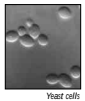
BIOTECHNOLOGY

AGRICULTURE

Classical Biotechnology

Bread, cheese, vinegar, marinades, wine and beer have been made using fermentations by microbes — yeasts, bacteria, molds and fungi — for thousands of years.



Yeast cells

Food Production

Developing improved livestock and crops for greater yield and better quality and new products with reduced impact on the environment. Examples include faster genetic analysis of cattle, improved flavor of vegetables and cheese-making enzymes from bacteria instead of from the stomachs of calves.

WHAT ARE THE TOOLS OF BIOTECHNOLOGY?

Selection & Breeding

Manipulating microbes, plants or animals and choosing desirable individuals or populations as breeding stock for new generations.

Fermentation

Using microbes to convert a substance such as starch or sugar into other compounds such as carbon dioxide and ethanol.

Genetic Analysis

Studying how traits and genes for traits are passed from generation to generation and how genes and the environment interact to result in traits.

Tissue Culture

Growing plant or animal tissues or cells in test tubes or other laboratory glassware, without other contaminating organisms, for propagation, chemical production and medical research.

Genetic Engineering / Recombinant DNA (rDNA)

Transferring a DNA segment from one organism and inserting it into the DNA of another organism. The two organisms can be totally unrelated.

DNA Analysis

Polymerase chain reaction (PCR) makes many copies of a DNA segment. RFLP mapping (restriction fragment length polymorphism) detects patterns in DNA that can indicate the presence of a gene for a trait.

Both PCR and RFLP analysis can be used in "DNA fingerprinting" for genealogical studies and forensics.

MEDICINE

Diagnosis

Using biotechnology to speed diagnosis of genetic disorders or infectious diseases and early detection of pregnancy. For example, strep throat can now be diagnosed in 20 minutes rather than in two days.

Pharmaceuticals: Prevention & Treatment

Using vaccines, antibiotics and therapeutics produced by microbes, plants or animals.

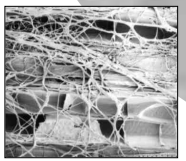
Genetic Counseling & Gene Therapy

Prospective or current parents learn about diagnosing and treating inherited diseases and whether their children may inherit such diseases.

INDUSTRY & ENVIRONMENT

Fiber: Biopulping

A new example of industrial biotechnology for fiber is biopulping — using a fungus to convert wood chips to paper pulp while reducing energy use and pollutants. Other fibers from plants and animals include cotton, wool, silk, linen, leather, lumber and paper.



Fungus strands growing on wood (magnified)

Fuel

Producing ethanol for gasohol, methane for natural gas and crops for biorenewable fuel. For example, yeasts ferment cornstarch to yield ethanol; bacteria decompose sludge, manure or landfill wastes to produce methane; and firewood heats homes.

Feedstocks: Bioplastics

Instead of petroleum, biorenewable materials such as starch from corn or whey from cheese-making can be used to make plastics. Industry uses microbes or their enzymes to convert biomass to feedstocks — building blocks for biodegradable plastics, industrial solvents and specialty lubricants.

Lactic acid bacteria

The Five "Fs": Food Fiber Fuel Feedstocks Pharmaceuticals

WHAT IS BIOTECHNOLOGY?

Defined broadly, biotechnology is the use of a living organism to make a product or run a process. Narrow definitions often limit biotechnology to genetic engineering and recombinant DNA technology. The root words are ancient Greek:

Bios: *"life"*

Technikos: *"skillfully made," "tool"*

Logos: *"study of," "word," "essence"*

Biotechnology –*"the study of living tools"* – is used in agriculture, food processing, industrial production, environmental cleanup and medicine.

WHAT TOOLS DOES BIOTECHNOLOGY USE?

Biotechnology researchers apply the tools below to living organisms: microbes (organisms you can only see with a microscope), plants, and animals.

Selection & Breeding

Manipulating microbes, plants or animals, and choosing desirable individuals or populations as breeding stock for new generations.

Fermentation

Using microbes to convert a substance such as starch or sugar into other compounds such as carbon dioxide and ethanol.

Genetic Analysis

Studying how traits and genes for traits are passed from generation to generation and how genes and the environment interact to result in traits.

Tissue Culture

Growing plant or animal tissues or cells in test tubes or other laboratory glassware, without other contaminating organisms, for propagation, chemical production and medical research.

Genetic Engineering / Recombinant DNA (rDNA)

Transferring a DNA segment from one organism and inserting it into the DNA of another organism. The two organisms can be totally unrelated.

DNA Analysis

Polymerase chain reaction (PCR) makes many copies of a DNA segment. RFLP mapping (restriction fragment length polymorphism) detects patterns in DNA that can indicate the presence of a gene for a trait.

Both PCR and RFLP analysis can be used in "DNA fingerprinting" for genealogical studies and forensics.

HOW OLD IS BIOTECHNOLOGY?

The word "biotechnology" cannot be traced to 1919, when it was used to refer to large-scale production of materials from microbes grown in vats. But the roots of the technology are as familiar and ancient as baking yeast breads — traceable back 6,000 years.

4000 BC Classical biotechnology: Dairy farming develops in the Middle East; Egyptians use yeasts to bake leavened bread and to make wine.

3000 BC Peruvians select and cultivate potatoes.

2000 BC Egyptians, Sumerians and Chinese develop techniques of fermentation, brewing and cheese-making.

500 BC Mediterraneans develop sunbrewing and Europeans develop salting, which leads to curing and pickling to flavor and preserve food.

1500 AD Acidic cooking techniques lead to sauerkraut and yogurt — two examples of using beneficial bacteria to flavor and preserve food. Aztecs make cakes from Spirulina algae.

1856 *On the Origin of Species* — English naturalist Charles Darwin's theory of evolution — is published in London.

1861 French chemist Louis Pasteur develops pasteurization — preserving food by heating it to destroy harmful microbes.

1865 Austrian botanist and monk Gregor Mendel describes his experiments in heredity, founding the field of genetics.

1879 William James Beal develops the first experimental hybrid corn.

1910 American biologist Thomas Hunt Morgan discovers that genes are located on chromosomes.

1928 F. Griffith discovers genetic transformation — genes can transfer from one strain of bacteria to another.

1941 Danish microbiologist A. Jost coins the term "genetic engineering" in a lecture on sexual reproduction in yeast.

1943 Oswald Avery, Colin MacLeod and Maclyn McCarty use bacteria to show that DNA carries the cell's genetic information.

1953 James Watson and Francis Crick describe the double helix of DNA, using X-ray diffraction patterns of Rosalind Franklin and Maurice Wilkins.

Early 1970s Paul Berg, Stanley Cohen and Herbert Boyer develop ways to cut and splice DNA, introducing recombinant DNA techniques.

1975 Scientists organize the Asilomar conference to discuss regulating recombinant DNA experiments. George Köhler and César Milstein show that fusing cells can generate monoclonal antibodies.

1982 First genetically engineered product — human insulin produced by Eli Lilly & Company using *E. coli* bacteria — is approved for use by diabetics.

1984 Kary Mullis develops polymerase chain reaction (PCR) to mass-produce specific DNA fragments.

1986 First release into the environment of a genetically engineered plant (a tobacco).

1987 First release of genetically engineered microbes in field experiments.

1990 Pfizer, Inc., introduces Chy-Max™ chymosin, an enzyme used in cheese-making — first product of recombinant DNA technology in the U.S. food supply.

1993 After nearly 10 years of scientific review and political controversy, the U.S. Food and Drug Administration (FDA) approves Monsanto Co.'s version of rBGH/rBST to increase milk production.

1994 Calgene, Inc., markets the FLAVR SAVR™ tomato — first genetically engineered whole food in the U.S. food supply.

ACKNOWLEDGMENTS

This publication was funded in part by a grant from the U.S. Department of Agriculture Cooperative State Research, Education and Extension Service, administered by the University of Wisconsin Biotechnology Center. Additional support came from UW-Extension Cooperative Extension and the UW Biotechnology Center, in cooperation with the North Central Region Educational Materials Project.

In addition to those named in the credits, the author thanks for reviewing and contributing to this publication: Richard Burgess and Leona Fitzmaurice, UW Biotechnology Center, UW-Madison; and Al Hovey, Jr., science education consultant, and colleagues at the Wisconsin Department of Public Instruction.

Timeline expanded and adapted with permission from: *Biotechnology in Perspective* by Dr. David B. Sattelle (Washington, D.C.: Industrial Biotechnology Association), 1990, copyright © 1988 by Hobsons Publishing PLC, Bateman Street, Cambridge CB2 1LZ UK; *The Emergence of Bacterial Genetics* by Thomas D. Brock (Cold Spring Harbor, N.Y.: Cold Spring Harbor Laboratory Press), 1990; "*Food Biotechnology: History of Food Development*" by the International Food Information Council, Washington, D.C., 1993; *Brief Book: Biotechnology and Genetic Diversity* by Steven C. Witt, Agricultural Lands Project, 1985; and *Brief Book: Biotechnology — Microbes and the Environment* by Steven C. Witt (San Francisco: Center for Science Information), 1990.

Photos by Wolfgang Hoffmann, Department of Agricultural Journalism, 440 Henry Mall, Madison, WI 53706.

Illustrations and graphics by Betsy True, Department of Medical Illustration, UW Medical School, UW-Madison.

Additional images courtesy of: Eli Lilly & Company; Advanced Care Products, Ortho Pharmaceutical Corp., Johnson & Johnson; Dr. Doris Ursic, R.M. Bock Labs, UW-Madison; USDA Forest Products Lab; and the UW-Madison Food Research Institute.

This publication contains copyright protected material. Permission is required from each copyright owner before photocopying or reprinting.

This material is based upon work supported by the Cooperative State Research, Education and Extension Service, U.S. Department of Agriculture, under special project number 93-EFSQ-1-4090.

Author: Tom Zinnen, biotechnology education specialist, University of Wisconsin-Extension and UW Biotechnology Center, UW-Madison. Produced by Cooperative Extension Publications, UW-Extension: Rhonda Lee, editor; Jody Myer-Lynch, designer.

North Central Regional Extension Publications are subject to peer review and prepared as part of the Cooperative Extension activities of the 13 land-grant universities of the 12 North Central States, in cooperation with the Cooperative State Research, Education and Extension Service, U.S. Department of Agriculture, Washington, D.C.

Reviewers: Kathleen Kennedy, North Carolina Biotechnology Center, Research Triangle Park, North Carolina; Martina McGloughlin, UC-Davis Biotechnology Department, Davis, California; James F. Plog, Northeast Wisconsin Technical College, Green Bay, Wisconsin.

Sponsored by the Extension Services of Illinois, Iowa, Michigan, Minnesota, Missouri, Nebraska, North Dakota, South Dakota and Wisconsin.*

* Publishing state

In cooperation with the NCR Educational Materials Project. Issued in furtherance of Cooperative Extension work, Acts of Congress of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture and Cooperative Extension Services of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota and Wisconsin. Programs and activities of the Cooperative Extension Service are available to all potential clientele without regard to race, color, national origin, age, gender, religion or disability.

For copies of this poster, companion *Biotechnology and Food: Leader and Participant Guide* NCR 569 or other NCR educational publications, contact your county extension office or the publishing state: Cooperative Extension Publications, 30 N. Murray St., Room 245, Madison, WI 53715, (608) 262-3346.

North Central Regional Extension Publication No. 570

BIOTECHNOLOGY

TOOLS FOR GENETIC INGENUITY

NCR 570 BIOTECHNOLOGY *TOOLS FOR GENETIC INGENUITY* (1994) 1-12-94-10M-300 -S

TOM ZINNEN

WHAT IS GENETIC ENGINEERING?

Humans not only use plants, animals and microbes that occur in nature, they also select and develop new varieties that have desired traits. This selection has resulted in improved crop plants, livestock and industrial microbes.

Breeders of plants, animals and microbes continuously select the more useful variants and keep those as breeding stock for new generations. Breeding can be sped up by methods that improve selection or by techniques that generate genetic variation. The more variation, the more options the breeder can choose from. These methods include producing hybrid plants, artificially inseminating livestock, and making mutants of microbes — changing the genetic material of a cell to cause that cell and all cells derived from it to look or behave differently.

Many recent biotechnology methods focus on manipulating DNA — deoxyribonucleic acid. DNA is the biological information tape that stores genetic information in organisms and transmits it from generation to generation. Previously, breeders mixed thousands of genes by crossing related organisms. But such crosses worked only with individuals from related species.

Genetic engineering techniques permit breeders to move one or a few genes from one organism to another. For example, a copy of a gene can be moved from a bull to a bacterium or from a cell of a human being to a bacterium. This type of gene transfer is also called recombinant DNA technology because it results in new combinations of DNA.

WHAT WAS THE FIRST COMMERCIAL USE OF GENETIC ENGINEERING?

Recombinant DNA technology was first used commercially to produce human insulin from bacteria. In 1982, genetically engineered insulin was approved for use by diabetics. People with certain types of diabetes inject themselves daily with insulin, a protein hormone that regulates blood sugar.

Insulin is normally produced by the pancreas, and pancreases of slaughtered animals such as swine or sheep were used as a source of insulin.

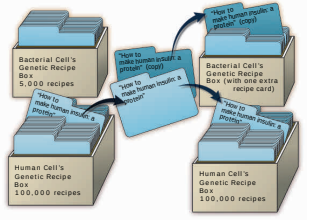
To provide a reliable source of human insulin, researchers obtained from human cells the DNA carrying the gene with the information for making human insulin.

Researchers made a copy of the DNA carrying this insulin gene and moved it into a bacterium.

When the bacterium was grown in the lab, the microbe split from one cell into two cells, and both cells got a copy of the insulin gene.

Those two microbes grew, then divided into four, those four into eight, the eight into sixteen, and so forth. With each cell division, the two new cells each had a copy of the gene for human insulin. And because the cells had a copy of the genetic "recipe card" for insulin, they could make the insulin protein. In this way, special strains of *Escherichia coli* (*E. coli*) bacteria or yeast given a copy of the insulin gene can produce human insulin.

E. coli picture courtesy of Eli Lilly & Company



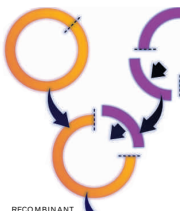
E. coli bacteria given copies of the genetic "recipe card" for human insulin can then make insulin protein for diabetics.

WHAT ARE SOME OTHER COMMERCIAL USES OF GENETIC ENGINEERING?

Using the same approach as in the insulin example, researchers found and transferred a copy of the gene for human growth hormone (HGH) to bacteria. The bacteria can produce large amounts of HGH, which can be purified and used to treat certain kinds of human dwarfism.

To increase milk production, other researchers transferred a copy of the gene for bovine growth hormone/bovine somatotropin (rBGH/rBST) to another strain of bacteria. And a copy of the gene for chymosin — a protein enzyme from calf stomachs used for cheese-making — was transferred into yet another strain of bacteria.

Four different strains of lab-grown bacteria and one strain of yeast are now used commercially to produce human insulin, human growth hormone, bovine growth hormone and chymosin.



RECOMBINANT DNA — *You can think of gene splicing like cutting a circle of tape. You can cut it once, insert a different piece, and join both ends.*

WHAT IS GENE THERAPY?

Some human diseases are caused by a defective gene. An example is cystic fibrosis, a disease of mucous glands throughout the body that usually develops during childhood and makes breathing increasingly difficult. If a child receives two copies of the defective gene called the CF gene — one copy from each parent — then the child will develop the disease.

Biotechnology is used in several ways in detecting, diagnosing and treating cystic fibrosis:

FIRST, genetic testing or "screening" enables healthy people to know whether they carry one copy of the CF gene. If both potential parents have one copy each of the CF gene, then the genetic counselor can provide information and help assess whether the couple may have a child who will develop cystic fibrosis.

SECOND, genetic testing can alert parents their child has two copies of the CF gene, permitting diagnosis even before the disease develops in the child.

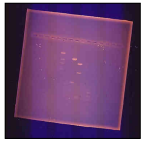
THIRD, children with cystic fibrosis can enjoy some relief from the mucus buildup in their lungs by breathing in a mucus-breaking drug made with recombinant DNA technology. The drug contains a protein that chews up the DNA so the mucus is easier to remove from the lungs by coughing.

FOURTH, an experimental approach to curing cystic fibrosis uses a genetically engineered cold virus that delivers to the patient's lung cells a working version of the defective gene. The new gene enables lung cells to make the protein that is lacking in cystic fibrosis patients.

You will find the scientific terms in bold letters in the glossary of companion notebook *Biotechnology and Food: Leader and Participant Guide* NCR 569. *Reference to products on this poster is not intended as an endorsement to the exclusion of others that may be similar.*

DO ALL MODERN BIOTECHNOLOGY TECHNIQUES INVOLVE GENE TRANSFER?

No, not all uses of DNA technology involve gene transfer. For example, one common technique uses DNA patterns to speed up breeding plants, animals or microbes. These DNA patterns — DNA "fingerprints" — are like the bar codes found on packages in the supermarket. Just as each item has its own bar code pattern so the computer can "read" its price, some genetic traits have their own DNA pattern. Breeders can use these patterns to find and select breeding stock with traits such as disease resistance.



HOW DOES BIOTECHNOLOGY HELP CLEAN UP THE ENVIRONMENT?

Microbes break down many chemicals in the environment. Sewage treatment plants harness these microbial recyclers to clean up waste water before it returns to streams, lakes and groundwater. Some sewage plants also collect methane the microbes produce to fuel generators, digesters and air compressors.

Another use is bioremediation — using microbes to clean up oil or chemical spills, such as gasoline leaking from an underground tank. A third use is biopulping — using selected fungi in the paper-making process and using less energy and fewer chemicals at the same time. Biopulping is still experimental.

A cleaner alternative to using fossil fuels is using renewable resources such as whey and corn to produce plastics and ethanol (gasohol). And, by selecting natural organisms to combat crop insect pests and diseases, farmers can reduce pollution by using fewer chemicals.

REGULATION AND FUTURE IMPACTS

WHO MONITORS BIOTECHNOLOGY?

The federal government reviews the safety and effectiveness of all new drugs, food additives and pesticides. This includes products made with classical biotechnology or with genetic engineering.

Agricultural biotechnology products may be regulated by a combination of three federal agencies: the U.S. Department of Agriculture (USDA), the Environmental Protection Agency (EPA), and the Food and Drug Administration (FDA). Together, these agencies are empowered by law to use three criteria when assessing new products: safety, efficacy and quality. This means the agencies answer these questions for each new product:

1) *Is the product sufficiently safe to humans and the environment?*
2) *Does the product work as intended?*
3) *Can the quality of the product be assured?*

Some people suggest that new products be reviewed by a fourth criterion:

4) *What are the potential or probable social and economic impacts of the product?*

New technologies often bring new legal, regulatory and ethical challenges. What you know about biotechnology will better prepare you to make personal choices and public policies about the use of new technologies and their products.

HOW *can you remember these uses of biotechnology?*

Here's an easy way to remember ways we use biotechnology. Think of them as "The 5 Fs" — five broad categories, beginning with an FF sound, of products from living microbes, plants or animals:

Food — for humans and feed for livestock.

Fiber — cotton, wool, silk, linen, leather, lumber and paper.

Fuel — ethanol (gasohol), methane, wood.

Feedstocks — building blocks for polymers and industrial chemicals.

Microbes are also essential in treating wastewater and can be used to clean up oil and toxic chemical spills.

Pharmaceuticals — diagnostics for detecting diseases or pathogenic bacteria; vaccines for preventing illness; antitoxins for blocking poisonings; antibiotics for treating infections; and therapeutics for treating disease.

Medical biotechnology also includes genetic testing and counseling for predicting susceptibility to gene therapy for correcting disorders caused by defective genes.