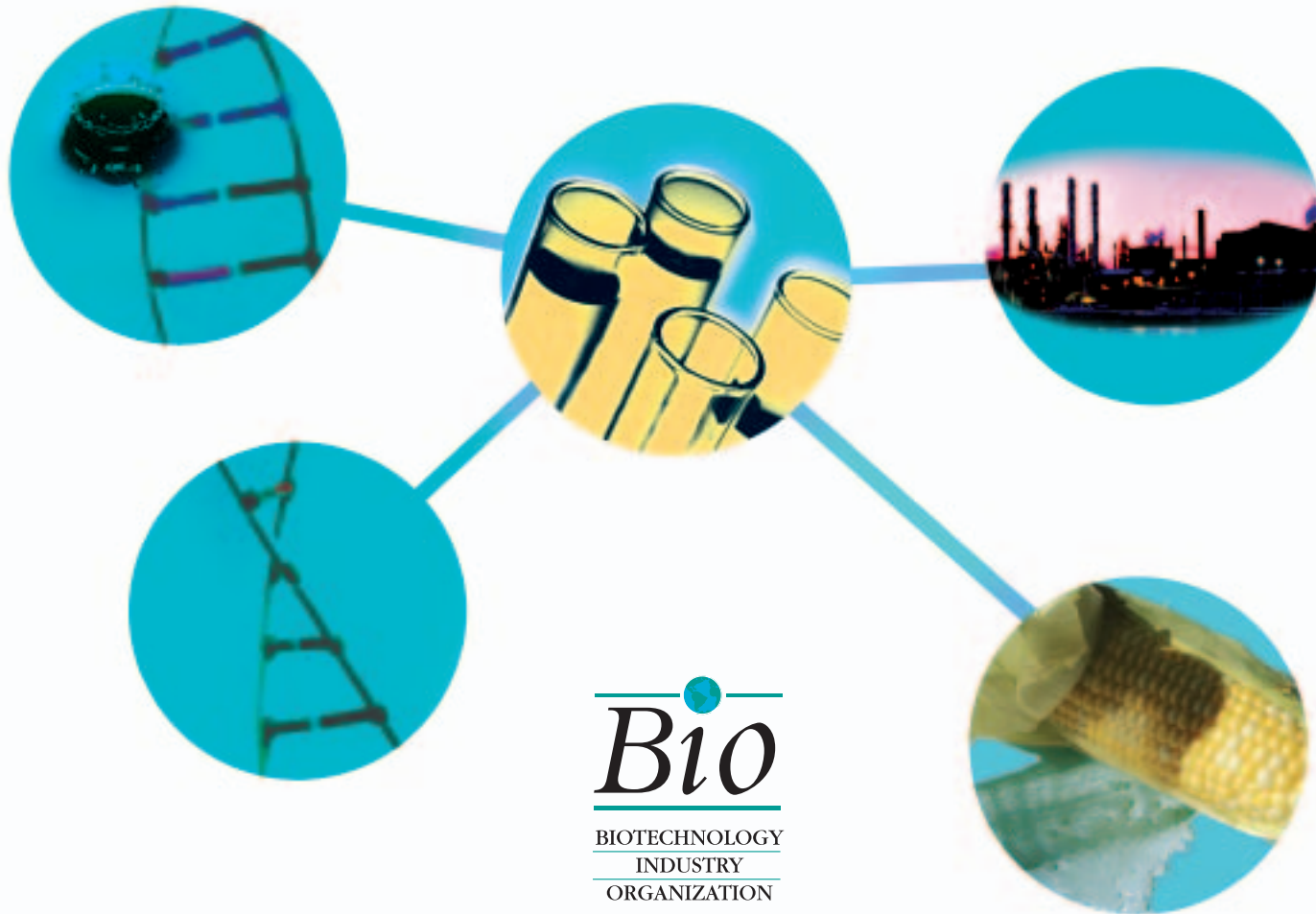


SUMMARY FOR POLICYMAKERS

New Biotech Tools for a Cleaner Environment

Industrial Biotechnology for Pollution Prevention,
Resource Conservation, and Cost Reduction



Bio
BIOTECHNOLOGY
INDUSTRY
ORGANIZATION

SUMMARY FOR POLICYMAKERS

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Report Objectives

1. Provide context for industrial biotechnology.

This report discusses the evolution and recent blossoming of industrial biotechnology, the development of pollution prevention policy, and the increasing potential for industrial biotechnology to offer new and transformative ways to prevent pollution and foster sustainable development.

2. Quantify the pollution prevention potential posed by applying certain industrial biotechnology processes to entire sectors within the United States.

This report applies performance outcomes detailed in the original Organisation for Economic Co-operation and Development (OECD) case study report to industrial sectors within the United States. Data for these sectors were drawn from the U.S. Environmental Protection Agency (EPA) and other publicly available databases. Extrapolations were then made from the OECD case studies across several discrete industry sectors in order to illustrate the largest potential magnitude of benefits.

3. Educate stakeholders about industrial biotechnology.

Industrial biotechnology is already reducing pollution and manufacturing costs in some industry sectors. It provides a whole new set of tools that hold great promise to further reduce pollution and the consumption of raw materials if deployed more broadly; this, in turn, can reduce the cost of producing goods and may lead to better products.

Because industrial biotechnology can utilize many renewable feedstocks, such as corn and other agricultural crops and crop residue, it may provide new sources of income for farmers. This report aims to deliver information on these powerful new biotechnology tools to the public, policymakers, nongovernmental organizations (NGOs), the press, and corporate America. All of these groups have a stake in a cleaner future and need to be informed about the latest technological developments that can improve all of our lives.

4. Inspire a wider inquiry into industrial biotechnology.

The Industrial and Environmental Section of Biotechnology Industry Organization (BIO), its members, and some national policymakers possess greater familiarity with the current and potential uses for industrial biotechnology than the target audience for this document. From that familiarity comes our optimism about the possible benefits that can be derived from greater industrial biotechnology use. BIO strongly believes that as an understanding of this field spreads, so, too, will the general sense of enthusiasm about this powerful technology. At the same time, we can not expect that reaction on the strength of this document alone. Industrial biotechnology encompasses a multitude of products and processes. Each will need to endure the scrutiny of potential customers, policymakers, NGOs, and the public. Our expectation is that this report will inform as well as raise questions. We invite those whose interest is aroused, but whose questions are not satisfied, to join with BIO in future research dialogues and other efforts to widen the inquiry into industrial biotechnology's current and potential benefits.

Summary

Industrial biotechnology is one of the most promising new approaches to pollution prevention, resource conservation, and cost reduction. It is often referred to as the third wave in biotechnology. If developed to its full potential, industrial biotechnology may have a larger impact on the world than health care and agriculture biotechnology. It offers business a way to reduce costs and create new markets while protecting the environment.

Today, the application of biotechnology to industrial processes is not only transforming how we manufacture products but is also providing us with new products that could not even be imagined a few years ago. Because industrial biotechnology is so new, its benefits are still not well known or understood by industry, policymakers, or consumers. This report includes analysis of only five industrial sectors to illustrate the potential to use industrial biotechnology for pollution prevention, energy savings, cost reduction, and other process improvements. It is intended to introduce readers to the possibility of pollution prevention and other benefits from greater use of industrial biotechnology. Our hope is that this information will inspire more interest in understanding, developing, and adopting these new industrial biotechnology processes.

Pollution control usually means adding equipment at the end of a process to capture or transform pollutants after they have been created. Devices ranging from a car's catalytic converter to a wastewater treatment plant to scrubbers on a power plant are technologies designed to manage pollution once it has already been created

by everyday activities. American industry spends billions of dollars yearly on technology systems to manage waste and capture polluting effluent and emissions. **The more sustainable and less expensive alternative is preventing pollution in the first place.**

From the beginning, industrial biotechnology has integrated product improvements with pollution prevention. Nothing illustrates this better than the way industrial biotechnology solved the phosphate water pollution problems of the 1970's caused by the use of phosphates in laundry detergents. Biotechnology companies developed enzymes that remove stains from clothing better than phosphates, thus enabling replacement of a polluting material with a non-polluting biobased additive while improving the performance of the endproduct. This innovation dramatically reduced phosphate-related algal blooms in surface waters around the globe, and simultaneously enabled consumers to get their clothes cleaner with lower washwater temperatures and concomitant energy savings.

Rudimentary industrial biotechnology actually dates back to at least 6000 B.C. when Neolithic cultures fermented grapes to make wine, and Babylonians used microbial yeasts to make beer. Over time, mankind's knowledge of fermentation increased, enabling the production of cheese, yogurt, vinegar, and other food products. In the 1800s, Louis Pasteur proved that fermentation was the result of microbial activity. Then in 1928, Sir Alexander Fleming extracted penicillin from mold. In the 1940s, large-scale fermentation techniques were developed to make industrial quantities of this wonder drug. Not until after World War II, however, did the biotechnology revolution begin, giving rise to modern industrial biotechnology.

Since that time, industrial biotechnology has produced enzymes for use in our daily lives. For instance, meat tenderizer is an enzyme and some contact lens cleaning fluids contain enzymes to remove sticky protein deposits. The applications for enzymes are increasing every day, especially in the manufacturing sector. In the main, industrial biotechnology involves the microbial production of enzymes, which are specialized proteins. These enzymes have evolved in nature to be super-performing biocatalysts that facilitate and speed-up complex biochemical reactions. These amazing enzyme catalysts are what make industrial biotechnology such a powerful new technology.

Industrial biotechnology involves working with nature to maximize and optimize existing biochemical pathways that can be used in manufacturing. The biotechnology revolution rides on a series of related developments in three fields of study of detailed information derived from the cell: genomics, proteomics, and bioinformatics. As a result, scientists can apply new techniques to a large number of microorganisms ranging from bacteria, yeasts, and fungi to marine diatoms and protozoa.

Industrial biotechnology companies use many specialized techniques to find and improve nature's enzymes. Information from genomic studies on microorganisms is helping researchers capitalize on the wealth of genetic diversity in microbial populations. Researchers first search for enzyme-producing microorganisms in the natural environment and then use DNA probes to search at the molecular level for genes that produce enzymes with specific biocatalytic capabilities. Once isolated, such enzymes can be identified and characterized for their ability to function in specific industrial process-

es. If necessary, they can be improved with biotechnology techniques.

Many biocatalytic tools are becoming available for industrial applications because of the recent and dramatic advances in biotechnology techniques. In many cases, the biocatalysts or whole-cell processes are so new that many chemical engineers and product development specialists in the private sector are not yet aware that they are available for deployment. This is a good example of a "technology gap" where there is a lag between availability and widespread use of a new technology. This gap must be overcome to accelerate progress in developing more economic and sustainable manufacturing processes through the integration of biotechnology. In addition, public officials in the environmental policy apparatus in the United States seem only vaguely aware of the existence of these new biotechnology tools and their ability to "green" the industrial landscape.

In 2001, the OECD investigated the use of industrial biotechnology processes in 21 case studies. The results of these case studies were released in a first-of-its-kind report and showed that biotechnology invariably led to a reduction in operating costs, capital costs, or both and to a more sustainable process—a lowered ecological footprint in the widest sense—by reducing some or all energy usage, water usage, wastewater production, and greenhouse gas production. The report further highlighted examples of reducing toxic chemicals and other environmental benefits.

Methodology

In 2001, OECD released a report called *The Application of Biotechnology to Industrial Sustainability*. This report was developed by the OECD Task Force on Biotechnology for Sustainable Industrial Development to assess how widespread industrial biotechnology use was in 2000–2001 and to assess the real-world experiences of 21 companies worldwide that furnished case-study data. The purpose of the report was to use these case studies to help answer questions regarding the costs and benefits of industrial biotechnology and to describe the factors that affected decisions by companies to use this technology. The OECD report provided a useful basis for this document because it examined numerous industrial sectors in nations with a range of economic resources and regulatory circumstances. Despite the varied settings where industrial biotechnology was used, the OECD found generally consistent and very positive results. The report found that industrial biotechnology processes invariably led to less expensive and more environmentally friendly processes. The distribution and the environmental and cost benefits of the 21 OECD case studies are shown in Tables 1 and 2.

Table 1. Cases by Sector and Country

Industry/ Sector	Pharma	Fine Chemicals	Bulk Chemicals	Food & Feed	Textiles	Pulp & Paper	Minerals	Energy
Austria						1		
Canada						2		2
Germany	2			1	1			
Japan		1	1	1				
Netherlands	1			1			1	
S. Africa							1	
UK		1	2					1
USA			1					

Table 2. Environmental and Cost Benefits from the Use of Biotechnology: Selected Cases

Case/ Sector	Energy	Raw Materials	Waste to Air	Waste to Water	Operating Cost
1/Pharma	same	-75% (non-renewable)	-50%	-66%	-50%
2/Pharma			-90%	-33%	-90% (env. related)
3/Pharma	elec +, steam -		-80%	-80%	considerable reduction
4/Food & Feed	same				-43%
6/Chem	-80%		down	down	down
7/Chem		down	down	down	-54% (raw material)
8/Chem	down		down		down
10/Food & Feed	-70%			-80%	-40%
11/Food & Feed		-50% (ground-water)			-30% (ground-water)
12/Textile	-15%	down (water)		down	-9%
13/Pulp & Paper	-30%–40%	down		down	
16/Pulp & Paper		-35% (Cl ₂), -65% (ClO ₂)		down	
17/Minerals		down (recycle)		down	
18/Minerals	down		down		down
21/Energy				down	increased productivity

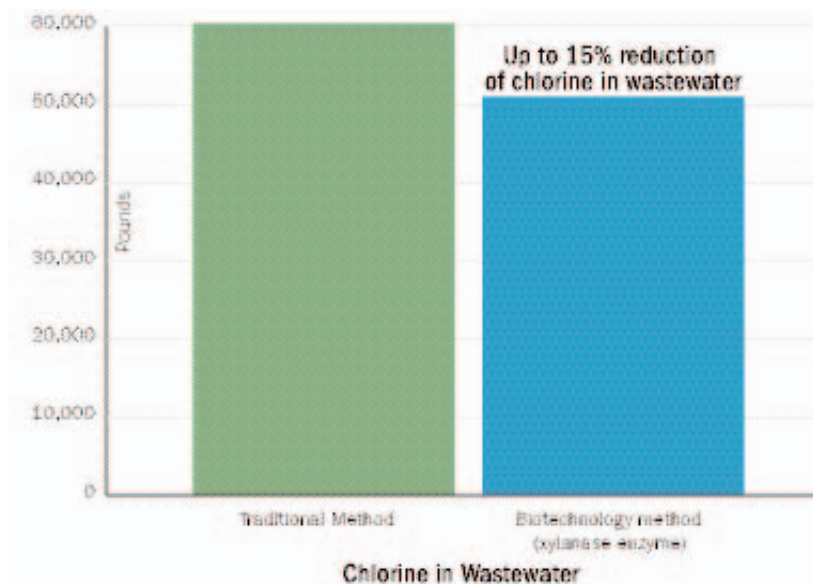
This report's analysis begins with the OECD report and goes on to address the question: **What if these biotechnologies were more widely used?** The analysis in this report takes the performance results of several OECD case studies in the pharmaceutical, chemical, paper, textile, and energy sectors and assumes they are applied across the board in similar industry sectors within the United States. In addition, information on bioplastics is drawn from the OECD report and other sources.

An important simplifying assumption of our analysis is that performance achieved through the application of a process in a case study can be extrapolated across the entire sector in the United States. For example, where a case study showed environmental benefits at a pulp and paper plant, our results assume that the same performance would be achieved across the U.S. pulp and paper industry.

The decision to employ the simplified analysis is the result of data and resource limitations. Much of the data necessary to do a finer analysis are not available—they are either gathered in an aggregated form or held as competitively sensitive information. It is also used in service of the larger objectives for this document: namely, to provide a sense of industrial biotechnology's maximum potential, and to stimulate interest in and support for more robust analysis of the topics touched on here.

The widespread uptake of this technology will not occur at the same speed in all sectors. We believe, however, that making projections across industry sectors is valid since there are many existing examples of entire industrial sectors using a technology. In some cases, this sector-wide uptake is based on economic considerations, in some, it is based on technology availability and in others it is based on legal regulatory requirements. For instance, virtually all paper pulping operations using the Kraft pulping process and virtually all

Figure 1. Projection for Reduction of Chlorine in Wastewater from Pulp Production/Bleaching with a Biotechnology Process



coal-fired power plants use sulfur dioxide scrubbers. We further acknowledge that in some cases, industrial biotechnology may be used in only part of a given sector. Nevertheless, projecting for a whole sector is a valid means of highlighting what is possible in the future.

For example, more than 90% of riboflavin (vitamin B₂) is currently produced with a biotechnology fermentation process that replaced a conventional chemical process that employed several highly toxic chemicals. In large part this transformation of standard production techniques was possible because A) the biotechnology-based process was less expensive and B) the pharmaceutical and vitamin industries are accustomed to, and structured for, rapid turnover of capital stock and processing techniques. Such rapid

penetration of biotechnology in sectors less situated for rapid transformation is less likely.

At the same time, because biotechnology has so many potential industrial applications, its uptake may occur differently—but with equally dramatic results—in other sectors. For example, nearly every aspect of papermaking from pulping wood to de-inking recycled paper could benefit from existing enzyme-based processes. So, instead of a single biotech process permeating the industry, one could envision the complete conversion of a single paper plant from chemical to biotechnology-based production.

The authors recognize that industrial plant age, technology availability and cost are but three factors that can result in performance

variability. Studies of technology uptake suggest that diffusion of technology into the broad economy can take decades or longer as individual companies and governments experiment with, deploy, and then adopt new technology. Rapid changes, however, can be driven by factors such as traditional fossil fuel feedstock cost increases, changes in environmental regulations, or other factors. A presentation by Barbara Miller of Dow Chemical Company describes the diffusion of biotechnology and is included in Appendix II of the full report. This report does not attempt to quantify the costs associated with adoption of biotechnology processes. As is also discussed by Miller, disruption and capital costs would be associated with uptake of these processes. This is an area for further research.

Figure 2. Projection for Reduction of Energy Consumption in Pulp Production/Bleaching with a Biotechnology Process

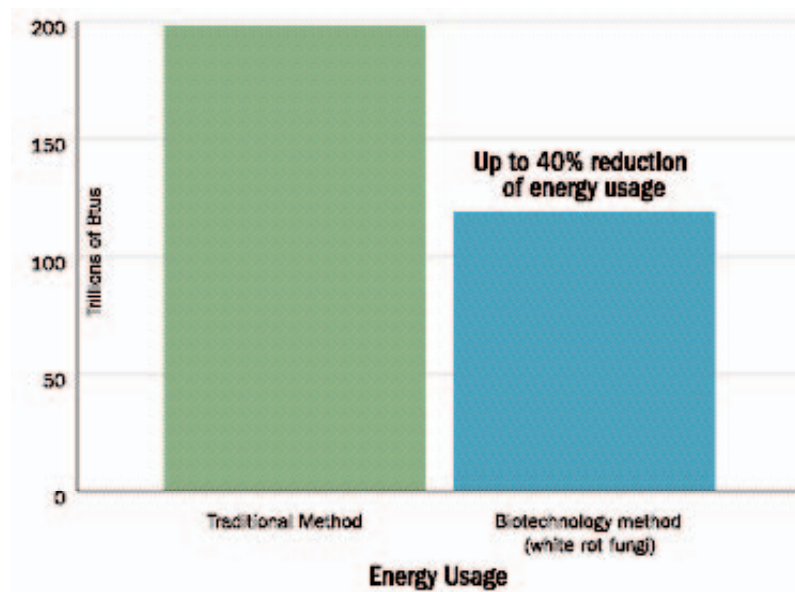
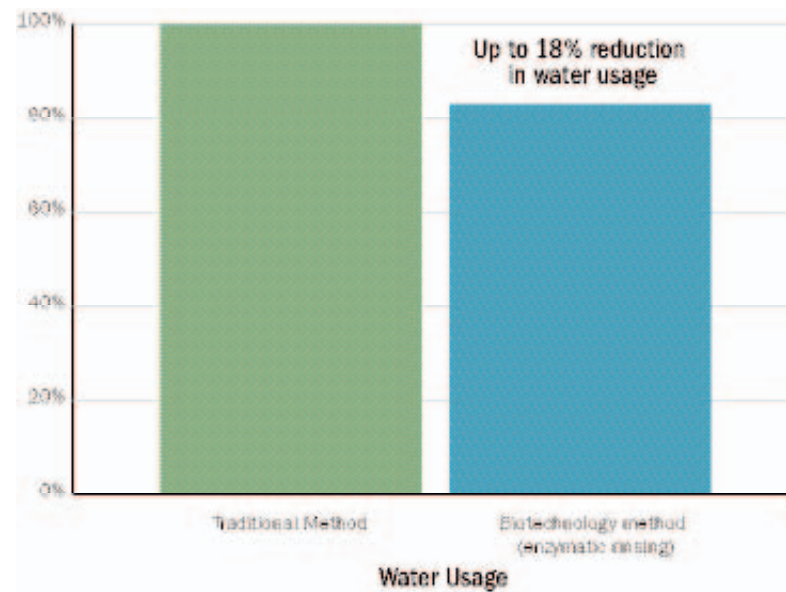


Figure 3. Projection for Reduction of Water Usage in Textile Finishing with a Biotechnology Process



Pollution prevention performance for specific processes is derived from the OECD case studies and applied to U.S. industry sector data obtained from the EPA and other public sources. In some cases, more recent data is now available than was used in assembling this report. Additional assumptions are included in the footnotes.

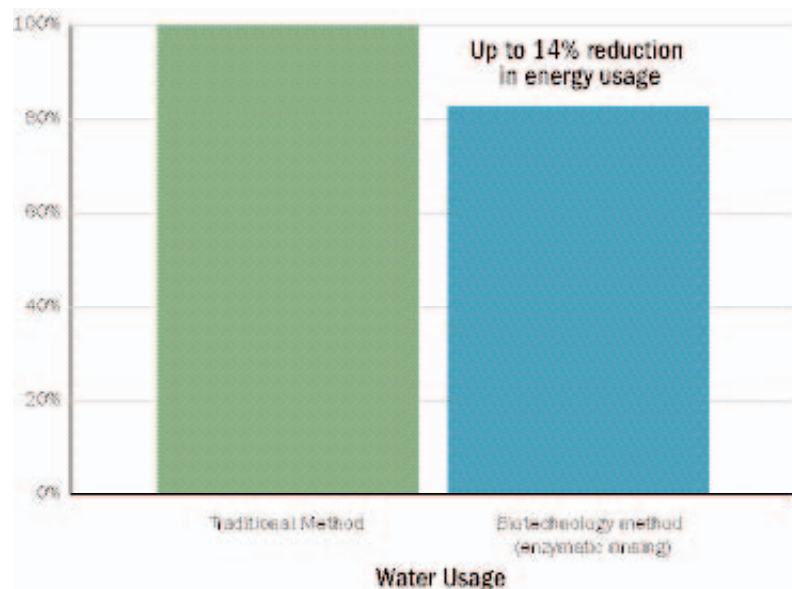
We used examples drawn only from OECD case studies measuring pollution reduction in a manner matching reasonably well with the data available from EPA and other public sources. Our analysis was also limited because industrial biotechnology does not have a discrete North American Industrial Classification System (NAICS) code that would allow for the collection of broad categories of data regarding its usage. It became apparent during our investigation that

the formulation and adoption of such a NAICS code for the biotechnology sector in general and for discrete biotechnology sectors in particular would contribute to more accurate assessments of costs and benefits.

More analysis is needed by federal agencies to draw out additional empirical information about possible environmental benefits in this rapidly expanding field. This report considers only a few of the many industrial biotechnology processes available today. It does not examine either upstream or downstream benefits. Because industrial biotechnology presents such a broad array of potential intersections with existing industrial activities one could easily speculate that the potential benefits of significant industrial biotechnology diffusion would be greater and more diverse than described in the following analysis.

Finally, our work leaves to future efforts detailed examinations of barriers, life-cycle, and cost benefit considerations, and existing protocols for storage, transportation and use of industrial biotechnology materials. Each of these considerations are outside the scope of this report. Furthermore, that work would best be done by cooperative efforts between private, government, and NGO entities. This report may stimulate new interest in such cooperative research.

Figure 4. Projection for Reduction of Energy Usage in Textile Finishing with a Biotechnology Process



Results of the Analysis

Members of the BIO Industrial and Environmental Section concluded that additional study of this issue was appropriate and necessary. This study takes the next step by asking the question: **What if industrial biotechnology were more widely used?** The report takes the performance described in the OECD report and applies it, unilaterally, to analogous sectors in the United States. This analysis indicates signifi-

cant pollution prevention and suggests cost savings as well as reduced consumption of raw materials and energy. The report also draws on the literature regarding policy hurdles and other factors influencing the decision of companies to adopt industrial biotechnology processes.

- Biotechnology process changes in the **production and bleaching of pulp for paper** reduce the amount of chlorine chemicals necessary for bleaching by 10–15% (Figure 1). If applied across the industry, these process changes could reduce chlorine in water and air as well as chlorine dioxide by a combined 75 tons per year. Biotechnology processes cut bleaching-related energy uses by 40%—a savings that can create additional pollution reductions (Figure 2). The biotechnology process also lowers wastewater toxicity.
- Biotechnology process changes in the **textile finishing sector** reduce

water usage by about 17–18% (Figure 3), cost associated with water usage and air emissions by 50–60%, and energy demand for bleaching by about 9–14% (Figure 4).

- Biotechnology process changes in **plastics production** replace petrochemical feedstocks with feedstocks made from organic material such as corn or even corn stovers, thereby reducing demand for petrochemicals by 20–80% (Figure 5). Because these bioplastics are biodegradable, their use could also reduce plastics in the waste stream by up to 80%. Waste burdens are reduced partly because disposable food service items such as plates, cups, and containers can be composted along with the food waste eliminating the need for separation. These bioplastics can be used to make products ranging from clothing to car parts, all of which can be composted

Figure 5. Projection for Reduction in Petroleum Usage in Plastics Production with a Biotechnology Process

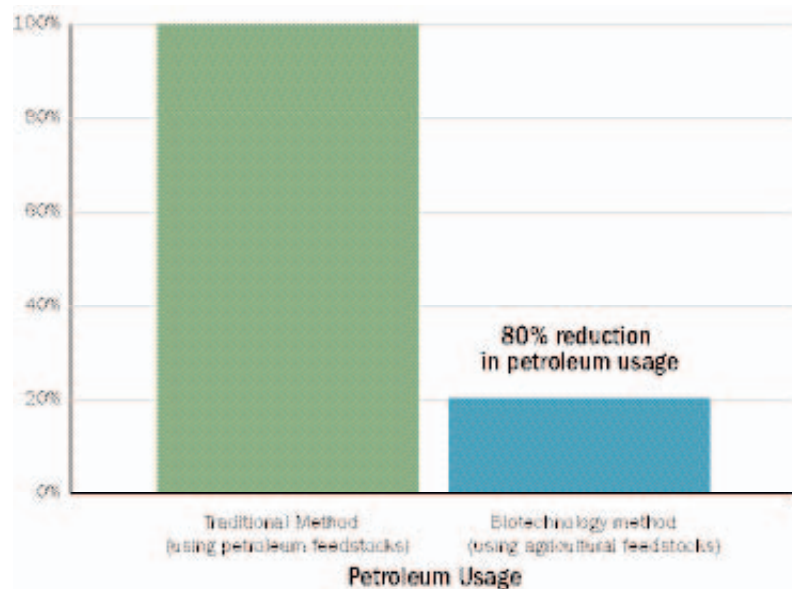
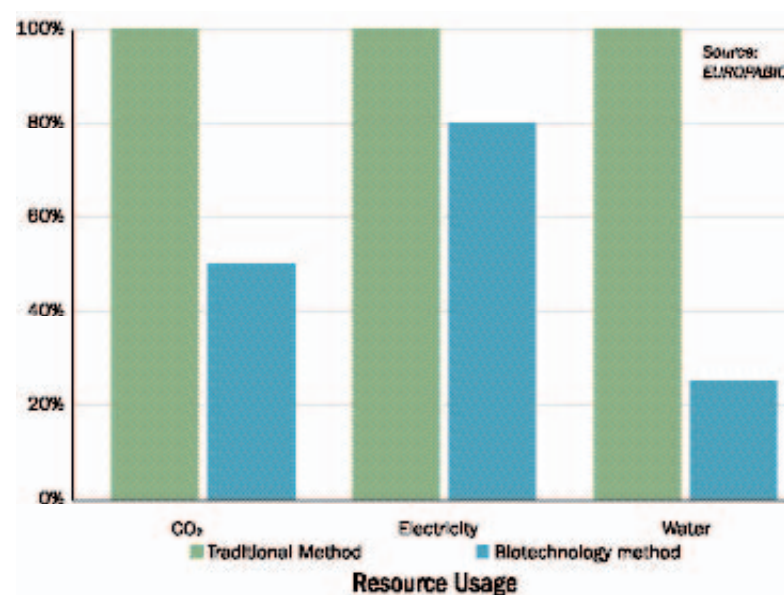


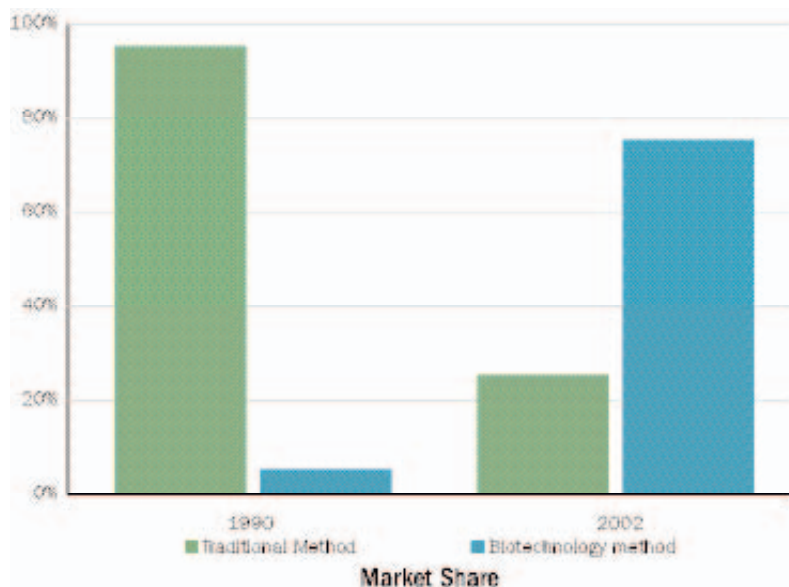
Figure 6. Biological versus Traditional Processing: Analysis of Resource Usage of Antibiotic Intermediate Processing



instead of disposed in landfills or incinerators.

- Biotechnology process changes allow for **bioethanol production** not only from corn but from cellulosic biomass such as crop residues; *bioethanol from cellulose generates 8 to 10 times as much net energy as is required for its production. It is estimated that one gallon of cellulosic ethanol can replace 30 gallons of imported oil equivalents.* The closed-loop nature of using cellulosic biomass to produce bioethanol can contribute substantially to the mitigation of greenhouse gas emissions and can help provide a partial solution to global warming.
- Ethanol emits carbon dioxide when combusted. Unlike fossil fuels, however, the plants and trees that are bioethanol's main feedstock are renewable and absorb carbon from the atmosphere while they are growing. DOE estimates cellulosic ethanol production would

Figure 7. Market Share of Vitamin B₂ Production, by Method of Production



absorb more CO₂ than would be emitted by its use.

- Biotechnology process changes in **the nutraceutical and pharmaceutical sector** during the production of riboflavin (vitamin B₂) *reduce associated carbon dioxide emissions by 80% and water emissions by 67%.* Changes in the production of the antibiotic cephalexin *reduce carbon dioxide emissions by 50%, energy demand by 20%, and water usage by 75%* (Figure 6). The market share of the biotechnology method of vitamin B₂ production increased from 5% in 1990 to 75% in 2002 (Figure 7).
- The potential energy savings of industry-wide application of biotechnology in the European paper industry would result in a *carbon dioxide emissions savings of between 155,000 and 270,000 tons annually.*
- Textile mills may *cut water consumption by as much as 30–50%* by using biotechnology.
- Industry-wide use of biotechnology in the textile finishing industry would *save about 3 trillion Btu per year*—about the equivalent of one natural gas combined-cycle power plant or the electricity consumed by 28,120 homes in one year.
- More than 80 billion pounds of plastic products are produced annually in the United States. Of that, 1 billion pounds are biobased plastics. The remaining potential for environmental benefits and reduced demand for foreign oil are substantial. For example, if all plastics were made from biobased polylactic acid, *oil consumption would decrease by 90–145 million barrels per year*—or about as much oil as the United States consumes in one week.
- Enough agricultural crop residue is produced each year to entirely *replace the 700 million barrels of petroleum used in organic chemical production.*

These are but a few of the potential environmental and resource conservation improvements that could result with wider use of industrial biotechnology.

Policy Considerations

There are different types of environmental regulations. Some prescribe the specific actions or technologies that must be used for compliance. Others set standards of performance that may be met in a variety of ways. Both of these regulatory approaches could play an important role in encouraging the development, testing and ultimately the deployment of technology innovations such as new industrial biotechnology processes. However, current regulations often seem to discourage the development and adoption of many technology innovations, including industrial biotechnology, for compliance.

EXISTING ENVIRONMENTAL REGULATIONS TEND TO BE GEARED TOWARD END-OF-PIPE, COMMAND-AND-CONTROL CLEAN-UP TECHNOLOGIES AND OFTEN DO NOT ENCOURAGE—OR EVEN RECOGNIZE—THE BENEFITS OF ADOPTING INNOVATIONS SUCH AS BIOTECHNOLOGY-BASED PROCESS CHANGES.

Industrial biotechnology has matured to the point that its potential to deliver public benefits now warrants consideration of how it might appropriately be treated in public policy. In this section, we review several existing environmental statutes and regulations to identify options for encouraging technological innovation from industrial biotechnology. Our review results in a list of potential options for modifying existing

programs. Development of this list also points to the option of developing an entirely new framework to address both the hopes and concerns related to greater diffusion of these technologies.

The list presents an intriguing set of potential opportunities to provide incentives for biotechnology. It is important to note, however, that this list is only meant to inspire further discussion. It is understood that policymakers, industry, NGO's and the public will be cautious about modifying existing policies to promote industrial biotechnology until they become better informed and are appropriately convinced of both the merits and the safety of industrial biotechnology products and processes.

Clean Air Act (CAA)

Greater substitution of industrial biotechnology manufacturing processes for traditional processes could reduce air pollution from a variety of sources. Some of the CAA's programs result in specific emission limitations that are included in an operating permit and would not necessarily discourage the use of industrial biotechnology. Much of the CAA is driven by the requirement that states meet overall air quality standards while individual facilities use prescribed emission control equipment. In many cases, conversion of an existing conventional process or part of a process to an industrial biotechnology process would make both economic sense (for the facility) and environmental sense (reducing local or regional air pollution). However, if the conversion does not meet the CAA technology requirements, it may be dismissed as a viable option. Specific areas for policymakers to consider for increasing the flexibility of the CAA might include

- *allowing states to get credit in their state implementation plans for emission*

reductions that are related to industrial facilities voluntarily converting to less polluting biotechnology processes;

- exploring ways to quantify emission reductions related to biotechnology conversions and allow those who create such reductions to *participate in emission trading market activities;*
- exploring the possibility of *including certain industrial biotechnology processes in the definitions of technology-specific programs including the RACT, BACT, LAER, and MACT definitions;* and
- allowing industrial biotechnology to *become eligible for pollution control technology research grants under the CAA.*

Clean Water Act

State and federal water programs are increasingly beginning to incorporate flexible permit programs that are less burdensome for the regulated community but ensure steady progress toward the water quality goals. Policymakers should consider the potential for greater use of industrial biotechnology to complement these ongoing efforts. Many of the permit programs should be examined by policymakers to ensure that, where appropriate, *permits issued under the Clean Water Act include incentives for permit holders to use industrial biotechnology* when it will result in less-polluted effluent being released into the nation's waterways.

Energy Policy Act

Industrial biotechnology processes could have sweeping consequences for the future of energy production and consumption in the United States. Industrial biotechnology can be used to produce energy products such as ethanol. It can also reduce the energy used in various manufacturing activities such as paper production. Future efforts to consider national energy policy should encourage greater deployment

of industrial biotechnology where it is consistent with other national energy objectives such as reduced dependence on foreign oil. *Funding should be made available under the existing law, or required by any revision to existing law, to assist in the development of a national biorefining industry.* This would enable a robust exploration of all of the technical, legal, and market implications of using biotechnology to replace oil consumption with the use of renewable resources.

EPA Pollution Prevention Innovation Strategy

EPA should explicitly include industrial biotechnology in its pollution prevention innovation strategy and should aggressively promote this technology where its effectiveness has already been demonstrated. An initiative similar to *EPA's source reduction review project could be undertaken to assess how new regulatory programs could achieve the dual goals of protecting the environment while encouraging a shift to more sustainable industrial practices.*

National Environmental Policy Act

The President's Council on Environmental Quality (CEQ) created by the National Environmental Policy Act is charged with looking at environmental issues that cut across the jurisdiction of multiple government agencies and departments. Greater deployment of industrial biotechnology can result in benefits ranging from improved environmental protection to greater national security; and industrial biotechnology can be used in nearly every sector of the economy including transportation, energy, and manufacturing. The broad scope of opportunity presented by industrial biotechnology fits well with the mandate given to CEQ for addressing multifaceted environmental issues. *CEQ should actively undertake specific activities to explore the myriad national benefits of industrial biotechnology and recommend ways to realize those benefits.*

Pollution Prevention Act

State grants authorized by the Pollution Prevention Act should add a focus on exploring the practical opportunities and limits of greater deployment of industrial biotechnology for pollution prevention. *These grants should also be made in a manner that will provide feedback about government policies that encourage or discourage the use of industrial biotechnology in cases where it would lead to environmental benefits.* Also, data related to industrial biotechnology should be collected and made available as part of the source reduction clearinghouse authorized in the act.

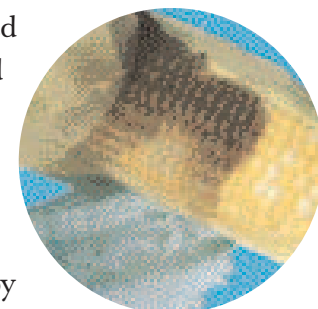
Toxic Substances Control Act

Policymakers should encourage the numerous benefits of reduced toxic substance usage, disposal, and release into the environment that could be driven by an increase in industrial biotechnology. Government authorities should ensure that industries regulated under the Toxic Substances and Control Act are aware of these benefits. *Equally important, policymakers should ensure that any new reporting requirements triggered by the use of industrial biotechnology processes are defined quickly so that market decisions are not disrupted and the realization of environmental benefits produced by biotechnology is not inadvertently or unnecessarily hindered.*

We believe that lawmakers, policymakers, regulators, the regulated community, nongovernmental organizations, the press, and the general public could all benefit from the information in this report and in the OECD report on which it is based. Because industrial biotechnology has the potential to achieve environmental benefits and cost savings at the same time, it is a powerful tool for solving many difficult environmental challenges without causing financial hardship to business or consumers. Existing environmental regulations tend to be

geared toward end-of-pipe, command-and-control cleanup technologies and often do not encourage—or even recognize—the benefits of adopting innovations such as biotechnology-based process changes. We also believe that efforts should be undertaken to study the development of policy mechanisms that provide incentives for such change rather than disincentives.

We recognize our enthusiasm for industrial biotechnology will be met with cautious reactions by some. Industrial biotechnology encompasses a multitude of products and processes. Some industrial biotechnology applications will necessarily encounter greater levels of public policy scrutiny. This is both appropriate and welcome. We view industrial biotechnology as a very promising technology, but not a panacea. Rather, it represents a vast new set of powerful and beneficial tools. Helping fit the appropriate tools to the appropriate jobs is a key goal. As stated elsewhere in this document, BIO believes that greater scrutiny of industrial biotechnology will lead to greater enthusiasm for its use. But we do not presume to skip over the need for full discussion of policy implications and the public interest in order to realize the maximum public benefits of this new technology.



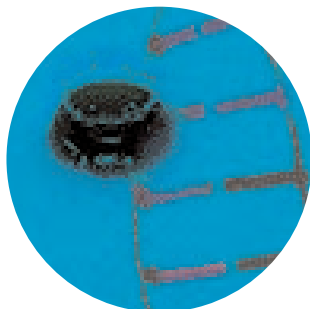
Conclusions

The analysis in this report provides an overview of the benefits; however, even this rough overview reveals that the potential magnitude of benefits is startling.

Biobased technologies are just beginning to be used in forestry, pulp and paper, chemicals and plastics, mining, textile production, and energy sectors. *The sectors examined in this report may account for up to 40% of energy use, 50% of industrial pollution, and are also a significant contributor to greenhouse gas emissions. With accelerated diffusion of industrial biotechnology into these sectors, rapid and dramatic environmental improvements are possible. In many cases, use of industrial biotechnology processes can also reduce the risk of chemical spills and accidents.* This risk reduction is in part due to the dramatic reduction in the use, storage, handling, and transportation of hazardous chemicals.

Industrial biotechnology is already demonstrating tremendous improvements in everyday products while producing them with less pollution and less energy. This focus on altering industrial process will allow business leaders and policymakers to concentrate on preventing - pollution rather than cleaning up pollution after it is generated.

It is clear that industrial biotechnology has the potential to greatly improve pollution prevention, control, and innovation strategies and could revolutionize current manufacturing and environmental protection strategies. *In fact, industrial biotechnology is creating a new industrial revolution where man and DNA are working hand in glove to green the industrial landscape.*



SOME INDUSTRIAL BIOTECH APPLICATIONS BY INDUSTRIAL SECTORS:

- Biological Fuel Cells
- Fine and Bulk Chemicals
- Chiral Compound Synthesis
- Synthetic Fibers for Clothing
- Pharmaceuticals
- Food Flavoring Compound
- Biobased Plastics
- Biopolymer for Automobile Parts
- Bio-Ethanol Transportation Fuel
- Nutritional Oils
- Oil and Gas Desulphurization
- Leather Degreasing
- Bio-hydrogen
- Biopolymers for Plastic Packaging
- Coal Bed Methane Water Treatment
- Chem/Bio Warfare Agent Decontamination
- Pulp and Paper Bleaching
- Biopulping (paper industry)
- Specialty Textile Treatment
- Enzyme Food Processing Aids
- Metal Ore Heap Leaching
- Electroplating/Metal Cleaning
- Rayon and Other Synthetic Fibers
- Metal Refining
- Vitamin Production
- Sweetener Production (high fructose syrup)
- Oil Well Drill Hole Completion (non-toxic cake breakers)
- Road Surface Treatment for Dust Control
- Textile Dewatering
- Vegetable Oil Degumming

Table 3: Consumer Products Made with Industrial Biotechnology

CONSUMER PRODUCT	OLD MANUFACTURING PROCESS	NEW INDUSTRIAL BIOTECH PROCESS	BIOTECH ENABLING TECHNOLOGY	CONSUMER BENEFIT
Detergent	Phosphates added as a brightening and cleaning agent	Addition of biotechnology enzymes as brightening and cleaning agents <ul style="list-style-type: none"> ■ Proteases remove protein stains ■ Lipases remove grease stains ■ Amylases remove starch stains 	Genetically enhanced microbes or fungi engineered to make enzymes	<ul style="list-style-type: none"> ■ Elimination of water pollution from phosphates ■ Brighter, cleaner clothes with lower temperature wash water ■ Energy savings
Bread	Potassium bromate, a suspected cancer-causing agent at certain levels, added as a preservative and a dough strengthening agent	Addition of biotechnology enzymes to <ul style="list-style-type: none"> ■ enhance rising ■ strengthen dough ■ prolong freshness 	Microorganisms genetically enhanced to produce baking enzymes (directed evolution and recombinant DNA)	<ul style="list-style-type: none"> ■ High-quality bread ■ Longer shelf life ■ No potassium bromate
Polyester Bedding	Polyester* produced chemically from petroleum feedstock *any synthetic fiber	Biotech polyester (PLA) produced from corn starch feedstock	Existing bacillus microbe used to ferment corn sugar to lactic acid; lactic acid converted to a biodegradable polymer by heating; polymer made into plastic products and polyester	<ul style="list-style-type: none"> ■ PLA polyester does not harbor body odor like other fibers ■ Biodegradable ■ Not made from petroleum ■ Does not give off toxic smoke if burned
Vitamin B ₂	Toxic chemicals, such as aniline, used in a nine step chemical synthesis process	One-step fermentation process uses vegetable oil and glucose as a feedstock	Genetically enhanced microbe developed to produce vitamin B ₂ (directed evolution)	<ul style="list-style-type: none"> ■ Biologically produced without chemicals ■ Greatly reduces hazardous waste generation and disposal
Stonewashed Blue Jeans	Open-pit mining of pumice; fabric washed with crushed pumice stone and/or acid to scuff it	Fabric washed with biotechnology enzyme (cellulase) to fade and soften jeans or khakis	Textile enzymes produced by genetically enhanced microbe (extremophiles and recombinant DNA)	<ul style="list-style-type: none"> ■ Less mining ■ Softer fabric ■ Reduced energy consumption ■ Lower cost
Paper Bleaching	Wood chips boiled in a harsh chemical solution then bleached with chlorine to yield pulp for paper making	Enzymes selectively degrade lignin and break down wood cell walls during pulping	Wood-bleaching enzymes produced by genetically enhanced microbes (recombinant DNA)	<ul style="list-style-type: none"> ■ Reduces use of chlorine bleach and reduces toxic dioxin in the environment ■ Cost savings due to lower energy and chemical costs

CONSUMER PRODUCT	OLD MANUFACTURING PROCESS	NEW INDUSTRIAL BIOTECH PROCESS	BIOTECH ENABLING TECHNOLOGY	CONSUMER BENEFIT
Ethanol Fuel	Food and feed grains fermented into ethanol (a technology that is thousands of years old)	Cellulase enzyme technology allows conversion of crop residues (stems, leaves, straw, and hulls) to sugars that are then converted to ethanol	Genetically enhanced organism developed to produce enzymes that convert agricultural wastes into fermentable sugars (directed evolution, gene shuffling)	Renewable feedstock <ul style="list-style-type: none"> ■ Reduces green house gas emissions ■ Increases domestic energy production ■ Is more energy efficient to produce than old process
Antibiotics	Chlorinated solvents and hazardous chemicals used to produce antibiotics through chemical synthesis	One-step biological process uses direct fermentation to produce antibiotic intermediate	Genetically enhanced organism developed to produce the key intermediate of certain antibiotics (recombinant DNA)	<ul style="list-style-type: none"> ■ 65% reduction in energy consumption ■ Overall cost savings
Contact Lens Solution	Surfactants and/or saline solutions (do not remove protein deposits) used to clean lenses	Protease enzymes remove protein deposits from the contact lens	Genetically enhanced microbes engineered to make protease enzymes (directed evolution)	<ul style="list-style-type: none"> ■ More effective contact lens cleaning ■ Less eye irritation and fever infections

Snapshots

Key Findings

- Industrial biotechnology offers the private sector remarkable new tools for pollution prevention that have not been widely available before now.
- These new tools not only prevent pollution but can also significantly cut energy demand, natural resource consumption, and production costs while creating high-quality intermediates or consumer products.
- Accelerated uptake of new industrial biotechnology processes could lead to further pollution prevention, waste reduction, and energy cost savings in related services such as waste disposal or energy production.
- Public policies and regulations do not provide adequate incentives for technological innovations, such as biotechnology-based pollution prevention and energy savings.
- The industrial biotechnology processes used in this analysis involve cutting-edge technologies. More research and development must be undertaken to increase the utility and efficiency of these biotechnology processes across a broad range of industrial applications.

Results of the Analysis

- Biotechnology process changes in the **production and bleaching of pulp for paper** reduce the amount of chlorine chemicals necessary for bleaching by 10–15%. If applied across the industry, these process changes could reduce chlorine in water and air as well as chlorine dioxide by a combined 75 tons per year. Biotechnology processes cut bleaching-related energy uses by 40% – a savings that has the potential to create additional pollution reductions. These processes also lower wastewater toxicity.
- Biotechnology process changes in the **textile finishing sector** reduce water usage by about 17–18%, cost associated with water usage and air emissions by 50–60%, and energy demand for bleaching by about 9–14%.
- Biotechnology process changes in **plastics production** replace petrochemical feedstocks with feedstocks made from organic material such as corn, thereby reducing demand for petrochemicals by 20–80%. Because these bioplastics are biodegradable, their use could also reduce plastics in the waste stream by up to 80%. Waste burdens are reduced partly because disposable food service items such as plates, cups, and containers can be composted along with the food waste, eliminating the need for separation. These bioplastics can be used to make products ranging from clothing to car parts, all of which can be composted instead of disposed of in landfills or incinerators.
- Biotechnology process changes allow for **bioethanol production** not only from corn but from cellulosic biomass such as crop residues; bioethanol from cellulose generates 8 to 10 times as much net energy as is required for its production. It is estimated that one gallon of cellulosic ethanol can replace 30 gallons of imported oil equivalents. The closed-loop nature of using cellulosic biomass to produce bioethanol can contribute substantially to the mitigation of greenhouse gas emissions and can help provide a partial solution to global warming.
- Biotechnology process changes in the **nutraceutical and pharmaceutical sector** during production of riboflavin (vitamin B₂) reduce associated carbon dioxide emissions by 80% and water emissions by 67%. Changes in the production of the antibiotic cephalixin reduce carbon dioxide emissions by 50%, energy demand by 20%, and water usage by 75%.

Policy Considerations

Increased Flexibility

- Opportunities may exist within the *Clean Air Act* to increase the flexibility of states and companies to use industrial biotechnology to help meet environmental goals. These opportunities may include options to allow states to get credit in their state implementation plans for emission reductions related to use of industrial biotechnology; emission reductions related to industrial biotechnology in existing emission trading markets; and certain industrial biotechnology processes in the definitions of allowed or preferred technologies in technology-specific programs, such as RACT, BACT, LAER, and MACT.
- Opportunities may arise under the *Clean Water Act* to include incentives for permit holders to use industrial biotechnology when it will result in less pollution.
- The Environmental Protection Agency may be able to explicitly include industrial biotechnology in its *pollution prevention innovation strategy*. Its *source reduction review project* could be undertaken to assess how new regulatory programs could achieve the dual goals of protecting the environmental while encouraging a shift to more sustainable industrial practices.

Funding

- Additional funding for the use of industrial biotechnology may be possible under the *Energy Policy Act* to assist in the development of the nation's first biorefining industry.

- Industrial biotechnology projects may be eligible for the grants under the Clean Air Act's research program on pollution control technology.
- There may be opportunities to add a focus on exploring the practical opportunities and limits of greater deployment of industrial biotechnology for pollution prevention to the state grants authorized by the *Pollution Prevention Act*.

National Policy Initiatives

- The *Council on Environmental Quality* may be able to proactively assess the myriad national benefits of industrial biotechnology and recommend ways to realize those benefits.

Outreach

- Opportunities may arise to inform industries regulated under the *Toxic Substance Control Act* of the numerous benefits of reduced toxic substance usage, disposal, and release into the environment that could be driven by an increase in industrial biotechnology. Government may be able to work with industry and environmental stakeholders to ensure that new reporting requirements triggered by the use of industrial biotechnology processes are defined quickly so as to facilitate rather than discourage use of these processes.

Recommendations

- Corporate leaders should review the benefits of industrial biotechnology processes by placing them on the agendas of their boards and business units.
- Corporate, governmental, and NGO stakeholders should work together to further define issues for analysis and identify next steps that could accelerate the uptake of specific industrial biotechnology processes.
- Policymakers should make a concerted effort to learn more about the wide range of industrial biotechnology applications and environmental benefits that can be derived from greater deployment of these biotechnologies.
- Federal and state policymakers should fund research that will quantify the pollution prevention benefits of this technology in greater detail to assist policy decision making.
- Policymakers should explore incentives for greater use of industrial biotechnology to accelerate pollution prevention and cleanup of the environment; approaches may include the incorporation of industrial biotechnology into regulatory and nonregulatory programs.
- International organizations such as the United Nations Conference on Trade and Development and the United Nations Industrial Development Organisation should help developing countries understand that these processes can contribute to economic development with less pollution. They should help identify appropriate technologies that can be readily adopted by the developing world and strategies for technology transfer.
- National representatives of countries participating in the Johannesburg Summit on Sustainable Development should seek to include specific references to industrial and environmental biotechnology in the implementation program resulting from the summit.

Areas for Further Study

Because data were not always available for specific processes being reviewed, estimates in this report often indicate trends or estimates rather than precise measurements. Furthermore, some factors of pollution reduction are not covered in U.S. government databases so that the total benefits are not fully described. Additional studies are needed to improve and expand on the information contained in this report and to clarify areas in which industrial biotechnology could provide environmental benefits. The research priorities are as follows:

- Existing and emerging biotechnology applications need further study to assess potential cost savings and to determine the value of speeding voluntary adoption in additional manufacturing sectors. This effort should quantify the economic benefits of biotechnology in specific industries.
- Greater investigation of available emissions data from public and private sources is needed. We believe that the much of the necessary data exist but are not published or are not in easily accessible formats.
- Further study is necessary to more accurately quantify the pollution prevention, natural resource conservation, and energy and societal benefits of emerging industrial biotechnologies.
- Studies are needed to quantify the public health benefits that could be achieved through greater use of industrial biotechnology by the private sector because reducing use of toxic chemicals can confer health benefits to both employees of industrial facilities and the general public.
- Because use of industrial biotechnology is rapidly spreading worldwide, organizations such as the Organisation for Economic Co-operation and Development, the European Commission, and others should also undertake assessments of pollution prevention potential in Europe and Asia.
- Another key component for study should be an economic and social analysis to quantify cost savings, job creation benefits, and transition costs that can develop as biobased industries arise and traditional industries are disrupted or restructured.

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“Biobased products have the potential to improve the sustainability of natural resources, environmental quality, and national security while competing economically.”

—*Biobased Industrial Products: Research and Commercialization Priorities*, National Research Council, 2000.

“The move to industrial bioprocessing clearly goes hand in hand with the public desire for a cleaner environment. It is in tune with increasing public enthusiasm for more sustainable lifestyles and the demand for cleaner products... As many of the founders of biotechnology were fond of saying in their youth, ‘Seize the time!’”

—*Nature Biotechnology*, editorial, June 2001.

About the Preparation of this Report

This report was published by the **Biotechnology Industry Organization's (BIO's) Industrial and Environmental Section**. As a whole, BIO represents more than 1,000 biotechnology companies, academic institutions, state biotechnology centers and related organizations in all 50 U.S. states and 33 other nations. BIO members are involved in the research and development of health-care, agricultural, industrial and environmental biotechnology products. For more information on BIO, visit the website at www.bio.org. The Industrial and Environmental Section is a discrete part of BIO, and the views expressed in this report do not necessarily reflect those of all BIO members. The mention of specific company, trade and product names does not constitute an endorsement.

AJW, Inc. was commissioned to develop the analysis in Chapter 6 and to assist in the development of the other chapters. AJW, Inc provides consulting and lobbying services related to energy and environmental issues. Its principals have more than 30 years combined experience working on these issues in the private sector, federal and state government, and the environmental community.

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