HIGHLIGHT

Life Sciences and Materials: A Successful Marriage Is Possible

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ABSTRACT: Although some companies are separating their life sciences and materials businesses, others are keeping these entities under the same corporate umbrella to take advantage of possible synergies at the biology/materials science interface. The following remarks, which provide some perspectives about DuPont’s approach to this strategy, were delivered as a keynote address at a conference titled “Life Sciences and Materials... Successful Marriage or Divorce?” organized in Pisa, Italy, in October 1999, by the European Polymer Federation and the University of Pisa. © 2000 John Wiley & Sons, Inc. J Polym Sci A: Polym Chem 38: 667–678, 2000

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In 1966, Phil received his B.A. in chemistry from Western Maryland College. In 1970, he was awarded his Ph.D. in chemistry from Duke University, where he specialized in cryogenic, spectroscopic analysis of single crystals of transition metal complexes of amino acids. After graduation Meredith joined DuPont as a research chemist at the Experimental Station in Wilmington, DE. His research focused on flame retardants for polymers. This work led to his receipt of a United States patent to use brominated phosphazenes to flame retard polyesters and polyacrylonitriles. Since 1974, Phil has held various management positions in R&D and manufacturing in Delaware, Ohio, and New Jersey. His experience includes managing research groups working on products for DuPont businesses in titanium dioxide, Freon® (he directed DuPont’s CFC alternatives effort from 1987–1991), hydrogen peroxide, and other inorganic chemicals, as well as various products for the healthcare and medical
INTRODUCTION

It is clear that the chemical industry is undergoing dynamic change, deciding where to place resources for long-term growth and opportunity. Many companies are splitting apart—“divorcing”—into units that specialize in “life sciences” (pharmaceuticals and agricultural/food products) and those focusing on “materials” (chemicals, polymers, fibers, etc.) (Fig. 1).

Ironically, many of the technologies underpinning all these businesses are increasingly converging. Biotechnologies and supporting information technologies are potentially valuable in both life sciences and polymer-based businesses. In fact, many of the technologies we can employ—combinatorial techniques, analytical techniques, molecular modeling, etc.—as well as the approaches to problem solving by biological scientists—can span both worlds—providing competitive advantage.

Because of this technological convergence, some companies are choosing an ongoing union between their life sciences and materials businesses. Our modern society is demanding that we come to grips with complex materials problems that require a multidisciplinary approach to create unique, high-value solutions. A response to these needs by DuPont involves a marriage of biological and materials sciences, because we see that such a union offers the possibility of unique solutions with incredible power to transform industries.

During these remarks, I would like to (a) provide some perspectives on how DuPont is thinking through the strategy to be successful at the “biology/materials” interface; (b) provide a few examples showing our progress in this arena; and (c) address a few of the symposium organizers’ questions related to technological needs in the “materials from biology” arena. I’ll conclude with an historical example to tie together several points that may be relevant to our current situation.

First, a little about the company. DuPont is one of the largest enterprises in the world, ranking 16th on the Fortune 500 list of U.S. companies. Also, 92M employees work in 70 countries, our 1998 revenues were just under $25 MMM (ex Conoco), and we spend $1.65 MMM on R&D with ca. 50% focused on “life sciences” research and 50% on “materials” research. We have about 70 research and customer service labs around the world.

Although DuPont is a very diverse company with over 20 strategic business units, polymers and materials represent the major portion of our product lines, and are the majority source of our revenues and earnings now. By year 2002, however, we’ve promised 30% of earnings from “life sciences” businesses.

In my company, there are five perspectives (at least) from which opportunities/challenges are considered in the business strategic planning process based on (a) an historical/cultural context, (b) our science/technology base, (c) an assessment of market/customer needs, (d) key business drivers, and (e) social responsibility.

The first perspective is a historical/cultural one. Founded in 1802, DuPont is approaching 200 years of continuous operation under one name, that of E. I. duPont, the original entrepreneur who studied under Lavoisier and saw a business opportunity to safely manufacture high-quality black powder to meet the needs of the emerging American society. Our long and rich history provides unique perspectives—not all necessarily positive!—on how to think about business strategies. This history also affects the way our organization works, thinks, and behaves—it affects our culture.

The mindset that “There Will Always Be a DuPont”—the title of a recent Forbes magazine article—results from the fact that DuPont has transformed itself in a major way at least twice since its founding.

The first transformation occurred earlier this century as DuPont started to move away from its explosives businesses, restructured, and renewed itself in the chemicals and materials businesses. In fact, the discovery of nylon in the late 1920s, by a team lead by Wallace Carothers, catapulted the synthetic materials revolution of the 20th century. Nylon—and subsequent other synthetic polymeric developments—was a “disruptive” technology—it changed things forever. New end-uses had to be found, new customers were identified, new processing technologies were developed; in fact, much of what we now call chemical engineering was developed...
to meet the needs of this burgeoning new industry. And the concept of "end-use," or applications, research was developed.

Later in this century, DuPont continued to evolve, moving into other businesses—electronics products, agricultural products, pharmaceuticals, energy, etc.—to facilitate the growth to the dimensions described earlier.

These historical transformations have created a culture that is continually searching for the next base of rejuvenation—a mindset that asks, "building away from what we know how to do, how can we transform ourselves again and grow for another 50–100 years?"

The second perspective is based on science and technology. People will always ask whether a company that seeks to combine the biological sciences with materials science is a chemical company, a "life sciences" company, or something else altogether. Our response is clear: DuPont is a science company. We know how to use the many disciplines of science and engineering to create materials and products that meet the needs of society in unique ways—which change the way society does things. Science provides and maintains our competitive advantage and inspires our products. The people of DuPont are proud that the applications of our scientific research contribute to saving lives, to cleaner water and food, to human health, to personal comfort and shelter, etc.

Two domains of science are of particular importance to us: the chemicals and materials sciences and the biological sciences. In each, DuPont scientists are among the best in the world. But our unique strength is our potential to integrate this scientific knowledge into commercial applications for our customers. So it is not surprising that our corporate technology agenda includes both new materials/polymer platforms as well as building and applying a biotechnology platform.

This scientific base—operating at the leading edge in many disciplines—makes us continually aware of the rapid impact of emerging technologies in arenas of importance to our businesses. We understand the implications of "S-curves"—both at the upper, "mature" end—as well as at the, earlier, "embryonic" end. Over the decades, we’ve lived through disruptive technologies—within our businesses and markets.

Currently, we see two trends: first, the pace of new material introduction based on traditional petrochemical catalysis appears to be slowing. Our own prodigious, half-century product introduction rate has begun to tail off, as new end-use applications and high-value properties become more difficult to find (Fig. 2).

Interestingly over the past decade there has been somewhat of a rebirth in knowledge-intensive, specialty polymer applications where new functionality is being created and polymer volumes are not the key part of the equation for business success.

But while we experience slowing technology growth in traditional materials areas, a second trend is emerging—explosive growth in biotechnologies. Gene sequence data is being acquired faster than computing power (c.p.), traditionally defined by Moore’s law that c.p. would double every 18 months.³

We are experiencing rapid growth in microbial genomics, in gene expression data, and in protein crystal structures (Fig. 3).

We also see an accelerating issue of U.S. patents related to "biotechnology." If a science-based company is looking for new growth platforms, it has to analyze these trends and their significance on its key business interests (Fig. 4).

Another learning provided by our science/technology heritage is that game-changing innovations usually occur at the interfaces between, often apparently disparate, scientific disciplines (Fig. 5). Analysis of the historical development of many major breakthroughs—xerography, the heart pacemaker, oral contraception, new agricultural chemicals, etc.—shows this phenomenon.³ The dramatic growth in the polymers area was fueled by interdisciplinary developments using organic and analytical chemistry, materials science, engineering, etc.

The opportunity to create this type of interdisciplinary scenario appears to be developing again as we see biological, engineering, materials, and information sciences merging to create new opportunities.

The recent announcement by the American Chemical Society that a new journal titled Biomacromolecules will begin publication next spring is an example. It will focus on research at the interface of polymer sciences and biological sciences. As the editor, Ann-Christine Albertsson, Professor of polymer science at the Royal Institute of Technology in Stockholm said: "Nature uses polymers in sophisticated materials and in complicated processes, and scientists, especially the younger generation, are increasingly integrating the knowledge from polymers in nature in a wide range of research areas.... Biomacromolecules will provide a home for interdisciplinary investigations that integrate polymer sciences with biology, biochemistry, or biotechnology."4

Thus, a key first step is to build a multidisciplinary technology platform on which to base our product development. We are rapidly developing capabilities in genomics, metabolic pathway engineering, protein engineering, industrial microbiology, bioengineering, combinatorial chemistry, gene expression technology, etc.—all focused on new routes to useful materials with enhanced, or new-to-the-world, product functionality—and based on the belief that the big break-
throughs will not come from any of these disciplines alone, but at the interfaces. Interlaced with these emerging biological sciences are our strong capabilities in applied mathematics and physics—where, because we can describe in numbers what we know, we often progress rapidly toward practical implementation.

At DuPont, we are leveraging these technologies across four major business arenas—in agricultural products, nutrition and health, pharmaceuticals, and bio-based materials—areas where we are seeing connections as we develop genetically improved seeds, soy-based products, new drugs, new polymers, etc.

Now, it is clear that many academic labs and other companies have great strengths in many of these arenas. However, most of the industrial strength is in relatively small companies that may have a difficult time bringing the multiple technologies together. Very few organizations can put together the interdisciplinary scenario required for large-scale commercialization of materials under one roof.

The third perspective relates to how we view our customers and potential markets. The technology platform we are building has no value unless it can be directed at significant market opportunities, and can meet the needs of society.

When nylon (and other subsequent new synthetic polymers) was invented, the ultimate market potential was unclear. Yes, we were trying to mimic nature and make man-made silk—but that vision, synthetic silk, turned out to be very short-sighted and limited.

The market had to be approached from several viewpoints: (a) what could the functionality of these new materials be used for? How could we define, measure,
and manipulate that functionality toward some market need? (b) What did our customers want? What were their needs—even if they could not articulate them? (I am reminded of Sony’s Mr. Morita who said: “A customer does not know what he needs or wants until he sees what he can have”). (c) How could we create more value for both our customers and DuPont? Our research had to be “use-inspired.” We had to develop end-use application technologies. We often had to teach our customers how to use these new synthetic products. But this gave us unsurpassed insights into customers’ needs.

Now, here at the end of the century, the potential for bio-based products in the materials sector is not fully

Figure 3. Rapid technology growth.

Figure 4. Major U.S. biotechnology patents issued.

Figure 5. Major opportunities for materials.
understood. But DuPont has a huge, sophisticated materials customer base that depends on us to help define their unmet needs. We understand the materials business. A major focus of our approach to our customers is how they—and we—fit into the value chain of the markets we serve. Our current products are already key parts of these value chains. This analysis is very difficult, but is critical to understand so that any new technology can have an impact.

So even though we are at the embryonic end of a development curve, we are beginning to sense a new world in which the enabling technologies of biology can be used as a platform to help us create novel materials—some of which are not yet imagined. Biotechnology will be “game changing” in numerous markets. We need to work with our customers to progress through the transition.

The fourth perspective is fundamental to a corporation—what are the key business drivers? Despite all the history, the technology, the market needs, and customer focus, DuPont ultimately must survive as a business entity—creating value for its shareholders as well as its other key constituencies—employees, customers, the community. How does a business organization that started in an era when sailing ships took 3 months to carry messages across the Atlantic compete successfully as well in an era when information flashes instantaneously across that same ocean via satellite transmission?

Our successful wealth creation has relied on our application of science to customer needs, as well as our ability to sense the changing external environment in which we exist. Some of the key business drivers here at the end of this century include: (1) our customers’ desire for new products—a potential source of business renewal and growth; (2) the need to reduce the manufacturing costs of existing chemicals, polymer intermediates, and materials; (3) the need to reduce capital intensity because reinvestment economics for many petroleum-based processes no longer exist; (4) the need to learn to use renewable resources as feedstocks—as petroleum supplies diminish and become more expensive; and (5) the need for more sustainable business models that will continue to provide “permission to operate”—from both our owners as well as society at large.

Our objective is “sustainable growth.” We are trying to envision what “sustainability” would look like for a company such as ours, which continues to grow and transform itself in a global economy that is itself-dynamic and unpredictable. For many industrial companies, the creation of value is still linked to the throughput of materials and increased pounds of production made possible by the expenditure of large amounts of energy in the form of fossil fuels. A sustainable growth company, by contrast, builds value for shareholders and society while decreasing its environmental footprint. We see biotechnology enabling us to fulfill the needs of a growing world while minimizing risk and environmental impact.

One of the challenges confronting business leadership is the relative lack of successful business models in the materials—from-biology arena. Unlike the pharmaceutical and agriculture businesses, the route to business success for bio-based materials is not as clear because the models are emerging and changing. We must, and are, learning to make money with smaller volume specialty materials that bring extraordinary value.

But we do think there is a huge business opportunity. In a $50+ trillion global economy, materials, broadly defined, represent at least a $2 trillion opportunity—comparable to the agricultural and health care opportunities.

With rapidly changing technologies creating potential new solutions to customer needs or raising the possibility of never-before-seen materials, it is not surprising that a company like DuPont would see this as a growth opportunity in a global economy.

The final perspective that impacts our strategic decisions relates to DuPont’s sense of social responsibility. If our fundamental business strategy for the next century is one of “sustainable growth,” it must include a commitment to principles that will meet the changing needs of society.

DuPont has a long history of striving to achieve society’s support and respect. We stand on our values of safety, ethics, a respectful workplace, and being a good neighbor in the communities and countries where we do business.

To reinforce these values and principles, our CEO, Chad Holliday, recently enunciated what DuPont will stand for and commit to in the arena of application of biotechnology to society’s needs:

1. We will support informed consumer choice through meaningful information and product assurances. Where labeling is determined to be the best way to provide information, we will join in developing workable “user-friendly” systems that are science based, clear, nonmisleading and non-discriminatory.

2. We will engage and listen to all interested parties, including biotechnology critics, to understand their positions and seek advice on strategies and direction. DuPont will establish a global advisory panel to guide and challenge us in the development, testing, and commercialization of new products based on biotechnology.
3. By 2010, we will derive 25% of our revenues from nondepletable raw materials. This is in addition to our goal of deriving 10% of our energy from renewable resources during the same time frame. Our objective is to increase our growth and value to both society and stakeholders while reducing our impact on the ecosystem.

4. We will make the same commitment to the safe practice of biotechnology that we have historically made to industrial safety.

For almost 200 years we have had an obsession with safety, which has made DuPont 10 times safer than the industrial averages. Since 1937, we have maintained a world-class capability in toxicology at our Haskell Laboratory in Delaware, with much of its work focused on our crop-protection products. This year we announced an alliance with the Institut Pasteur de Lille in Northern France, focused on improving food safety and public health worldwide. And we have a small, but fast growing business—"Qualicon"—which uses DNA-based technology to determine the presence of bacteria in food much more quickly than current detection methods.

So how is DuPont's corporate/business strategy affecting our R&D/technology strategy—given the fact that we are at the embryonic phase of development?

Within the context of the five perspectives I've just discussed, DuPont has a vision to transform itself by applying the exploding progress in the biological sciences to our materials businesses.

Our corporate biotechnology research has two focuses: one is to build a "platform" of enabling technologies that can be leveraged across many businesses and aimed at several markets. The second is to focus these enabling technologies on specific relevant business needs.

We have three major projects underway: the first is focused on using microbes as "programmable" manufacturing factories to make chemicals and polymers; the second is focused on the potential use of green plants as manufacturing plants to make useful chemicals and polymers; and, (3) the third is aimed at exploring market opportunities by applying biotechnology to new or improved product functionality. I believe this is where the major research frontier—and the major opportunity—is!

This area of research is multidisciplinary, and requires teams of experts that work together. I would like to provide some examples of how we are approaching the bio-based materials opportunity in our laboratories including: (a) production of a key intermediate for a crop protection chemical; (b) metabolic engineering of a microbe to make a key polymer intermediate; and (c) exploiting an industrial bioreactor as a source for novel enzymes and metabolic pathways.

If we are ultimately going to be building new material structures, we need to focus on precise synthesis of building blocks using biological processes.

An example of this is our recently commercialized enzymatic synthesis of 5-cyanovaleramide (from adiponitrile) which is a key intermediate for an agriculture herbicide (Fig. 6). The traditional chemical route involved heavy metal catalysis, which was not site specific enough to convert only one cyano group to the amide at high yield.

By embedding in a polymeric bead a cell with the requisite enzyme that preferentially converts only one end of the adiponitrile at very high yield and with very high catalytic efficiency, we've been able to create a commercially viable process for this building block. By eliminating the heavy-metal catalyst, we have reduced environmental impact such that the U.S. EPA wrote a favorable citation to DuPont complimenting the biological approach to chemical synthesis. This is clearly a more sustainable "business" case—lower cost, higher quality, reduced environmental impact. But this relatively simple, one-step enzymatic bio-transformation is only a first step to impact the chemical and materials industry.

A larger vision is to genetically modify the metabolic pathways of microbes or green plants to make materials that are difficult (or near impossible) to make economically by traditional chemical catalysis (Fig. 7).

An example of this is our proprietary technology to manufacture 1,3-propanediol (which we call 3G) using a genetically modified form of E. coli. 3G is a long-sought intermediate which, when polymerized with terephthalic acid, creates a polymer, called "3GT," which has a broad range of applications in material end-uses.

A key driver here is to start with a low-cost, renewable resource—in this case, glucose—which is derived from maize through the corn wet-milling process. No one has yet found in nature a single micro-organism that can convert glucose to 1,3-propanediol. However, organisms were known that convert glucose to glycerol as well as organisms that can convert glycerol to 3G. Working with our research and development partner, Genencor International, we've combined genes from two different organisms into one E. coli host, and have been able to make this key monomer with yields, fermentation titers, and quality required for commercial success.

We are applying multiple enabling technologies to create the 3G production organism. For example, we have solved the three-dimensional structure of glycerol dehydratase, a key enzyme in the modified E. coli pathway. This is, by the way, one of five new protein struc-
Biocatalytic production of 5-cyanovaleramide from adiponitrile.

We have determined in the last 2 years using our capabilities at the Advanced Photon Source at Argonne National Lab near Chicago.

We also have employed DNA array technology to examine the expression of the key genes in the inserted pathway. Controlling gene expression in a specific manner to enhance the productive pathway while blocking unproductive and destructive pathways is crucial for creating an economically viable process. We have a team of scientists developing some of the latest techniques to look at global gene expression profiles in microbes and plants. (Think of this as creating an aerial photograph of a city to determine traffic patterns, congestion, by passes, etc.)

The power of these technologies is enormous. What used to take biochemists, microbiologists, and geneticists several years to understand now can be addressed in a matter of months.

As this curve demonstrates, our progress has been steady. We will be moving to pilot phase in early 2000, and are planning to commercialize this process as market demand for 3G expands (Fig. 8).

For a Fermentation Process:

We have invented** a single bacterium to do both steps.

Single Microorganism

*3G = 1,3-propanediol
** U.S. Patent 5686276
Figure 8. Engineering a microorganism to convert corn sugar to 3G for 3GT (120× improvement).

Of course, R&D work does not move in such a smooth curve (Fig. 9). This is a more realistic picture of the progress we have made showing the periods of time when we were developing technologies and accumulating knowledge!

Now, I would like to provide a final example of how we are scouting for new proprietary biocatalysts and isolating novel genes. We have come to realize that instead of going to thermal springs in Yellowstone National Park, a key source of microbial diversity exists within our own plant bioreactors, where, over time, microbes have evolved to live on the nutrients available around our plants, creating the basis for many chemical reactions of interest to our materials businesses. The microbes in these bioreactors compete for different car-
bon sources and have to constantly evolve new metabolic capabilities to survive. As a result, these bioreactors are a rich source of novel biocatalysts. We have isolated several microbes that carry out interesting chemical reactions that are relevant to our business interests.

For example, adipic acid production from cyclohexanone by chemical conversion has been practiced by DuPont for a long-time using high temperature, pressure, and corrosive processes. While “mining” our waste bioreactors, we’ve been able to isolate microbes that oxidize cyclohexanol to adipic acid. The biological route has a series of interesting potentially valuable metabolites in addition to the production of adipic acid. We have constructed recombinant E. coli that produces the adipic acid only when the key genes are present as shown in the histogram (Fig. 10). All the relevant genes in this pathway have been isolated, and now we can produce any of the intermediates in the pathway. This project was accomplished in 3 months by applying genomics, biochemistry, and analytical sciences. We’ve quickly uncovered a lot of novel genes in this type of analysis.

Our early success with the metabolic pathway engineering of several key microbes has encouraged us to look more broadly into microbial diversity as a potential source of enzymatic chemistry as a route to new materials.

Using our in-house high-throughput DNA sequencing capability, built originally to support the genomics effort of our Agricultural Products business, we have embarked on a strategy to sequence 20-30 of the key industrially significant microbes over the next 2-3 years. The first microbe is complete and we will be announcing the specifics on that as soon as our proprietary position is solidified. This microbial genomics effort will provide us a key part of the platform on which we can build our emerging materials-from-biology business.

We also have projects in which we are seeking to provide a platform for an array of end-uses—just as a single monomer, tetrafluoroethylene, has created an entire business enterprise centered on fluorocarbons and fluoropolymers. The monomers being sought have historically been difficult to make using petrochemical catalysis. We are learning to make silk-like proteins in microbes and plants. We are also looking for the gene that codes for the protein that polymerizes isoprenylpyrophosphate—the key intermediate for very high molecular weight natural rubber. All these projects are requiring close coupling of biologists and material scientists to make progress.

We are often asked in what areas we see needs for research that could facilitate the application of biotechnology to the materials arena. Several come to mind, such as (a) the need to characterize large numbers of small material samples (that might be typically made from genetically modified microbes or green plants) and relate any changes in structure to ultimate product functionality. This inability to evaluate the small material candidate samples created in the early stages of research is one of the high frustration areas I hear from the biologists. (b) The broad area of engineering research is another critical arena. I mentioned earlier that, when the materials revolution triggered by the discovery of nylon began in the 1930s, new engineering sciences had to be developed to create commercially viable processes. Once again, here at the end of the century, we see such a need. What types of new “bioreactors” are possible? How will we deal with the many separations issues that will result from new bioprocesses? Will new bio-based materials require different types of postprocessing (spinning, molding, etc.)? (c) We need to understand how the emerging areas of biological science will impact the world of electronics materials. (d) How will combinatorial techniques be applied to new materials discovery (beyond catalysis)? Can we make and characterize large volumes of small samples quickly?

I would like to conclude this section on opportunities and challenges by focusing on an issue that I believe goes at the heart of this forum—the issue is relationships. Many scientists tell me that the biggest challenge they see at this life sciences/materials interface is about relationships among the people required to work across very disparate disciplines. One of our lead biologists who is working on an interdisciplinary program with materials scientists expressed some “common sentiments”: (a) “how do I get educated in materials science (or biology) when it is difficult to keep up with my own specialized field?” (b) “I work in acetonitrile—you work in water!” (c) “I work with grams—you work with micrograms.” (d) “I view molecules in terms of their effects (activity)—you view them in terms of structure and properties.” (e) “Materials need to be durable and manufacturable, BUT the very properties of biomolecules are typically fragile, and depend on constant renewal.” If we are to be successful at this interface, we’re going to need to learn how to facilitate the basic elements of any good relationship: trust, respect, communication skills such as listening, meaningful dialogue, less field-specific jargon (which only enhances feelings of alienation), and shared values/goals. And we are going to have to train increasing numbers of students at the materials/biology interface. I am hopeful that this type of forum can move us in the needed, desirable direction—so that we can have a successful marriage across these disciplines.

I would like to conclude with an historical perspective on the collaborative, needs-focused research that I think will be required to be successful. Some might suggest that there is an inherent conflict between building a
strong science base and "needs"- or "use"-inspired basic research. Our experience suggests that needs-focused research at the interface between materials and life sciences can provide routes to commercial success.

Donald Stokes was professor of politics and public affairs at the Woodrow Wilson School at Princeton University. In his recent book, Pasteur's Quadrant, he discussed at length the ongoing debate over the apparent conflict between "basic" and "applied" research down through the centuries.

In his description of the philosophical evolution of science and technology, he points out that the "coupling of knowledge and action characterized the Italian Renaissance, the cultural seed-bed of early modern science ... The enterprises of Brunelleschi, Leonardo da Vinci, Michelangelo, Christopher Columbus ... were animated by the same instinct that later formed a Galileo, namely that knowledge finds its purpose in action and action its reason in knowledge." (As an aside, I think it is not irrelevant to point out that any historian would describe a more mundane drive by these noble Italian heroes—to make money, to earn a living, to survive!)

Stokes went on at some length to discuss how Louis Pasteur epitomized the scientist who could extend the frontiers of understanding but was also inspired by "considerations of use." While renowned for his scientific discoveries made in his quest for knowledge related to racemic mixtures, crystallography, etc., Pasteur very early in his career became enmeshed in trying to solve some of society's problems of the day. In fact, as dean of the local faculty, Pasteur encouraged his students to do "practical work in industry." Thus, he was often called upon by local industrialists to deal with "real-world" problems.

One of these industrial problems was experienced by those who made alcohol from beets. Pasteur visited a factory and took samples of the fermenting beet juice to his laboratory for microscopic examination. Stokes continues: "threading his way through a maze of scientific misconceptions, Pasteur identified the microorganisms responsible for fermentation and showed they could survive without free oxygen—indeed, that they produced the alcohol resulting from fermentation by wresting oxygen from the sugar in the fermenting juice. This insight gave his industrial clients an efficient means of controlling fermentation and limiting spoilage."

Later in his career "no one can doubt that Pasteur sought a fundamental understanding of the process of disease and of the other microbiological processes he discovered ... But there is also no doubt that he sought this understanding to reach the applied goals of preventing spoilage in vinegar, beer, wine and milk and of conquering flacherie in silkworms, anthrax in sheep and cattle, cholera in chickens, and rabies in animals and humans. ... As Pasteur's scientific studies became progressively more fundamental, the problems he chose and the lines of inquiry he pursued became progressively more applied. ... Many of his detailed lines of inquiry, such as the experiments by which he developed the process of the 'pasteurization' of milk or his experiments in growing attenuated bacterial strains to immunize patients from disease, are unintelligible from his applied goals. The mature Pasteur never did a study that was not applied, as he laid out a whole new branch of science."

I believe Pasteur's example illustrates how we in industry need to think about our customers' needs and how to link our scientific prowess to society. Who is "society"? To us, "society" is often represented by our customers—the vast majority of whom are in the materials businesses. Our success depends on the success of these materials-using customers. But we also must be cognizant of the needs and concerns of those who are not direct customers—who may not be able to afford our products but who might be impacted by our actions. Our recently enunciated principle to seek input from all segments of society is an attempt to do this.

Just as Pasteur tried to understand the needs of his society—in industry, in agriculture, in Napoleon III's government, of the people in the street who were sick, etc.—and applied the basic science of microbiology to solve those needs, so we are trying to use the modern "life sciences" to meet our societies' needs—many of which are just as unknown and mysterious here at the end of the 20th century—as were the needs of Pasteur's day.

To summarize, we at DuPont believe that there is a huge opportunity being created at the interface of biological and materials sciences—opportunities to meet unmet customer needs in many markets, with new, sometimes unimaginable, product functionality. A technology revolution is setting the stage to transform the processes and functionality of materials.

We believe there is a potential competitive advantage by building a life sciences-based technology platform that can be leveraged across several materials businesses as well as our agricultural products, nutrition, and pharma businesses. The new technologies being created by the biological sciences will have a difficult—if not impossible—time being applied to materials opportunities, unless there is a close-coupled connection with materials scientists and customers—and their needs. We intend to enhance that coupling of scientific strengths with the marketplace.

We believe the knowledge from life sciences CAN be applied into the field of materials in an economically acceptable way. I have cited a couple of examples where we are at, or are near, commercialization of key chemical intermediates using enzymology and fermentation.
REFERENCES AND NOTES