Industrial Biotechnology Meets the Presidential Green Chemistry Challenge

Background

The Federal Pollution Prevention Act of 1990 established policy tools and goals for environmental protection, specifically recommending "pollution should be prevented or reduced ***at the source*** whenever feasible..."

The law defines **source reduction** as any practice that:

- Reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal.
- Reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants.

Biotechnology and Green Chemistry[1]

Green chemistry or sustainable chemistry aims to design and produce cost-competitive chemical products and processes that reduce pollution at the source.

Specifically, green chemistry minimizes or eliminates the hazards of chemical feedstocks, reagents, solvents, and products. Additionally, green chemistry prevents waste by using renewable feedstocks, increasing energy efficiency and working in real time to prevent pollution. U.S. EPA recognizes that industrial biotechnology meets these criteria of green chemistry.[2]

Twelve Principles of Green chemistry:

1. Prevent Waste
2. Reduce Byproducts
3. Design Less Hazardous Synthesis
4. Design Safer Chemicals
5. Use Safer Solvents
6. Design for Energy Efficiency
7. Use Renewable Feedstocks
8. Reduce Derivatives
9. Use Catalytic Reagents
10. Design for Degradability
11. Employ real-time Analysis for Pollution Prevention
12. Prevent Accidents

Presidential Green Chemistry Challenge

The annual Presidential Green Chemistry Challenge Awards recognize novel technologies that provide significant environmental and economic benefits through chemical design, manufacture, and use.

EPA presents awards in five categories:

1. Greener Synthetic Pathways
2. Greener Reaction Conditions
3. The Design of Greener Chemicals
4. Small Business* (for a technology in any of the three focus areas developed by a small business)

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[1] http://www.epa.gov/sciencematters/june2011/principles.htm

[2] D. Ahmann, and J. Dorgan. "Bioengineering for Pollution Prevention through Development of Biobased Energy and Materials." 117-29. Washington: National Center for Environmental Research, US Environmental Protection Agency, Office of Research and Development 2007

5. Academic (for a technology in any of the three focus areas developed by an academic researcher)

From its inception in 1996 until 2014, the EPA has awarded a total of 98 technologies which have led to a reduction of pollution at the source by billions of pounds, including:

- 826 million pounds of hazardous chemicals and solvents eliminated each year—enough to fill almost 3,800 railroad tank cars or a train nearly 47 miles long.
- 21 billion gallons of water saved each year—the amount used by 820,000 people annually.
- 7.8 billion pounds of carbon dioxide equivalents released to air eliminated each year—equal to taking 810,000 automobiles off the road.

Out of these 98 technologies, the EPA has awarded 33 industrial biotechnology applications. See these awards listed below.

Presidential Green Chemistry Awards for Industrial Biotechnology and Biobased Products

Year	Winner	Description of the Winning Technology
Biotech Awards		
1996	Professor Mark Holtzapple, Texas A&M University	Converts waste biomass (including manure and agricultural residues) into animal feeds, chemicals, and fuel via treatment with lime and anaerobic fermentation to volatile fatty acid salts (full summary)
1998	Argonne National Laboratory	Fermentation of sugars to lactate esters, using membranes and catalysts to efficiently separate and reuse waste products. (summary)
1998	Dr. Karen M. Draths and Professor John W. Frost, Michigan State University	Genetically engineered microbes convert glucose to catechol -- a feedstock for some pesticides -- replacing the traditional synthesis of catechol from petroleum-derived benzene (summary)
1999	Lilly Research Laboratories	Synthesizes a drug candidate for the treatment of epilepsy using yeast, eliminating 3 pounds of chromium waste and 41 gallons of solvent for every pound of the drug (summary)
1999	Dow AgroSciences LLC	Spinosad is a highly selective insecticide derived naturally from a soil microorganism (summary)
2000	Professor Chi-Huey Wong, The Scripps Research Institute	Enzymes and environmentally acceptable solvents replace traditional reactions requiring toxic metals and hazardous solvents; enzymes also enable otherwise impossible or impractical reactions (summary)
2001	Novozymes North America, Inc.	BioPreparation™ separates natural waxes, oils, and contaminants from cotton before it is made into fabric. By using enzymes instead of corrosive chemicals, the process saves 7–12 billion gallons of water each year. (summary)

2001	EDEN Bioscience Corporation	EDEN Bioscience discovered and commercialized harpins -- nontoxic, naturally occurring, biodegradable proteins -- as an alternative to traditional pesticides. The company manufactures Messenger® -- a harpin-containing, EPA-approved product -- using a water-based fermentation system. (summary)
2002	Cargill Dow LLC (now NatureWorks LLC)	Uses a natural fermentation process to produce lactic acid for biobased, compostable and recyclable polylactic acid plastics, substituting renewable materials for petroleum-based feedstock while eliminating the use of solvents and other hazardous materials. (summary)
2003	DuPont	DuPont and Genencor International jointly developed a new platform for DuPont's Sorona® polyester. Sorona® polyester can be now made from 1,3-propanediol, a monomer synthesized by a genetically engineered microorganism instead of chemical synthesis from petroleum. (summary)
2003	Professor Richard A. Gross, Polytechnic University	Strong, tough plastics (polyesters) made by immobilized yeast lipase enzymes, eliminating heavy metal catalysts and toxic solvents. (summary)
2003	AgraQuest, Inc. (now Bayer CropScience)	Serenade®, a EPA-registered microbial biofungicide, made by a naturally occurring bacterium. (summary)
2004	Jeneil Biosurfactant Company	Uses simple fermentation to produce a series of rhamnolipid biosurfactants from soil bacterium. These rhamnolipid biosurfactant products are more cost-effective, less toxic, and more biodegradable than traditional, petroleum-based surfactants. (summary)
2005	Metabolix, Inc.	Metabolically engineered microbes are used to directly produce Polyhydroxyalkanoates or PHAs -- natural plastics that can reduce reliance on fossil carbon, solid wastes and greenhouse gas emissions. (summary)
2005	Archer Daniels Midland Company; Novozymes	Enzymatic transesterification reduces or eliminates *trans* fat from food products, maintaining healthier fats and oils. (summary)
2008	Dow AgroSciences LLC	Spinetoram is a new environmentally friendly insecticide -- fermented from spinosyns -- that replaces organophosphate pesticides for tree fruits, tree nuts, small fruits, and vegetables. (summary)
2009	Eastman Chemical Company	A variety of esters, such as emollients and emulsifiers, used in cosmetics and personal care products are made in a solvent-free enzymatic process (summary)
2010	Professor James C. Liao, Easel Biotechnologies, LLC and University of California, Los Angeles	Dr. James Liao has genetically engineered microorganisms to make higher alcohols directly from glucose or carbon dioxide and can be made available for use as chemical building blocks or as fuel. (summary)
2010	LS9, Inc.	Genetically engineered industrial microorganisms selectively convert fermentable sugars to alkanes, olefins, fatty alcohols, or fatty esters, in a single-unit operation. The process enables precise control of the molecular composition and performance characteristics of the resulting fuel or chemical. (summary)

2010	Merck & Co., Inc. and Codexis, Inc.	Used directed evolution to create a transaminase enzyme to produce sitagliptin, the active ingredient in Januvia™ – a treatment for type 2 diabetes. The enzymatic process improves productivity by 56 percent over a prior award-winning process. (summary)
2011	BioAmber, Inc.	BioAmber has been producing succinic acid by bacterial fermentation of glucose in the world's only large-scale, dedicated, biobased succinic acid plant. (summary)
2011	Genomatica	Using genetic engineering, Genomatica has developed a microbe that makes 1,4-Butanediol (BDO) by fermenting sugars. BDO is used to make spandex, automotive plastics, running shoes, and other products while serving as a better alternative to petroleum. (summary)
2012	Buckman International, Inc.	New cellulase enzymes and combinations of enzymes derived from natural sources and produced by fermentation are used to modify the cellulose in wood to increase the number of "fibrils" that bind the wood fibers to each other, thus making paper with improved strength and quality—without additional chemicals or energy. (summary)
2012	Codexis, Professor Yi Tang, UCLA	Uses a genetically engineered enzyme and a practical low-cost feedstock to synthesize Simvastatin, a leading drug for treating high cholesterol. The new one-step process is more cost-effective and greatly reduces hazardous waste. (summary)
2013	Life Technologies Corporation	Reagents for polymerase chain reaction (PCR) DNA testing are made with a one-pot, three-step synthesis that is much more efficient, eliminates hazardous solvents, and greatly reduces waste (summary)
2014	Amyris	Amyris took a step toward this goal by engineering yeast to make a chemical called farnesene instead of ethanol. Farnesene is a building block hydrocarbon that can be converted into a renewable, drop-in replacement for petroleum diesel without certain drawbacks of first-generation biofuels. (summary)
2014	Solazyme	Solazyme has engineered microalgae to produce oils tailored to customers' needs that can mimic or enhance properties of traditional vegetable oils These micro-algae-derived oils are consistent regardless of season, geographic origin, and feedstock source. (summary)
2015	Renmatix	Renmatix in King of Prussia, Pennsylvania, is being recognized for developing a process using supercritical water to more cost effectively break down plant material into sugars used as building blocks for renewable chemicals and fuels. (summary)
2015	LanzaTech	LanzaTech in Skokie, Illinois, is being recognized for the development of a process that uses waste gas to produce fuels and chemicals, reducing companies' carbon footprint. (summary)
Year	**Winner**	**Description of the Winning Technology**
Biobased Awards		
2006	Codexis, Inc.	The key chiral building block for atorvastatin calcium (the active ingredient in Lipitor®, which is used to lower cholesterol) synthesized

		by three biocatalysts greatly improved by directed evolution (summary)
2007	NovaSterilis Inc.	Uses carbon dioxide and a form of peroxide to sterilize a wide variety of delicate biological materials, such as graft tissue, vaccines, and biopolymers. (summary)
2012	Elevance Renewable Resources, Inc.	Elevance employs highly efficient, selective catalyst technology to break down natural oils and recombine the fragments into novel, high-performance biobased chemicals. (summary)
2012	Professor Geoffrey W. Coates, Cornell University	Professor Geoffrey Coates has developed innovative processes to synthesize plastics from inexpensive, biorenewable substances including carbon dioxide, carbon monoxide, plant oils, and lactic acid.(summary)
2013	Cargill, Inc.	Cargill has developed a vegetable-oil-based transformer fluid that is much less flammable than mineral oil, provides superior performance, is less toxic, and has a substantially lower carbon footprint. (summary)
2013	Professor Richard P. Wool, University of Delaware	Professor Richard Wool has created several high-performance materials, such as adhesives and foams, using biobased feedstocks, including vegetable oils, chicken feathers, and flax (summary)