and 2004, and the loss of four marketing VPs had reduced the joint venture's effectiveness over its short life. Some thought the parent companies did not focus on the details of the business's unique challenges. Others believed the joint venture had served its useful life and a new ownership structure was necessary to go forward.

Many outside the company assumed PLA would be adopted quickly. But the complexity of differentiating the corn-based plastic pellets that came out the door of the Nebraska PLA plant, selling a sufficient volume to downstream buyers to get plant capacity greater than 70 percent, and selling the plastic as part of a buyer's sustainability strategy proved to be tough challenges.

By 2005, when Cargill-Dow became NatureWorks, it claimed more than 15 years of experience in biopolymer technology and applications. Sometimes in meetings, however, some felt that Cargill still viewed Dow as the polymer company providing the "technology." Managing Natureworks under two different parent organizations created its own set of issues. Two accounting books had to be kept. Fiscal calendars and IT software systems were different. Dow required that its process methods and proprietary software be purchased and incorporated by the joint venture. The plant was located on Cargill's property, thus Cargill was paid by NatureWorks for site management services in addition to the corn raw material, and the business tapped into Cargill's steam and electric infrastructure.

A member of the top management team commented in 2004 that, until recently, Cargill and Dow had not meaningfully discussed what each of the investing parent companies wanted from its investment. Complicating matters was Cargill's historical unwillingness to discuss genetically modified organisms (GMOs) and its general reluctance to engage in public dialogue about environmental concerns and, in particular, sustainability. Dow, on the other hand, understood the growing interest in the sustainability agenda and had some (though not necessarily successful) experience with environmental groups and the growing regulatory activity.

Making Plastic

The Cargill-Dow undertaking was an industrial biotech project, as opposed to *molecular* or gene-focused biotechnology, that evolved from Cargill's corn-milling business director's interest in finding new product opportunities for corn sugars. Among the key questions when the duo considered the project in the 1990s:

- Was it possible to create a cost- and performance-comparable plastic product using corn sugar instead of petroleum as the primary feedstock?

- Was there a business in bioplastics?

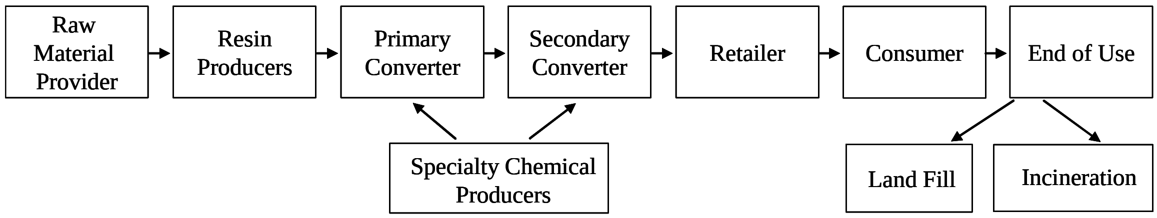
Polylactic acid (PLA) innovation held the potential to revolutionize the plastics and agricultural industries by offering benign, bio-based polymers to substitute for conventional, petroleum-based plastics. But, in those days, plastics industry experts repeatedly told Pat Gruber and his small team that he would never find a low-cost biological supply for lactic acid production. They were informed that polymers from that source could never work in the variety of applications they had in mind. Yet the team of scientists Pat Gruber formed around the PLA project kept at their work, believing the technology could be developed and that markets would favor environmentally sound and renewable-resource-based materials. Using Cargill's corn-milling facility and a 34,000-ton-per-year prototype lactic acid pilot plant built in 1994, the small and expensive project moved determinedly forward.

Polylactic acid was not new. Wallace Carothers, the DuPont scientist who invented nylon, first discovered lactic acid polymer in the 1920s and DuPont research continued through the 1930s. Plant sugars were processed into polymers in small volumes in the laboratory, producing very similar characteristics to petroleum-based polymers, the traditional building blocks of commodity plastics. Costs were orders-of-magnitude too high, however, and the material's technical performance was not acceptable for large-scale plastics and fibers applications. While research continued on polylactic acid and polylactides, the DuPont-ConAgra joint venture "Ecochem" in the early 1990s ultimately failed. Subsequently, only small volumes of PLA plastic were produced for specialized applications in which the safe dissolution of the material was valued (implants and controlled drug release applications, for example). In the 2000s, DuPont sold medical sutures made from PLA for $1,000 per kilo. Cost and technology constraints prohibited PLA production in large volumes or for alternative uses.

Making Plastic

Plastic is made by cracking petroleum through heating and pressure. Long chains of hydrocarbons are extracted and combined with various additives to produce polymers that can be shaped and molded. The polymer material, called resin, comes in the form of pellets, powder, or granules and is sold by the chemical manufacturer to a processor. The processor, also called a converter, blends resins and additives to produce a buyer's desired product characteristics. For example, an automobile dashboard part needs to be flexible. The processor adds plasticizers to make the resin more flexible and moldable. Plasticizers, often supplied by specialty chemical providers, are the most commonly used additives. Other additives include flame-retardants, colorants, antioxidants, antifungal ingredients, impact modifiers (to increase a material's resistance to stress), heat or light stabilizers (to resist ultraviolet rays), and lubricants. In addition to those additives, some plastics also include fillers, such as glass or particulate materials. First-tier processing companies typically sell resins with specific qualities in the form of rolled sheets or pellets. Additional converters along the supply chain melt the sheets or resin pellets and convert them by processes such as injection-molding (for storage tubs like yogurt containers or waste bins), blow-molding (for plastic drink bottles), and extrusion (for films).[2]

Figure 1. Simple Value Chain for Polymer Transformation into Plastic Consumer Products



In contrast, NatureWorks' process for creating a proprietary polylactide—trade-named NatureWorks PLA (for plastics) and Ingeo (for fibers)—is based on the fermentation, distillation, and polymerization of a simple plant sugar, corn dextrose. The process harvested the carbon stored in plant sugar and made a polylactic acid polymer with characteristics similar to those of traditional thermoplastics. The production steps are as follows:

- Starch is separated from corn kernels.
- Enzymes are converted from starch to dextrose (a simple sugar).
- Bacterial cultures ferment the dextrose into lactic acid in a biorefinery.
- A second plant uses a solvent-free melt process to manufacture lactide polymers.
- Polymer emerges from the plant in the form of resin pellets.
- Pellets have the design flexibility to be made into fibers, coatings, films, foams, and molded containers.

NatureWorks' manufacturing sequence reduced consumption of fossil fuel by 30 to 50 percent compared with oil-based conventional plastic resins. PLA plastic waste safely composted in about 45 days if kept moist and warm (above 140 degrees Fahrenheit) or, once used, burned like paper, producing few byproducts. PLA offered a renewable resource replacement material for PET and polyester, both used widely in common products such as packaging and clothing.

Field corn is the most abundant and cheapest source of fermentable sugar in the world, and the standard variety used by NatureWorks (yellow dent number 2) is commonly

[2] Plastic Materials and Resins, Industry Profile for SIC Code 2821, 2001.

used to feed livestock.[3] The corn is sent to a mill, where it is ground and processed to isolate the sugar molecules (dextrose). Dextrose was purchased from Cargill and fermented using a process similar to that used in beer and wine production. The resulting lactic acid is then processed, purified, melted, cooled, and chopped into pellets. Processing companies along the supply chain buy these pellets and make them into cups, plates, take-home containers, polyester-like fabrics, or laptop computer covers. Once the product was used, it could be either composted (meaning it would biodegrade) or melted down and recycled into products of equal quality.[4] Though NatureWorks had the technical capacity to combine post-consumer PLA products with virgin corn feedstock to make new product, large-scale collection required a reverse logistics system. Bader and Gruber hoped that capability would someday exist, allowing them to close the loop of their industrial process and practice fully renewable, "cradle-to-cradle"[5] manufacturing, a new model then gaining credence as a substitute for the linear, cradle-to-grave industrial processes that had traditionally characterized western industrial economies.

A key breakthrough resulted in a dramatic cost reduction to manufacture the lactic acid for making PLA polymers. A new fermentation and distillation process enabled cheaper purification, better optical composition control, and significant yield increases over existing practice. In contrast, two-thirds of the material inputs in conventional PLA processing were lost to waste streams. The company's patented new process enabled a single plant, using a flexible manufacturing system, to inexpensively produce different PLA grades for multiple markets while adhering to environmentally sound practices.

Buyers

Typically buyers—such as food service companies (Cisco, Guest Services), restaurant chains, and supermarkets—needing, for example, hundreds of thousands of drinking cups would contract with cup producers. The producers had relationships with materials converters, who purchased either plastic resins or previously fabricated plastic sheets, foams, or coatings. Some supply chains were simple, with only three steps from NatureWorks feedstock resins to the ultimate user. Other supply chains could be much longer and more complex. Long-established and preferential working relationships with plastic resins producers were standard, as were multiyear contracts and lines optimized for conventional materials. But converters could be persuaded to source differently and to change molds and even line equipment if customers demanded. Fortunately, PLA could be dropped into PET molds and lines with only minor changes. It was harder to

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[3] NatureWorks LLC, FAQs. http://natureworks.custhelp.com/cgi-bin/natureworks.cfg/php/enduser/std_alp.php?p_search_text=yellow+dent+number+2&p_new_search=1 (accessed March 3, 2009).

[4] NatureWorks LLC, NatureWorks® Biopolymer Technical Overview. http://www.natureworksllc.com/earth-month-2007/press-materials/technical-overview.aspx (accessed March 3, 2009).

[5] Frosch, R.; Gallopoulos, N. Strategies for Manufacturing. *Scientific American*. 1989, *261*: 3; see also McDonough, W.; Braungart, S. *Cradle to Cradle*, North Point Press. New York, 2002.

drop PLA into polystyrene lines, and optimizing for PLA might mean cutting new tools, new mold designs, or even new lines, depending on the application. For example, PLA might be thinner than conventional plastic sheets it replaced, and require retooling. Conversion to PLA could mean significant additional throughput or faster line times (cost savings), but it might also require expenditures of time and money. That could yield financial gains to converters but few were interested in making changes when profit margins already were slim.

The Market

NatureWorks brought its new product to market in the late 1990s and early 2000s, at a time of economic recession, uncertain market dynamics, and rapidly intersecting health, environmental, national security, and energy independence concerns. While the economy seemed to settle by 2005, oil supplies and dependency concerns loomed large, with oil exceeding $65 per barrel. Volatile oil prices and political instability in oil-producing countries encouraged the United States and other oil-dependent economies to decrease their oil dependence. European countries were moving more quickly than the United States, however.

Yet plastics were a visible reminder of societies' heavy reliance on petroleum-based materials. The U.S. food industry and demographic trends were creating rapidly growing markets for convenient prepared foods, and clear plastic packaging helped get customers' attention at retail. Consumers had become increasingly well informed about chemicals in products and were becoming more aware that few had been tested for health impacts. Certain plastics known to leach contaminants even under normal use conditions raised government and health nonprofits' scrutiny. Health concerns, in particular health worries related to infants, children, and pregnant women, had put plastics under the microscope in the United States, but with nowhere close to the microscopic focus plastics had received in the European Union and Japan, where materials bans and regulatory frameworks received significant citizen support. Strong interest in green building in China and Taiwan, along with strong government motivations and incentives to reduce oil dependency (true also for Europe), drove international market buyers to find alternative feedstocks for plastic.

The volatility of petroleum prices between 1995 and 2005 wreaked havoc on the plastics industry. From 1998 to 2001, natural gas prices (which typically track oil prices) doubled, then quintupled, then returned to 1998 levels. The year 2003 was, again, a roller coaster of unpredictable fluctuations, causing a Huntsman Chemical Corp. official to lament, "The problem facing the polymers and petrochemicals industry in the United States is unprecedented. Rome is burning."[6] Others were assured that oil supplies, then central to plastics production, would be secured one way or another.

In contrast to petroleum-based plastics and fabrics, PLA, made from a renewable resource, offered performance, price, environmental compatibility, high visibility, and,

[6] Frosch.

therefore, significant value to certain buyers and consumers for whom this configuration of product characteristics was important. But there was an information gap. Most late supply-chain buyers and individual consumers had to be reminded that plastics came from oil.

Competition

Several companies throughout the world had perfected and marketed corn-based plastic materials on a small scale. Japan was early into PLA technology. By the 1990s, Shimadzu and MitsuiTuatsu in Japan were producing limited quantities of polylactic acid and exploring commodity plastics applications. Their leadership reflected Japanese technological skills, greater public and government concern for environmental and related heath issues, and pressing waste disposal needs, given the country's limited territory and dense population. By 2004, Japanese companies were buying NatureWorks PLA and transporting the pellets to Chinese subsidiaries for research and production. Japan already had safely incinerated and composted PLA.

Larger companies took stabs at bio-based materials, but none was as far along or as targeted as NatureWorks. For example, Toyota entered a joint venture with trading house Mitsui & Co. Ltd., which produced PLA from sweet potatoes. Toyota reportedly used PLA resins in its Prius hybrid car. Toyota announced plans in 2004 to construct a pilot plant to produce bioplastics made from vegetable matter. A new facility—to be built within an existing manufacturing plant in Japan—was expected to generate 1,000 tons of the polylactic acid plastics annually. Operations began in August 2004. Competitors and critics called these claims "greenwash." They were skeptical of Toyota's real intention to produce its own plastic resins, a vertical integration step atypical of the auto company. But Toyota's "Biogreen Division" recently had purchased a biopolymer feedstock company.

DuPont had a seven-year research program with the biotechnology company Genencor, using its enzyme to create a predominantly corn-based fiber called Sorona[7] through a joint venture with Tate & Lyle. The Sorona polymer, expected to replace the company's more expensive petrochemical-based product, was to emerge from a new, 100-million-pound-capacity plant in 2005. Sorona was only half bio-based, however, and still relied on petroleum for half its feedstock. DuPont's goal was to have 25 percent of its revenues derived from products made using renewable materials by 2015. Eastman Chemical Company's new product, called "Eastar Bio GP & Ultra copolyester," was designed to biodegrade to biomass, water, and carbon dioxide in a commercial composting environment in 180 days.

Metabolix (Cambridge, Massachusetts) was awarded $1.6 million from the U.S. Department of Commerce's Advanced Technology Program to help fund a project to improve the efficiency of a bioprocess to make polyhydroxyalkanoate (PHA)

[7] Mapleston, P. Automakers Work on Sustainable Platforms. *Modern Plastics.* 2003, *45*, 3.

biodegradable plastics from corn-based sugars. Metabolix said it was engineering bacteria to make production of PHA cost-competitive with petrochemical-based plastics.

A report on Metabolix in 2002 stated:

> Genetically engineered microbes that produce thermoplastic polymers by fermenting cornstarch or sugar are going to start nibbling away at hydrocarbon-based resins more quickly than is generally expected. That is the view of James Barber, president of Metabolix Inc., whose company operates a pilot plant for polyhydroxyalkanoate (PHA) fermentation at its headquarters in Cambridge, Massachusetts. Metabolix was created in 1992 to develop PHA technology. In 2001, the company acquired Biopol technology from Monsanto. Biopol was originally developed by ICI in the 1980s. A recent $7.4 million grant to Metabolix by the U.S. Dept. of Energy will help develop a new route to bioproduction of PHA. Instead of fermentation, Metabolix will investigate making PHA through photosynthesis in the leaves or roots of the switchgrass plant. This is a fast-growing, native American grass that grows relatively well even on marginal farmland. “Direct plant-grown PHA could allow us to challenge volume resins in lower-cost packaging and other markets,” Barber says.[8]

Germany’s BASF began R&D collaboration with Metabolix in 2003 to investigate PHA’s materials and processing properties, but much of that competitive activity was intended to forge “platform” technical capacities to use biomaterials and processing for wide varieties of pharmaceutical and industrial applications. The partnership was in its infancy stages and not necessarily a threat to NatureWorks. In late 2004, agriculture giant Archer Daniels Midland formed a 50-50 joint venture with Metabolix to make alternatives to petrochemical plastics.

In terms of its stage and scale of technology, NatureWorks was alone among companies in the emerging industry, a situation that caused them some additional challenges. Buyers preferred comparing the cost and performance of two products, rather than having to choose the only product available. In addition, NatureWorks could hardly lobby for government subsidies or regulations for its industry, since it was the sole representative of that industry.

Yet factors continued to line up favorably. The chemically tough nature of oil-based plastic polymers was both its most desirable and problematic trait. Plastic polymers can take hundreds and even thousands of years to break down. With steadily increasing consumption rates of plastics (predicted to be 2.58 billion tons between 2004 and 2015)[9] and short product life spans (approximately 30 percent of plastic is used in

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[8] PlasticsTechnology [online]. http://www.ptonline.com/articles/200204bib1.html (accessed December 12, 2006).

[9] Global Plastic Companies Plan to Make Biodegradable Products. *Financial Express.* October 4, 2004.

packaging; this material is thrown away immediately), communities faced a significant solid waste problem. In 2004, plastic represented almost 40 percent of the municipal waste stream by tonnage.[10] The disposal issue caused several countries to require recyclability in plastic products. In 1994, the European Union passed the “Packaging Recovery and Recycling Act,” which required member nations to set targets for recovery and recycling of plastic wastes. By 2005, manufacturers had to take packaging back. The European Union (EU) also set a precedent with the Directive on End-of-Life Vehicles, which established a goal of 85 percent reuse/recycling (by weight of vehicle parts) by 2006. NatureWorks set up its EU office in 1996.

Japan enacted similar laws in 1997. One stated that the manufacturer was responsible for the cost of plastic packaging disposal. Japan added to their waste regulations in 2001 by mandating that all electronics must contain 50 to 60 percent recyclable materials and that the manufacturers must take the electronic device back at the end of its useful life. This spurred the Japanese “GreenPla” designation (so named for green plastics, not polylactic acid), a strict labeling program that identified products that met all government regulations for recyclability. The first product to receive the GreenPla designation was NatureWorks PLA resins.

In 2003, Taiwan initiated a phase out of polystyrene foam and shopping bags. These regulations used the “polluter pays” approach, which required manufacturers to take responsibility for the disposal/reuse of their products. The efforts were designed to inspire a movement toward the development of “readily recyclable” products, and two of three implementation phases were complete. The third would fine people for using non-biodegradable materials. Whether termed sustainable business, triple-bottom-line (economic, social, and environmental) performance, the 3E’s (economy, equity, ecology), or simply good business, drivers of change were growing.

Additives

No discussion of plastics can leave out the issue of additives and related health concerns. Chemical specialty companies provide packages of additives that converters incorporate into melted resins to achieve the customer’s desired look and performance. One physical characteristic of plastic molecules is that the additives are not chemically bound but rather physically bound in the polymers (envision the additive molecule “sitting” inside a web of plastic molecules, instead of being molecularly “glued” in place). As plastics undergo stress, such as heat or light, during normal use or are subjected to landfill pressure, additive molecules are released into the environment. These “free-ranging” additives caused scientists to raise questions about health impacts. Sources such as the American National Academy of Sciences and the U.S. Center for Disease Control were accumulating alarming data. A 2005 Oakland Biomonitoring Project found evidence of the following chemicals in the blood of a 20-month-old child in California: DDT, PCBs, mercury, cadmium, plasticizers, and flame retardants (PBDEs). PBDEs,

[10] Global Plastic Companies Plan to Make Biodegradable Products. *Financial Express.* October 4, 2004.

known to cause behavioral changes in rats at 300 parts per billion (ppb), registered at 838 ppb in the child.

Plasticizers, such as phthalates, were the most commonly used additives and had been labeled in studies as potential carcinogens and endocrine disruptors. Several common flame retardants regularly cause developmental disorders in laboratory mice. Possibly most startling were studies that found significant levels of phthalates, PDBEs, and other plastic additives in breast milk. Those findings were confirmed for women in several industrially developed economies, including the United Kingdom, Germany, and the United States.

These trends led to a series of regulations that plastic producers and other companies active in the international market could not ignore. In 1999, the European Union banned the use of phthalates in children's toys and teething rings, and, in 2003, it banned some phthalates used in beauty products. California took steps to warn consumers of the suspected risk of some phthalates. The European Union, California, and Maine banned the production or sale of products using certain PDBE flame retardants.

Attempting to address the fact that the majority of the thousands of chemical additives used in plastics have never been tested for health impacts, in 2005, the EU was in the final phases of legislative directives that required registration and testing of nearly 10,000 chemicals of concern. The act, called the Registration, Valuation, and Authorization of Chemicals (REACH), became law in 2007. Imports into Europe would need to conform to REACH requirements for toxicity and health impacts. Europe used the precautionary principle in its decisions about chemicals use: unwilling to wait until conclusive scientific data proved causation, member countries decided that precautionary limits on, and monitoring of, chemicals would best protect human and ecological health.

Sales in Europe

NatureWorks' innovation had received more attention in the international market than in the United States. In 2004, IPER, an Italian food market, sold "natural food in natural packaging" (made with PLA), and attributed a 4 percent increase in deli sales to the green packaging.[11] NatureWorks established a strategic partnership with Amprica SpA in Castelbelforte, Italy, a major European manufacturer of thermoformed packaging for the bakery and convenience food markets. Amprica was moving ahead with plans to replace the plastics it used, including PET, PVC, and polystyrene, with the PLA polymer. In response to the national phase-out and ultimate ban of petroleum-based shopping bags and disposable tableware, Taiwan-based Wei-Mon Industry (WMI) signed an exclusive agreement with NatureWorks to promote and distribute packaging

[11] Radice, C. Sustainable Packaging Takes Hold: Its Components May Break Down. *Grocery Headquarters.* 2004, *70*, 76.

articles made with PLA.[12] In other markets, high-end clothing designer Giorgio Armani released men's dress suits made completely of PLA fiber; Sony sold PLA Discman and Walkman stereos in Japan; and—due to growing concerns about the health impacts of some flame retardant additives—NEC Corp. of Tokyo combined PLA with a natural fiber called kenaf to make an ecologically and biologically neutral flame-resistant bioplastic.[13]

Though the U.S. market had not embraced PLA, it was evolving. In its 11 "green" grocery stores, Wild Oats Markets, Inc.—a growing supermarket chain based in Portland, Oregon—switched to PLA packaging in its deli and salad bar. The stores advertised the corn-based material and had special recycling bins for the plastic tubs, which looked identical to petroleum-based containers. Wild Oats collected the used PLA containers and sent them to a composting facility. The chain planned to expand that usage nationally into all 77 Wild Oats stores.[14] Smaller businesses, such as Mudhouse, a chain of homegrown coffee shops in Charlottesville, Virginia, changed over to NatureWorks' PLA clear plastic containers for cold drinks, sourced from Plastics Place in Kalamazoo, Michigan, a company that states its mission as "making things right."

NatureWorks marketing head Dennis McGrew noted that experimental companies and firms trying to catch competitors were moving more quickly to explore PLA applications. Significantly, both smaller early-adopter purchasers and large companies were interested. Soon, mainstream companies entered the mix. In 2004, Del Monte aced its rival Dole at the southern California food show with PLA fresh fruit packaging. Also that year, Marsh supermarkets in Indianapolis, Indiana, agreed to use PLA packaging at its stores, representing an important new retail channel: the traditional supermarket.[15]

Clothing Fiber from PLA

Opportunities for fiber applications were growing. NatureWorks launched the Ingeo brand of PLA in January 2002, targeting fiber markets then dominated by PET, polyamide (PA), and polypropylene (PP) fibers. Ingeo could be used for clothing, upholstery, carpets, and non-woven furnishings as well as fiberfill for comforters and industrial applications. In 2004, the company FIT developed a range of man-made fibers derived from PLA, following a master license agreement between the Tennessee-based fiber maker and NatureWorks to produce and sell the fibers under the brand name

[12] E-Wire press release, Taiwan to Get New Solution to Environmental Problems. http://www.ewire.com/display.cfm/Wire_ID/1408 (accessed March 3, 2009).

[13] Climate Biz, NEC Develops Flame-Resistant Bio-Plastic. http://www.climatebiz.com/news/2004/01/27/nec-develops-flame-resistant-bio-plastic (accessed March 3, 2009).

[14] *Business Wire* [online], NatureWorks PLA Makes North American Commercial Debut … June 2, 2003. http://www.allbusiness.com/retail/retailers-food-beverage-stores-grocery-supermarkets/5723574-1.html (accessed March 10, 2009).

[15] Radice, C. Sustainable Packaging Takes Hold: Its Components May Break Down. *Grocery Headquarters.* 2004, *70*, 76.

Ingeo in North America and in select Asian markets. The agreement included technology licenses, brand rights, and raw material supply to manufacture and sell Ingeo. The U.S. supply chain for apparel fiber moved to Asia in the 1990s, so India and China were the fabric markets to watch.

In 2004, Faribault Woolen Mill Company sold blankets and throws made with 100 percent PLA and a PLA/wool blend. Biocorp North America, Inc., based in Louisiana, was one of a handful of companies producing compostable PLA cutlery, and it offered the new product at a price competitive with conventional disposable knives, forks, and spoons. Biocorp successfully sold its corn-based cutlery to sizable buyers such as Aramark and the EPA. In 2003, Ford introduced its Model U SUV, which boasted a range of "green" features, such as a hydrogen engine, soy-based foam seating, and tires, roofing, and carpet mats, all made with NatureWorks' PLA.[16] Though their new model was still only a "concept vehicle," Ford claimed that it was using the same cradle-to-cradle approach to design a market-ready vehicle.

Genetically Modified Organisms (GMOs)

A significant obstacle to marketing NatureWorks PLA in the United States was that the corn feedstock included genetically modified (called GM or GMO) corn. Naysayers were not assuaged by the facts that GeneScan, Inc., certified that PLA was free of any detectible genetic material and that the base sugar source (GMO or not) had no impact on PLA performance. Furthermore, the business was not in a position to control the corn sources coming to the mill, and GMO and non-GMO were typically intermixed.

When PLA was initially released in 2002, outdoor clothing company Patagonia jumped at the revolutionary product. After determining that PLA fibers were suitable for its products and moving toward a sizable partnership, Patagonia realized that the corn feedstock, like nearly all the corn produced in the United States, had been genetically modified to be more pest resistant. Patagonia shared the concerns of many environmental NGOs throughout the world in fearing that GM products had not been sufficiently tested for their full ecological and social impacts. The uncertainty that still surrounded GM products caused such groups to lobby for a total ban on genetically modified crops until more sound investigations were conducted. Patagonia abandoned the NatureWorks partnership and launched a publicity campaign against PLA. Environmental groups also questioned the use of food material (the corn) as feedstock when hunger remained a seemingly intractable problem internationally. NatureWorks expected to spend about $2 billion to develop commercial and production technologies to convert other agriculturally based materials—such as corn stalks and other post-harvest waste, wheat straw, and grasses—into PLA.

Though NatureWorks would have preferred to produce GMO-free products, purchasing separate quantities of GM-free corn at a comparable price was challenging. In 2002 the

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[16] Muller, J. Lean Green Machine: Bill Ford's Environmental Hankerings May Have Benefits. *Forbes*. 2003.

company quantified the proportion of GMO/non-GMO corn in their final resin and designed a system of offsets to support customer choice regarding non-GMO sourcing. In this system, any PLA customer could pay $0.10 more per pound of PLA. NatureWorks would use this money to buy an equivalent offset amount of non-GMO corn (per one pound of PLA) for the processing plant's primary feedstock. Though resin purchasers (under the direction of their buyers) could not guarantee that the product was 100 percent non-GMO, they could voice their preference for non-GMO corn. NatureWorks experts pointed out that since the genetically modified DNA was no longer present in the corn after it had been fermented, hydrolyzed, and distilled to make PLA, this system was the only way to work proactively on this customer issue. Parent company Cargill had reservations about the program, however. In early 2005, Public Affairs and Communications Director Ann Tucker worked on reconfiguring the program on a more customer-directed and focused platform. Sensitivity to the issues and the use of terms like genetically modified was not limited to Cargill. Dow too preferred that the company not say "from renewable resources."

In 2005, the plant was operating at a lower capacity than projected. Bader repeatedly heard the refrains: "You cost a lot of money; make the bleeding stop;" and "Your product doesn't work because it does not offer a 'drop-in' (easily adopted) substitute for PET and polystyrene." The management team found it hard to determine and stay focused on priorities—they needed to do so much simultaneously. The team had to constantly ask themselves, what are the core issues to be tackled first, and what strategy would generate essential sales volumes?

Marketing

After successfully overcoming the scientific and technological barriers of producing PLA on a large scale, the team now had to create and manage a new market, a challenge that had not been attempted for 30 years. Manufacturers did not understand how to reconfigure their machinery to handle this new polymer, and many customers needed convincing that sustainable products were worth the investment. The pilot plant in Nebraska only had the capacity to produce 300,000 million pounds of plastic per year, hardly a contribution to the three billion oil-based pounds produced in the world annually.

Dennis McGrew, chief marketing officer, joined the business in April 2004 after 21 years at Dow in the plastics side of the business. McGrew was solutions oriented and brought with him considerable experience working on new business models for materials markets. The challenge, as he described it, was "taking PLA from niche to broad market play." NatureWorks had a solution for companies that wanted to move in the direction of more sustainably designed corporate strategies. For McGrew, the company was selling resin pellets, yes; but really it was selling environmental responsibility. McGrew had realigned commercialization to global markets where environmental concerns were more familiar concepts.

Formerly a marginal topic, by 2005, sustainable business practices were mainstream. Although the definition of sustainability depended somewhat on where you stood, clearly insurers, investors, banks, end-consumers, and governments worldwide were increasingly emphasizing corporate accountability for the impact of their activities on communities, health, and the natural environment. Large companies were publishing social and environmental reports in response to investor demand, and there was a significant movement toward uniform international corporate reporting standards on what was called triple-bottom-line performance (economic, social, and environmental). The Dow Jones Sustainability Index tracked high performers in sustainable management practices. In April 2005, JPMorgan, the third-largest bank in the United States, announced new guidelines restricting lending and underwriting when projects harm the environment, following European financial institutions' strategies. As the first U.S. financial institution to incorporate environmental risk management into the due diligence process of its private equity divisions, this policy signaled far beyond financial markets. A negative reputation for a company going forward could result in more expensive capital, higher insurance premiums, costlier bank credit, lower stock price, and even consumer boycotts.

These larger trends might support initiatives by firms such as NatureWorks, but they seemed remote to Bader and her senior management team. To go from niche to mainstream with PLA, NatureWorks needed to create an ongoing profitable business. This meant increasing PLA production from tens of millions of pounds to hundreds of millions of pounds.

Appendix A
BIO for Patrick Gruber, PhD
(former) Vice President and Chief Technology Officer, Cargill Dow LLC

Patrick Gruber, Ph.D., [at the time this case was written] is the vice president and chief technology officer of Cargill Dow LLC. One of the founders, Gruber has served in his current position since the company's inception in 1997. Since 1988, Gruber has spent his career focused on the technology and business development of products made from renewable resources targeted to industrial chemicals and polymers, as well as animal feed products and food ingredients. His work has shown that it is possible to make chemicals and polymers using industrial biotechnology at world scale from renewable resources while achieving a reduced environmental footprint compared to petrochemical based products, without sacrificing price or performance.

In 2002, Gruber's work received the Presidential Green Chemistry Award. In 2001, Gruber received the *Discover* Award for Environmental Innovation from the Christopher Columbus Fellowship Foundation. Gruber received the Lee W. Rivers Innovation Award, which recognizes paradigm-changing innovation, from the Commercial Market Development Association in 2003. In 2002, he received the Julius Stieglitz Award presented by the American Chemical Society and University of Chicago. In 2003, Gruber was honored with the Society of Plastics Engineers' Emerging Technology Award and *Chemical Engineering's* Kirkpatrick Award, both of which are awarded for significant innovation in process development and commercialization. Other awards include *Popular Mechanics* Design and Engineering Award, *Industry Week's* Technology of the Year award, *Finance and Commerce's* Innovator of the Year Award, the U.S. Department of Energy OIT Technology of the Year Award, Frost and Sullivan's Technology of the Year Award, and the Industrial Energy Technology Conference (IETC) Energy Award. In 1993, his work on stabilized enzymes was recognized as one of *R&D's* Top 100 Inventions of the Year. Gruber is a member of the Federal Advisory Committee for Biomass R&D and is on the Advisory Committee for the Energy Future Coalition. Gruber holds 48 U.S. patents, with a number of others pending. Gruber was inducted to the Minnesota Inventors Hall of Fame in 2003.

Prior to the formation of Cargill Dow and even for a time after, Gruber held several positions in the technology and business development areas of Cargill, Incorporated. He was director of technology development for Cargill's bio-products areas from 1995-1998 and technical director of Cargill's BioScience Division from 1998 through 1999. In 1988, Gruber was the leader and, later, the general manager of Cargill's renewable bioplastics project. This position led to the development and marketing of a lactic acid polymer, now known as NatureWorks™ PLA and Ingeo™ fibers, which is the basis upon which Cargill Dow LLC is built today.

Dr. Gruber received a bachelor's degree in chemistry and biology from the University of St. Thomas, St. Paul, Minnesota, and a doctorate in chemistry from the University of Minnesota. He also earned a master's degree in business administration from the Carlson School of Management at the University of Minnesota.