Biobased Industrial Products: Back to the Future for Agriculture

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In 2000, the National Research Council published a report on the potential impact of biobased industrial products in the twenty-first century. The priorities for research and commercialization were described in terms of agriculture expanding into health, energy, chemicals and materials. Agriculture is now armed with new biotechnology and bioprocessing tools, and is going back to reclaim the markets it lost to the petrochemical industry after the 1930s. This paper will discuss new markets and research and development priorities, and provide examples of new biobased industrial products that are entering commercialization. These include transgenic plants, pharmaceuticals, biochemicals, fuels, agri-chemicals, bioplastics, and higher-value polymers and materials. As an example, the role of MBI International in the scale-up and demonstration of these new biobased industrial product technologies will be highlighted.

Introduction

The NRC report, *Biobased Industrial Products*, assumes that "biological sciences will have the same impact on the formation of new industries in the next century as physical and chemical sciences have had on industrial development in this century" (NRC 2000). This prediction is supported in part by four dominant themes. First, US agriculture's history of making industrial products from agricultural feedstock before the advent of the petrochemical industry, and the realization that agricultural carbohydrates are a lower-cost resource than petroleum-based hydrocarbons (Figure 1). Before 1940, medicines, synthetic fibers, plastics, paints and inks were made from agricultural feedstock. For

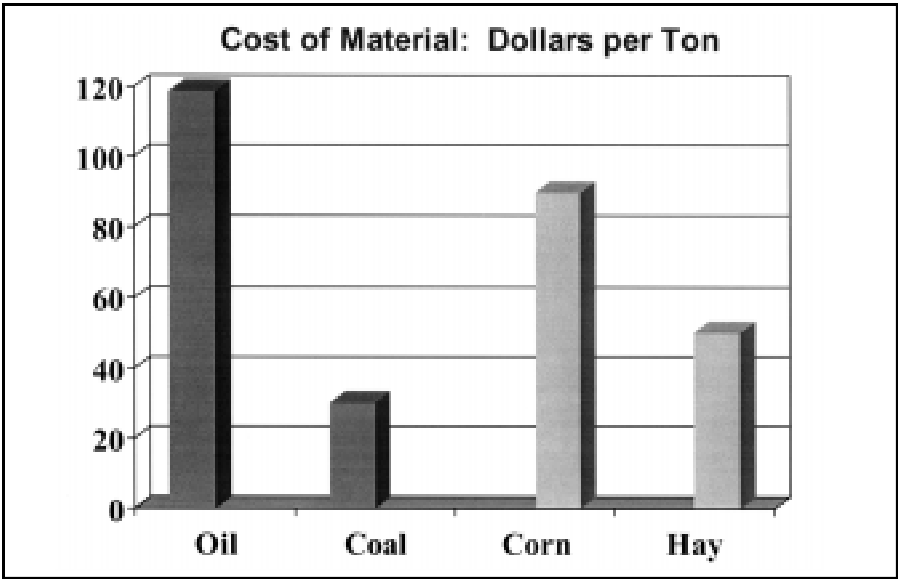

Figure 1. Cost of raw materials: fossil vs. renewable plant materials (NRC 2000).

example, in 1935, each Ford car contained components manufactured from two pounds of soybeans. Second, the new tools of genetic and bioprocess engineering now enable economic improvements in feedstock utility and manufacturing systems. They produce a wider diversity of higher-value products than is feasible by petrochemical processing. Third, significant environmental problems, including pollution and global warming, are associated with industrial processing of fossil fuels. Finally, it is common sense that petroleum, a non-renewable chemical and energy resource needs to be replaced by renewable agricultural carbohydrates to drive the economy of the new millennium.

These factors invite the question, "Are biobased industries America's next frontier?" If so, there is need for a national awareness far greater than that used to launch the space program that put the first man on the moon. Both our future economic and our planetary well being are at stake in developing the "Biobased Industrial Products Society." In the rest of this discourse, I will address market-pull and technology-push issues, the NRC report, research and commercialization priorities, and the role of universities, federal laboratories, MBI International and others in making this vision of the future a reality.

Market Pull–Technology Push

A wide variety of industrial products, including biomaterials, fuels, and biochemicals are already manufactured from biobased raw materials (Figure 2).

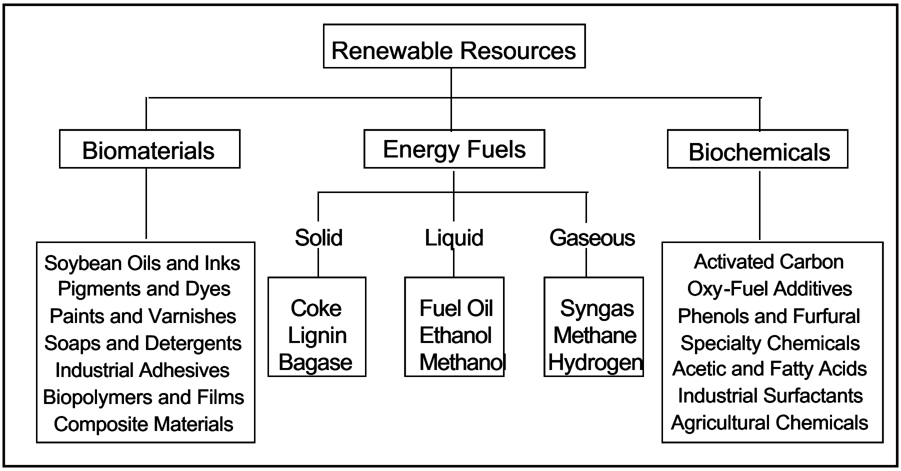

Figure 2. Biobased products manufactured today (NRC 2000).

The current emphasis placed on production of liquid fuels (i.e. ethanol) is a difficult challenge because it competes with a petroleum product, gasoline, which requires minimal refining. Oxychemicals, on the other hand, offer the possibility to produce higher value organic molecules via biobased processes, because costs to introduce oxygen into hydrocarbons are higher for oil refining. The NRC report targets for increasing biobased industrial products manufactured in the US over current levels for liquid fuels, organic chemicals and materials are 50 percent, 90 percent and 99 percent, respectively, of total industrial production by 2090 (Table 1).

TABLE 1. TARGETS FOR A NATIONAL BIOBASED INDUSTRY (NRC 2000)

	Biobased production levels (percent derived from biobased feedstocks)		
Biobased product	Current level	Future target: intermediate (2020)	Future target: ultimate (2090)
Liquid fuels	1–2%	10%	Up to 50%
Organic chemicals	10%	25%	90+%
Materials	90%	95%	99%

Industrial products are already made in large amounts from processed agricultural carbohydrates (Zeikus 1990). Sales of these products increased from $5,400 million in 1983 to $11,000 million in 1994 (Table 2). Sales of specialty biochemical products (phytoceuticals, nutraceuticals, biocontrol agents, vitamins, food-ingredient agents, etc.) are growing at greater than 15 percent annually. Crop processing has many added economic benefits for the US when compared to petroleum processing (Table 3), including decreased oil imports, enhanced balance of trade, decreased environmental pollution, and the development of renewable sources of chemicals, fuels and materials.

TABLE 2. WORLDWIDE SALES OF BIOTECHNOLOGY PRODUCTS, 1983 AND 1994 (NRC 2000)

	1983 ($ millions)	1994 ($ millions)
Fuel and industrial ethanol	800	1,500
High-fructose syrups	1,600	3,100
Citric acid	500	900
Monosodium glutamate	600	800
Lysine	200	700
Enzymes	400	1,000
Specialty chemicals	1,300	3,000
Total	5,400	11,000

TABLE 3. BENEFITS OF CROP PROCESSING TO INDUSTRIAL PRODUCTS

Better use of agricultural resources
Revitalize rural communities
Functionally superior products
Reduced dependence on foreign oil
Export more value-added industrial products vs. crop commodities
Potential greenhouse gas benefits

Today, many new kinds of genetically engineered crops are entering the marketplace. They lack approval in foreign markets and from the US public because they are being viewed as “altered and unsafe.” This false perception is not currently a problem in the marketplace for biobased industrial products. For example, enzyme products from genetic engineering are already used in making cheese and high-fructose corn syrup. Genetically engineered plants for pharmaceutical synthesis are viewed as positive for lowering costs of drug production. It is anticipated that genetic engineering of plants and microbes will lower costs for both the feedstock and the manufacturing process for biobased industrial products.

Research Priorities

Decades of agronomic research have shown us how to inexpensively grow crop commodities. Now, investment is needed to learn how to inexpensively convert value-added crop commodities to industrial products. The NRC report established research priorities for systems, biology, engineering, and research.

Research priorities for systems include:

- evaluate sustainability/environmental issues
- integrate biological and engineering research
- emphasize risk reduction/proof of concept
- develop infrastructure of trained people, databases, demonstration facilities, etc.
- consider incentives/preferences.

Research priorities for biology include:

- the genetics of plants and bacteria that will improve understanding of cellular processes and plant traits
- the physiology and biochemistry of plants and microorganisms directed toward modification of plant metabolism and improved bioconversion processes
- protein engineering methods to allow the design of new biocatalysts and novel materials for the biobased industry
- maximization of biomass production.

Research priorities for engineering include:

- principles and processing equipment to handle solid feedstock
- fermentation technology to improve the rate of fermentation yield and concentration of biobased products
- downstream technologies to separate and purify products in dilute aqueous streams.

MBI International

MBI is an entrepreneurial center that develops new industrial products made from agricultural resources. MBI's sole focus is on the risk reduction/proof of concept stages of research and development. We call this "Death Valley" because many new discoveries do not meet the objectives that are required for commercialization. Negligible funds are available from industry and investors to develop products from discoveries unless technical and economic validations are presented (Figure 3). Since 1992, MBI has launched eleven technologies into new biobased companies via our business pipeline model (Figure 4). MBI (a non-profit 501c3 corporation) researches technologies and markets for new inventions, and performs scale-up and economic demonstrations. The commercial-ready technology is then transferred to Grand River Technologies, Inc. (MBI's wholly owned for-profit subsidiary), for commercialization via a start-up company, joint venture or warranted out-license.

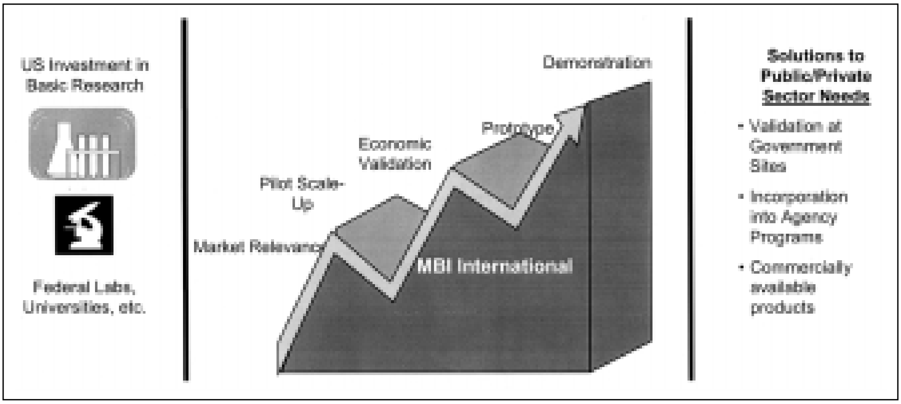

Figure 3. Death Valley

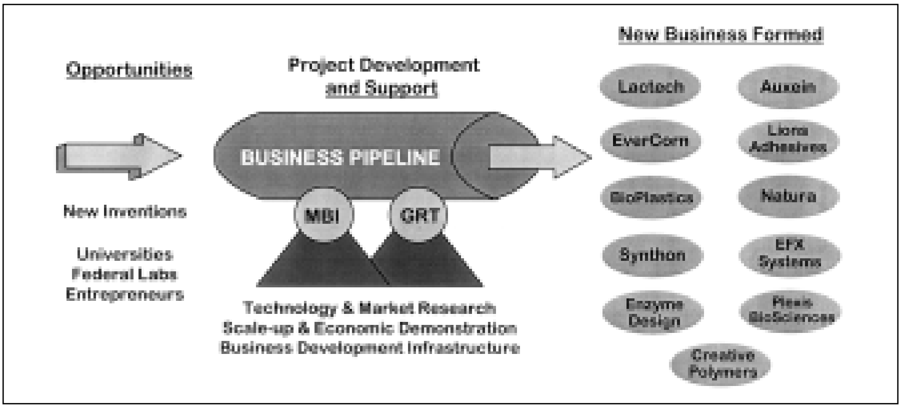

Figure 4. MBI International

Lactech, Inc. was a joint venture with Cargill to develop low-cost polymer-grade lactic acid by fermentation of corn glucose. At the completion of the scale-up/demonstration phase, Lactech was fully acquired by Cargill, who then formed a joint venture with Dow Chemical, Cargill Dow Polymers, LLC. This new joint venture has invested $300 million in the first of three plants. Cargill Dow plans to sell 3 billion pounds of polylactic acid in industrial fibers and 1.5 billion pounds in packaging plastic films, coatings and containers. The first plant in Blair, Nebraska will use 40,000 bushels of corn per day.

Synthon Corporation of Princeton, NJ, is a second company launched by MBI/GRT. It makes chiral intermediates from optically pure sugars, for drug manufacture. The first technology used lactose, a by-product of cheese making, to synthesize hydroxygamma butyl lactone, a compound used in $5 billion worth of drugs including cholesterol depressants, analgesics, broad-spectrum antibiotics and HIV protease inhibitors.

Auxein Corporation of Lansing, MI, is a third company launched by MBI/GRT. It produces natural "plant metabolic primers" (i.e. γ-amino butyrate, succinic acid, and glutamate) that enhance plant growth and decrease pesticide usage under environmentally stressed growing conditions. This product increases the yield of all crops, but most noticeably increases flowering, the size of potatoes, Brix content of grapes and the solids content of tomatoes.

MBI has a full pipeline of biobased industrial product technologies currently at various stages of proof-of-concept, scale-up and economic demonstration (Table 4). One platform technology under development is succinic acid, which promises to be a large-volume product (Zeikus et al. 1999). The reason ethanol production from biomass is not economical without a subsidy is the loss of carbon in current corn-processing systems. Notably, 2 moles of CO_2 are lost per mole of glucose fermented into two moles of ethanol. In the dry milling process, non-fermented fiber is used as an even lower-value animal feed

TABLE 4. MBI'S CURRENT BIOBASED INDUSTRIAL PRODUCT R&D PROJECTS

Coatings for medical devices
Coatings to prevent biofouling
Coatings for use in electronic devices
Low-cost, premium animal feeds
Oral vaccine production and delivery systems
Phytoceuticals
Biorepellents / biocontrol agents
Bioabrasives
High-value co-products from ethanol production (including succinate and derivatives)

byproduct in lieu of direct conversion to ethanol or higher-value products. Succinic acid can be made by fermentation of a variety of carbohydrates, including starch, cellulose, glucose and xylose. The succinic acid fermentation fixes CO_2, hence it can be integrated into ethanol fermentation to convert both CO_2 and cellulose fiber wastes into ethanol, thus improving the overall product value and economics. Succinic acid can be utilized as an intermediary carbon feedstock to make nylon, polyesters, engineered plastics and other commercial solvents and chemicals (Figure 5).

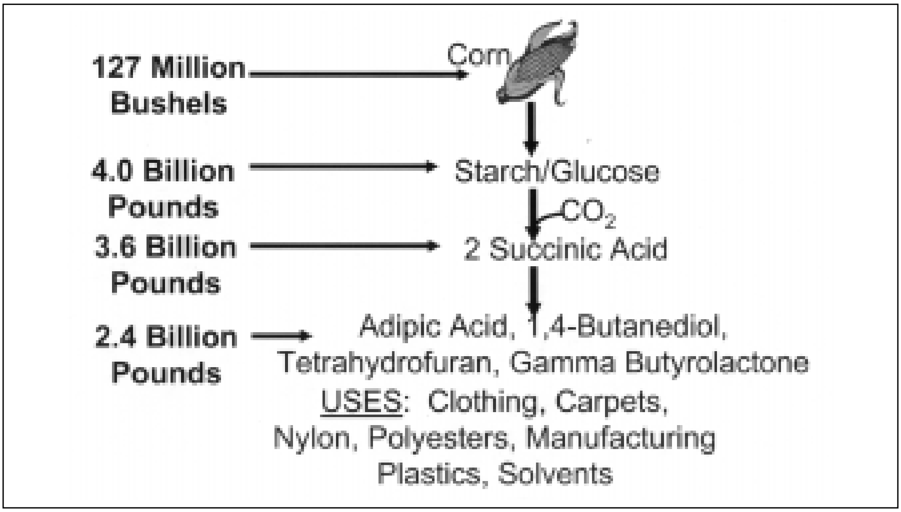

Figure 5. Industrial use opportunity for corn to succinic acid derivatives in U.S. markets.

Conclusion

The NRC report on biobased industrial products provides a roadmap for research and commercialization policy needed for agriculture to go back to the future and reclaim its higher-value industrial product markets. The market-pull and technology-push dynamics are poised for this, and the US desperately needs to reclaim control of its agricultural, chemical and energy economies as well as enhance overall environmental quality for the future.

References

NRC (National Research Council) *Biobased Industrial Products* (Washington: National Academy Press, 2000).

J.G. Zeikus, “Biotechnology: Science, Education and Commercialization,” in *Accomplishments in Microbial Biotechnology* (New York: Elsevier Science Publishing Co., 1990).

J.G. Zeikus, et al., “Biotechnology of Succinic Acid Production and Markets for Derived Industrial Products,” *Applied Microbiology* 51 (1999): 545–552.