THE IMPACT OF BIOTECHNOLOGY AND NANOTECHNOLOGY ON THE CHEMICAL AND PLASTICS INDUSTRIES

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Abstract

Nanotechnology, Biotechnology and an increased awareness of the environment are generating new and emerging technologies that could have a disruptive effect on various segments of the plastics industry.

This paper will discuss the areas where the greatest disruption will occur and how. For these emerging technologies to be adopted in the mainstream they will need to demonstrate performance advantages as well as total cost performance benefits. This transition is beginning to occur. Taking the time to understand where these new technologies could change the way we do business will keep us ahead of the competition and help us determine the opportunities which are available to us.

Introduction

The stage is being set for a transformation of the chemical industry in the 21st century. The traditional boundaries separating chemistry and biology in production strategies is blurring and this is a growing trend. The advancement of materials and systems at the nano scale is expanding.

Leading chemical companies such as DuPont, Dow, Eastman, Aventis (Hoechst and Rhone Poulenc merger), Novartis and Monsanto which will merge with Pharmacia-Upjohn are reinventing themselves as "life Sciences" companies or are using acquisitions and strategic alliances with companies like Genecor and Diversa to take advantage of the increasingly important role of biotechnology. Through biotech-based R&D these companies will likely grow and prosper throughout the coming century.

Nanoscale science and engineering is the creation of functional materials, devices and systems through the control of matter on the nanometer (1 to 100+nm) length scale and the exploitation of novel properties and phenomena developed at that scale. Nanoscale materials are not new, but our understanding of them is. With better analytical techniques we are gaining a better understanding of the kinetic and thermodynamic conditions that give rise to nanoscale structures.

The following table lists some examples of old nano-technologies which have been re-juvenated by the availability of better analytical tools.

Old technology	**New technology**
Carbon Black	Carbon Nanotubes
Fumed Silica	NEMS
Colloidal silver	Quantum dots
Zeolites	De-aggregated nanoparticles
Catalysts	Nanowires

Experts believe that the US chemical industry will offer a "library" of diverse, high quality nanomaterial building blocks (less than 100 nanometers) that can be synthesized by well-defined, economically viable manufacturing processes into materials with well-characterized compositions, stable architectures and predicted properties. Reproducible, cost-effective and clearly defined methods of assembly will be available to incorporate nanomaterials into systems and devices designed to perform specified functions.

Developments in nanotechnology will also enhance the role biotech plays. Examples include: the silicon nano interface, the carbon nano interface and functional materials based on these technologies. For example Dow Corning and Genecor have formed a partnership to explore nanoscale systems for biosensing devices and performance materials.

Some of the companies involved in an industry partnership (Vision 2020) to advance nanotechnology are: Air Products, DuPont, Eastman, Honeywell, GE, Rohm and Haas, Dow Chemical, Cargill and Ciba Specialty Chemicals.

Background- Industrial Biotech

Industrial biotechnology uses the same tools developed for medical biotechnology to discover new ways to make energy, industrial raw materials, intermediates and consumer goods. "Green Biotech" or agricultural applications and "Red Biotech" Pharmaceutical applications are now being joined by "white" or industrial biotech. Advances in genetic engineering and bioprocess pave way for refinement of subtleties in catalytic processes. With applications in several industries, industrial applications are just now entering their growth phase.

Advances in three key areas of biotechnology are driving this transformation of the chemical industry:

Biocatalysis- the use of microorganisms and especially enzymes to catalyze certain reactions and the use of molecular biology techniques to modify enzymes so they will have specific catalytic properties.

Metabolic Engineering- genetically engineering plants, animals and especially microorganisms, to have all the biocatalytic steps for production of a particular

chemical contained within their cells so that the cells are in effect highly efficient mini-reactors

Plant Biotechnology- genetic engineering of plants to have specific characteristics (e.g. lower levels of lignin or higher levels of starch) which increase the efficiency and yield when they are processed into certain products.

Lower capital expenditures, lower raw material costs, the ability to create new functionality and the promise of low environmental footprint are all potential benefits which are motivating the increased research in the field of biotechnology and industrial chemicals.

Discussion

Mc Kinsey states that biotechnology will be one of the key innovation drivers in chemicals and polymers over the next 10 years. With less than 3% penetration today, they predict biotechnology will penetrate industrial chemical and polymers applications to 20% of the chemical market ($280 Billion US) by 2010. The benefits of "white biotech" are numerous. Biotechnically based chemicals and polymers have faster cycle times, low cost bio-feedstocks, more efficient bio-processes and more means of production than conventional processes.

Some commercial products that use bioenergy or are bio- based products include bio-polymers (PLA,PDO,PHAs), fuel(bio-ethanol), chemicals (ethyl lactate, succinic acid and lactic acid) and lignin..

Experts believe that biotechnology will play a big role in many markets-drugs and vitamins, textiles, leather, pulp and paper, mining, metal refining, electro-plating, molded goods, film packaging and fibers.

Factors Affecting Acceptance

In addition to an acceleration in technical developments, there are socio-economic factors that are influencing the movement of biotech and nanotech into the industrial chemicals and polymers businesses. The globalization of industry is causing the migration of lower technology, higher volume manufacturing sectors to lower labor, emerging economic regions of the world. China, India and South America represent sources of low cost labor and an emerging source of demand for commodity products and services. North America and Western Europe in contrast are low growth demand markets.

Energy costs have sky-rocketed in recent years causing the more developed countries a serious crunch on profitability in the production of goods. Alternate routes to fossil fuels are now being more seriously considered than they have been in the recent past.

The third factor which will influence the expansion of these technologies is the "war on terrorism" and similar socio-political developments that are influencing sourcing of energy and raw materials.

These factors along with ever-present environmental concerns like global warming are making the environment more favorable for industrial biotechnology. This is coined the "Triple Bottom Line"-biotechnology provides economic, environmental and social benefits.

Industrial Biotechnology is becoming attractive from a business perspective because it:

- Decreases production costs
- Increases sustainability profile
- Allows broader use of agricultural feedstocks instead of petroleum
- Provides precision catalysis
- New bio-catalysts constantly being discovered
- Not controversial like medical biotech

Recent developments in industrial biotechnology include:

- Broad spectrum of available enzymes and fermentation systems
- Enhanced speed of biotech development (genome sequences, libraries, screening, mutagenesis, pathway engineering)
- Higher yields and lower cost (process optimizations, enzyme stability, immobilization techniques)
- Growing public demand for sustainable production methods

Some examples of product benefits using biotechnology:

- Improved enzyme activity for antiobiotic production
- Improved enzyme activity for biomass (low cost energy source)
- Bio-based polymers with enhanced or added-value properties

How has Biotechnology added to Industrial Sustainability?

A study was done in 2001 by the OECD (The Organization for Economic Co-operation and Development) to analyze companies who have adopted new biotechnology processes (21 case studies). The objective was to understand the factors affecting their decision making and policy lessons that emerged.

Companies participating in the study included: Cargill Dow, Ciba, DSM, BP Amoco and Mitsubishi Rayon.

The OECD Report concluded some significant findings: Biotech invariably led to a more environmentally friendly process and resulted in a cheaper process. The role of the environment was secondary to cost and product quality. However environmental legislation/regulation was sometimes a driver.

Biotech is providing significant benefits to the polymers market. For example, to produce dodecane dioic acid, a monomer for nylon, requires four synthesis and four isolation steps in the traditional process but only one synthesis and one isolation step in a biotech process. The result could be a 75% savings in capital equipment and a 50% cut in operation cost.

Drivers to Industrial Biotech and Nanotech Research

Radical new business models will appear and threaten traditional players. Opportunities will develop for fast movers with novel products. Companies that are early adopters of industrial biotech processes will realize a competitive advantage. Only very large players will really be able to realize the full value created by biotech, however smaller players can benefit by partnering with each other or larger players.

One of the biggest challenges facing our planet is finding ways to run our conventional industrial processes that use non-renewable feedstock into processes that are eco-efficient. At present more than 85% of the United States' energy supply is fossil-based with less than 4% coming from solar, wind, geothermal and biomass, 8% coming from Nuclear and 4% coming from hydro. Currently hydro energy constitutes almost half (48%) of the renewable energy used in the US, but that figure is expected to decline as concerns over water shortage continue. The next largest segment is biomass (44%) comprised primarily of lumber company waste.

A report written by the DOE and USDA in 2001 highlighted the need not only for investment by public-private partnerships but also the use of integrated R&D to foster innovation. Currently there are more than 250 companies in the US producing a variety of biobased products. A number of these companies were fostered by the federal mandated use of recycled products and by the low cost agricultural availability of the starting materials. Conversion to biobased products would provide more income to agriculture and forestry producers and processors.

Nanotechnology upgrades the properties of lower cost materials so that they can compete in new applications or where applications have been over-engineered.

Companies Leading the Way in Industrial Biotech

With 2002 revenues of about $340 million, Genencor is the 10th largest biotech company worldwide. Genencor has formed various partnerships including one to develop silicon products with Dow Corning. Genencor's bioproducts profile and product development pipeline include:

1. DOE funding of the development of advanced cellulases to hydrolyze biomass is a three year R&D program initiated in 2000 to reduce the cost of fermentation of raw materials (renewable carbon for the biorefineries of the future.

2. Metabolic pathway engineering and biological routes to small molecules, e.g. ascorbic acid with Eastman Chemical; and propanediol with DuPont (a precursor for the high-performance polyester, Sorona)

3. Silicon biotechnology™; an alliance with Dow Corning to develop new biologically mediated organosilicon-based compounds.

4. Active ingredients for personal care including low-allergenic proteins (enzymes) and peptides, both with specially designed features to deliver new consumer benefits.

Diversa is taking a different approach to the development of enzymes. The company is engineering enzymes in the same way that drugs are developed. Diversa has partnered with Celanese, Ltd. for whole cell optimization opportunities for commodity and specialty chemical applications.

While enzymes are a key part of the equation, we must build biorefineries that are fully integrated industrial facilities capable of transforming not just corn, but the cellulosic biomass into a full range of products.

Researchers are already seeking ways to genetically engineer plants to produce not only higher levels of sugar and starch but also to make the plastics precursors within their own cellular factories.

Dow's industrial biotechnology venture, Cargill Dow, has pioneered corn-based products in packaging, apparel and solvents. Since 1989, the firm has invested $750 million in developing and manufacturing polylactic acid from corn and is turning its efforts toward using corn stover (plant biomass other than the jernel) as a raw material to lower production costs.

By far the highest profile accomplishment in 2001 has been the completion of Cargill Dow's polylactic acid plant in Blair, Nebraska. The biorefinery converts sugars from conventional corn into polylactic (PLA)-a biopolymer that is compostable and can be used for everything from packaging films to textiles. Within the next few years, Cargill Dow is planning to convert this process into one that uses cellulosic biomass (the corn stover, i.e. the leaves and stalks and not the ear) as well as other sources of cellulose. Also in 2001, DuPont and its development partners demonstrated at their pilot plant in Decatur Illinois, the commercial feasibility of making the key ingredient for its new high-performance polymer, Sorona™, from the bioprocessing of corn sugar.

Within the next few years, Cargill Dow, DuPont and others will no doubt be operating fully integrated second-generation biorefineries that take in any vegetable matter

available in sufficient quantities, and churn out fuels and polymers with specified characteristics designed in protein and metabolic engineering. DuPont plans to build a bioprocessing facility for Sorona ™ near a corn wet mill and Cargill Dow says it plans to build four large integrated biomass plants with the next 7-8 years.

The market for plastic and polymers (now made primarily from petrochemicals) is an estimated 300 billion pound market generating some $70 billion in U.S. sales in 2002. Over the next 50 years petroleum will become shorter in supply and we will need to have another source of carbon. Cargill Dow has a 300 million pound PLA plant and lactic acid plant with a $1.00/pound capacity. They plan to convert that technology to use biomass. This will make them even more competitive and open up a whole host of new market opportunities.

Metabolix Inc. also uses biotechnology to produce environmentally friendly performance plastics and specialty chemicals renewable resources. The company applies metabolic engineering and molecular biology to create efficient production of biopolymers in microbial systems via fermentation, and directly in non-food crops.

In a report from the Office of Industrial Technologies, "Fostering the Bio-Economic Revolution", the authors provided a pictorial example of today's costs and volumes (distribution) of biobased and fossil-derived plastics. In the future, these distributions could change markedly. Biobased products could generate 3 billion pounds or more of products covering a wide range of costs and volumes by 2010 and significantly offset petroleum use.

Activity in Nanotechnology

What is the market size for Nanotechnology? The answer to this question is three-fold. What is the market size for microtechnology or nanotubes? What is the opportunity size for specific applications enabled by nanotechnology? What new markets can be created as a result of enabling nanotechnology?

Capturing value is a major issue today for nanotechnology. Who will get the value …the nanomaterials manufacturer or nanocomponents manufacturer or systems/applications supplier?

Nanomaterials	Nanocomponents	Targets
Buckyballs and tubes	Transistors, electrodes, coatings	Process Power Construction Electronics Medical Materials

More than in Biotech the value creation will vary with the application. It depends on the advantage which Nano creates, the complexity of the target application, manufacturing and market presence and issues.

For the purpose of our discussion we will focus just on the developments in materials where the majority of the patents are represented. The market estimate for materials is $340 billion worldwide. Under materials we include: superstrong adhesives and cements, net shape manufacturing of ceramics, metals, and cements, novel resins (strong, fire-resistant), high temperature, light weight, high strength metals and ceramics, high-strength nano-dimensional fibers. (See Table1- A.)

There will need to be new business models and strategies developed. As physical volumes drop and knowledge content increases, material suppliers will need alternative business models. This will be necessary in order to reward investments in new materials research and development. There will be a need for more cooperative partnerships and more ways to capture value for knowledge content.

Conclusion

Biotechnology is having a profound impact on the way we create, use and dispose of products. It provides alternative sources of energy from biomass; plastics, surfactants and fibers made from biobased materials; biobased specialty chemicals, biocatalysts and bioenzymes.

Nanotechnology is transforming how we develop and enhance material properties and systems.

The government is fostering intra-agency initiatives to foster progress in both areas. There is serious public investment and new companies are emerging.

Industrial biotechnology and nanotechnology need to be on your radar screen. We believe that we are now entering a period of accelerated growth and a new age in the chemical and polymer industries. We all need to see where we and our businesses fit in the penetration of these newer technologies into the mainstream of the chemicals and polymer businesses. This includes polymer producers, compounders, fabricators and end-users of chemicals and polymers.

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Keywords:

Biotechnology, Nanotechnology, Chemical and Polymer Industries

Table 1-A. Nanotechnology-Innovative Products in Materials

Industry sector	Features added through Nanotechnology	Innovative product
Plastics Industry	Nano powder. Surface improvement, dispersion technology	Thermal insulation, anti-UV, antibacterial, high fade resistant materials
Man Made Fiber Industry	Nano-function formulation technology	High strength, anti-bacteria, abrasion resisting, electric conducting, low gas permeation, environmentally friendly packing materials
Coating Industry	Nano porous structure technology	Abrasion resistant, antibacterial/UV, high temperature stable, flame retarding, nano-color paste/ink, high thermal conducting material
Paper Production Industry	Self-assembly process technology	Food preservation bag, high quality printing paper, high-stiffness film
Construction Industry	Nano Interface processing technology	Self-cleaning, thermal insulation, anti-fog
Metal Industry	Nanocrystal lattice control technology	High strength steel aluminum alloy, abrasion resisting surface treatment
Chemical Industry	Nano-catalysts, sensor, high thermal; conducting materials, glass coating	

Table 1-B Segmentation of Nanotechnology by Technology

Nanoscale Materials	Nanostructured Systems	Devices and Tools
Inorganic nanoparticoles	Nonporous materials	NEMS
Organic nanoparticles	Consolidated nanoparticles	Nanomanipulators
Carbon nanomaterials	Nanocomposites	Analytical tools