
Biotechnology Solutions for Renewable Specialty Chemicals & Food Ingredients



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Introduction

Many of the products consumers purchase and use on a daily basis are made from petroleum, natural gas or petrochemicals. The availability and affordability of these products contributes to improved standards of living in countries around the world.

The volatility of prices for oil and natural gas present a challenge to manufacturers seeking to keep consumer goods at competitive prices. Further, consumers are increasingly seeking products with natural or renewable ingredients, enhanced performance qualities, or environmental benefits. The use of biotechnology presents an opportunity to meet these consumer demands.

Biotechnology enables the use of renewable resources in the production of chemicals that are identical, drop-in replacements for petrochemicals. In many cases, the only difference between the petrochemical and renewable chemical is the stability of the price. In other cases, renewable chemicals provide enhanced formulation qualities.

Biotechnology processes are inherently cleaner than petrochemical or thermochemical processes, producing fewer byproducts or using less energy. Renewable chemicals can meet consumer expectations for environmental sensitivity.

Renewable chemicals represent an opportunity to commercialize innovative biotechnology applications because they are competitive on cost and performance in low-volume, high value markets. The capital investment costs for building small-scale renewable chemical production plants is lower than for a bulk chemical such as a biofuel.

Personal Care Products That Combine Performance with Natural Ingredients

Consumers look for natural ingredients in personal care products such as shampoos, cosmetics and creams, often paying a premium for them. Using natural ingredients alone in these products can present challenges in terms of shelf stability and consistency. However, using petrochemical ingredients as stabilizers and emulsifiers can defeat the purpose of formulating a product with natural ingredients.

[Elevance Renewable Sciences](#) has developed technology for producing emulsifiers, waxes and emollients from natural lipids derived from soy. These products are being used by Dow Corning to replace petrochemical products – such as polyethylene glycol and petrolatum – in creams, lotions, hair pomade, and cosmetics.



Elevance employs metathesis – a process that uses proprietary catalysts to rearrange the carbon bonds in a natural lipid – to transform soy into novel olefins. Metathesis technology often utilizes fewer process steps and lower process temperatures than petrochemical synthesis. It also minimizes byproducts and produces products with less toxicity.

Through a partnership with Elevance, Dow Corning now offers Soy Wax and a Soy Wax blend that can

be used as a naturally derived alternative to petrolatum in both hair and skin care products. The wax contributes to these products a natural moisturizing agent with a smoother, less greasy feel. A newly introduced Emulsifying Soy Wax eliminates the need for multiple emulsifiers and thickeners, reducing ingredients and costs for product formulation.

Delivering Enhanced Cleaning Products

Each year, approximately 5.7 billion barrels of oil go into 30 to 50 chemical raw materials that form the backbone of modern society and appear in end products that range from automobiles, fabrics and plastic bottles to adhesives, cell phones, shoes and building materials. The chemical market is worth \$2 trillion annually.

Levulinic ketals are bio-based compositions with performance advantages in many applications. Enabled by selective ketalization of levulinic acid esters, these compounds have broad solubility and can be used as cleaning solvents or coupling agents in liquid formulations. When extended by trans-esterification, levulinic ketals can make effective plasticizers for compounds such as PVC, polyols for polyurethane materials, and polyester thermosets or thermoplastics.

By applying industry standards for performance, Segetis is able to identify the specific levulinic ketals that enable reduction or replacement of fossil-fuel-based chemicals and plastics on a functional and cost basis.

A CLEANER CLEAN IS
BRIGHT GREEN ON
THE OUTSIDE.
AND DARK GREEN
ON THE INSIDE.



“We’re incredibly proud of this innovation because it solves one of the traditional problems in green cleaning – how do you clean effectively without dirty solvents? Instead of formulating around the problem as others must, Method delivers powerful solvency in our products through renewable alternatives.”
Adam Lowry, Method Co-Founder and Chief Greenskeeper

Segetis, Inc. a technology enabled green chemistry company, has established a new partnership with Method Products, Inc., a manufacturer of home cleaning and laundry products, to use bio-based materials in a variety of Method’s products moving forward. Segetis’ materials deliver a performance and sustainability profile that matches Method’s clean, safe, and sustainable objectives. The new bio-based molecules in Method’s products offer awesome performance and replace the traditional fossil fuels that are commonly found in ordinary cleaning

products. This new partnership between Method and Segetis highlights the potential for a new biobased technology to enhance the home care products category. The two companies share a desire and mission to be industry catalysts bringing novel, efficacious green chemistries to market quickly.

Personal Care Products from Sustainable, Renewable Raw Materials

Surfactants are among the most useful and widely sold chemicals because they enable the stable blending of ingredients that do not typically mix well, like oil and water. In addition, surfactants are the ingredients that give shampoos and body washes their cleansing power.



Today, nearly all surfactants are manufactured from either petrochemicals or seed oils, such as palm or coconut oil. Petrochemical surfactants introduce carbon dioxide into the atmosphere as they degrade. Expansion of palm and coconut oil production can also introduce carbon dioxide into the atmosphere if it displaces rainforest.

Modular Genetics, Inc. has developed microorganisms that convert clean agricultural residue into surfactants by the natural process of fermentation. Modular has demonstrated that these surfactants can be produced from a wide variety of underutilized agricultural



materials, including soybean hulls (the woody case that protects the soybeans), crude glycerol from biodiesel production and potato waste generated by the food processing industry. These raw materials are typically sold as low value animal feed. Modular is able to convert these low-value raw materials into high-value surfactants that will be used in personal care products like cosmetics and shampoos.



Making Alternatives into Mainstream Products



On a pound-for-pound basis, producing bio-based 1,3 propanediol consumes 38 percent less energy and emits 42 percent fewer greenhouse gas emissions compared to petroleum based propanediol or propylene glycol.

Bio-PDO™ is fermented from corn sugar using a biotech process. The 1,3 propanediol monomer is separated from the fermentation broth and then available to be used in direct product formulations or as an ingredient in polymers. Over a dozen products can be made using Bio-PDO™ (renewably sourced 1,3 propanediol) as a key

ingredient.

Zemea® and Susterra® propanediol are two grades of 100 percent renewably sourced Bio-PDO™, manufactured by [DuPont Tate & Lyle Bio Products](#). Zemea® propanediol has been developed for use in cosmetics, personal care and home cleaning products, offering high purity, low irritation and sustainability to formulators and manufacturers. Zemea® propanediol also offers a luxurious feel and superior hand in lotions and creams.

Susterra® propanediol is used in aircraft deicing, anti-freeze and heat transfer industrial fluids as well as unsaturated polyester resins and polyurethanes. In fluid applications, Susterra® propanediol offers excellent low-temperature characteristics and improved degradation versus conventional glycols. In polymer applications, the unique structure of Susterra® propanediol contributes to increased flexibility and better impact resistance. Susterra® propanediol is a key ingredient for [DuPont™ Sorona®](#) polymer and [DuPont™ Cerenol™](#) polyols.

DuPont™ Sorona® contains 37 percent renewably sourced 1,3 propanediol by weight. Fabrics made with Sorona® offer a unique combination of attributes including: exceptional softness, comfort, stretch and recovery, and easy care.

[Mohawk Industries](#) offers SmartStrand® with DuPont™ Sorona® carpet. As a fiber for residential carpeting, Sorona® offers a soft carpet that provides durability and permanent stain protection. Carpet made with Sorona® can contribute to Leadership in Energy and Environmental Design (LEED®) credits. In 2009, the U.S. Federal Trade Commission determined that the polymer composition of Sorona® is uniquely different from the composition of polyester and nylon and is worthy of its own generic subclass name, Triexta.

Exploring Renewable Resources and New Ways of Producing Chemicals

Novozymes' vision is a bio-based society in which biotechnological solutions convert renewable biomass to basic building blocks or intermediates for a large number of products for both industrial markets and end consumers. The renewable raw materials needed to replace the shrinking availability of relatively cheap crude oil include corn, wheat, soy, sugar, agricultural waste material and biomass. Novozymes is working with partners to develop biotechnology solutions that enable use of renewable raw materials for widely used intermediate chemicals, including acrylic acid, polypropylene, and glycols.

Acrylic acid is used in a wide range of applications and materials such as textile fiber, coatings, paints, cosmetic products, and super absorbent polymer, an important component of diapers. Novozymes has entered into an agreement with Cargill to develop technology to produce



acrylic acid from renewable raw materials.



Polypropylene is a plastic found in a wide range of everyday products. Braskem (a Brazilian petrochemical company) and Novozymes are collaborating on a new technology to convert sugar into polypropylene. The two companies signed a joint development agreement in December 2009.

The latest examples of biochemicals under development are glycols. As part of a collaboration with the Chinese Dacheng Group, Novozymes will provide the know-how and enzymes to convert biomass such as corn stover, wheat straw, and

rice straw into sugar, which the Dacheng Group will subsequently convert into glycols.

Novozymes' commitment and technology is breaking down barriers and helping to hugely increase the share of biotechnology in a broad range of markets, slowly but surely moving the world toward a bio-based society.

Sustainable Chemicals for Sustainable Materials on Track for Commercial Production

Many of the materials that surround us, like plastic, paint, carpet and running shoes, are made from chemicals – a multi-trillion dollar industry.

[Genomatica](#) has developed technology and manufacturing processes that can make the exact same chemicals from 'sustainable' ingredients rather than crude oil or natural gas hydrocarbons. Genomatica's technology allows it to rapidly develop organisms and cost-effective manufacturing processes for dozens of the most significant intermediate and basic chemicals that make up the core of the chemical industry. Genomatica's technology also offers the potential to use a range of feedstocks, including conventional sugars, cellulosic biomass and syngas.



The first-ever renewable BDO produced for greener materials by Genomatica.

Genomatica has been successfully producing Bio-BDO, a biobased 1,4-butanediol, at pilot scale since the first half of 2010 and is moving to demonstration-scale production of two tons per week in 2011. BDO is used in products like spandex and automotive plastics. Commercial-scale production is expected in late 2013. [Waste Management, a Fortune 200 company, signed a strategic joint development agreement](#) where Genomatica will use its technology to create methods to turn syngas from municipal solid waste into higher-value chemicals.

Genomatica's biological production can reduce the cost to build a chemical plant; reduce the production and operating cost; reduce energy use by 60 percent; and reduce greenhouse gases by 70 percent. Better economics is the essence of innovation, which is needed to bring more cleantech manufacturing jobs to the United States. Genomatica's novel approach to making greener materials was named one of '10 Big Green Ideas' by [Newsweek](#) and was featured on [Forbes.com](#).

Rethinking Synthetic Building Blocks: Bio-based Succinic Acid



The chemical industry has been delivering solutions for many years, by creating new specialty chemicals for applications ranging from food ingredients to plastics to industrial coatings and everywhere in between. Price and performance are the most important characteristics of any new product, while the size of the environmental footprint is often given less consideration. However, manufacturers and, ultimately, consumers value products with a smaller environmental footprint. The chemical industry has not been able to satisfy that need while maintaining the performance and affordability of new products.

[Myriant Technologies](#) has developed a process to produce specialty chemical building blocks that deliver in all three areas, price, performance, and environmental footprint. Myriant's technology takes advantage of the inherent efficiency of biological processes to manufacture succinic acid, using less energy and generating less waste than conventional synthetic processes. Myriant's succinic acid performs at the highest level of quality, while remaining cost competitive with petroleum-based succinic acid. Biobased succinic acid can be used in the manufacture of a range of high-value chemical products, including 1,4-butanediol, tetrahydrofuran, and as a substitute for adipic acid.



Myriant succinic acid is available as a new bio-based building block in the toolkit of specialty chemicals. Any chemistry that today uses petroleum-derived diacids is a candidate for substitution with a bio-based material with comparable performance and price competitiveness. Succinic acid may have been overlooked in the past because of availability and price, but soon [Myriant's commercial-scale manufacturing plant](#) will provide the volumes of quality building blocks needed for successful new products.

Biosuccinic Acid: Superior Performance, Cost, and Environmental Profile

Consumers and companies today are looking for products that perform, are cost-effective and have a better environmental profile. [BioAmber](#)'s biobased succinic acid platform offers all three advantages.

Succinic acid, commonly referred to as amber acid, is a key building block for a wide range of secondary chemicals used in the chemical, pharmaceutical, food and agricultural industries. Until now, succinic acid was produced from petroleum feedstocks. Offering cost-competitiveness and superior functionality and performance, BioAmber's biosuccinic acid can replace conventional petroleum-based succinic acid, substitute for other chemicals like adipic acid in products such as nylon, and serve as the starting



material for the production of high-value, high-volume chemicals such as 1,4-butanediol (BDO) and tetrahydrofuran (THF).



BioAmber is a renewable chemistry company, leading the field in biobased succinic acid. BioAmber's new product platform creates a foundation for customer innovation in a broad range of applications and markets, where biobased succinic acid is cost-competitive and offers superior functionality or performance with a better environmental footprint.

Biobased succinic acid is one of the core building blocks of renewable chemistry and the foundation of a portfolio of products, including polybutylene succinate (PBS), an innovative biodegradable polymer with high growth potential globally. BioAmber's modified PBS (mPBS) has better heat resistance and overall processability than other

biodegradable polymers. It can be used to replace plastics made from oil in any number of applications, from everyday disposable items like coffee cup lids and cutlery to durable applications like medical devices, office equipment and vehicle components. Green solvents, green plasticizers and biorenewable plastics are among the applications in development through partnerships with industry leaders.

"We don't just plan to produce Biosuccinic Acid. We already do."

*Jean-Francois Huc,
Chief Executive Officer, BioAmber*

BioAmber's biosuccinic acid platform harnesses the power of biology, combining it with chemistry, to enable a portfolio of cost-effective renewable products that can replace more energy-intensive and expensive petrochemical-derived chemicals and materials. In addition, BioAmber's fermentation process to produce biosuccinic

acid consumes CO₂, helping to reduce emissions of greenhouse gases. By eliminating the need for fossil fuel combustion, BioAmber's biorenewable processes also reduce the production of other gases that are harmful to human health.

A Renewable Chemical That Replaces a Scarce Natural Resource

Synthetic cis-polyisoprene is a suitable replacement for natural rubber in many applications. Biolsoprene™, derived from renewable feedstock, is expected to deliver a more sustainable alternative to petrochemical-based isoprene in producing synthetic rubber. The Biolsoprene™ process offers a real possibility for obtaining meaningful quantities of low-cost isoprene, which is needed to produce a high-volume alternative to Hevea natural rubber and petroleum-derived isoprene.

Biolsoprene™ offers a lower carbon footprint in the manufacture of synthetic rubber and the potential for various other applications, such as specialty elastomers and adhesives as well as advanced biobased transportation and jet fuels derived from the Biolsoprene™ C5 building block. The development of Biolsoprene™ represents a major achievement for industrial biotechnology because it has the potential to enable production of isoprene from renewable raw materials to deliver commercial quantities of a basic C5 hydrocarbon that, in principle, can be used as a feedstock for a large number of value-added products. Genencor unveiled a breakthrough prototype tire made with Biolsoprene™ through a collaborative research effort with the Goodyear Tire and Rubber Company.



Unlike other biobased systems used to produce biochemicals, Biolsoprene™ is produced as a gas-phase product that is released as soon as it is produced into the vapor phase of the reactor without any noticeable negative physical or inhibitory impacts on the biological host. Polymer-grade Biolsoprene™ is recovered from the integrated process. Potential benefits of the gas-phase nature of the product include:



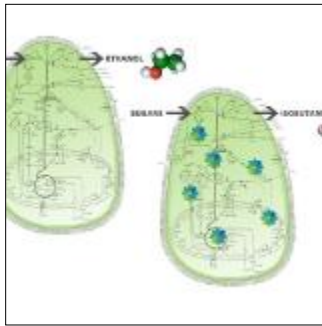
- reduction and/or elimination of feedback inhibition by the isoprene product on further synthesis;
- efficient recovery and purification of polymer-grade Biolsoprene™ product from the fermentation broth; and
- possibility to use low-cost feedstocks.

[Genencor](#)® has a long history in the design and operation of cells that function as factories. Examples of these factories at work include industrial enzymes, commodity chemicals and advanced metabolic pathway systems for the production of biochemicals, including amino acids (lysine, tryptophan, threonine), 1,3-propanediol, indigo and ascorbic acid.

A Sugar-Derived Building Block for Chemicals and Fuels

Isobutanol is a building block chemical that can be used in solvents, rubber, and transportation fuels, each of which constitute multi-billion dollar markets. Through standard chemistry, isobutanol can be used as an ingredient in nearly 40 percent of traditional chemicals (such as butenes, toluenes and xylenes) as well as many transportation fuels. Used as a solvent, isobutanol appears in paints and cosmetics such as nail polish. The solvent, rubber and fuel ingredients markets are each worth several billion dollars.

Volatility in petroleum prices can have a significant impact on these markets. Bioisobutanol is a drop in replacement for petroleum-based that offers stability in pricing and a potential savings of more than \$1 on each gallon produced, on average.



Gevo has developed an Integrated Fermentation Technology (GIFT) that combines genetically engineered yeast with a continuous separation process to screen the isobutanol from the fermentation broth, allowing the yeast to survive longer. Using synthetic biology, Gevo has engineered a yeast to concentrate on production of butanol – which is a standard product of fermentation by brewer’s yeast, as in beer or wine making – by blocking production of ethanol and acetic acid. Through the integrated process, Gevo has reached 94 percent of theoretical yields in production.

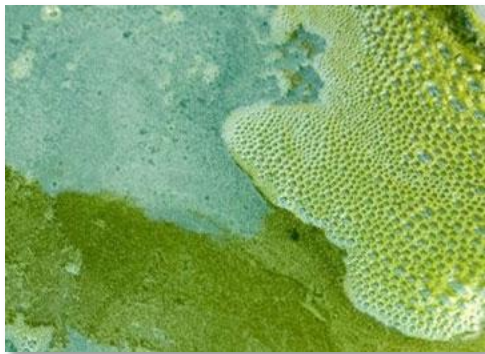
Gevo, using a 1 million gallon per year plant in St. Joseph, Mo., has demonstrated production of butyl rubber, butenes, solvents and lubricants through partnerships with chemical manufacturers Lanxess, Sasol and Toray. Gevo has also demonstrated production of biofuels in partnership with Total. The company is currently retrofitting a corn ethanol plant in Luverne, Minn., to produce 18 million gallons of isobutanol or ethanol per year.

Industrial Cooling Fluid From Algae Oil

Electrical transmission over long distances requires transformers. To insulate and cool some these transformer units, the industry uses more than 500 million gallons of dielectric insulating fluids. These fluids must withstand electric stress and heat without impeding the flow of the electrical current.



Currently, mineral oil, high-temperature hydrocarbons, silicone fluids, and vegetable oil are used. In the past, polychlorinated biphenyls (PCBs) were used, but they presented a potential environmental hazard. Solazyme has developed algal oils for a new generation of dielectric fluids that are fire safe, environmentally sound, and provide increased performance for transformers and other electrical applications.



Solazyme's technology allows algae to produce oil and biomaterials in standard fermentation facilities quickly, efficiently and at large scale. These oils can be tailored as replacements for fossil petroleum and plant oils in a diverse range of products running from clean fuels and chemicals to cosmetics and foods. Under the terms of the joint development agreement, Dow will combine its extensive knowledge of specialty fluid formulations and dielectric insulation capabilities with Solazyme's unique feedstock

capabilities to develop of a new class of algal oils tailored for optimized performance and cost in dielectric insulating fluids.

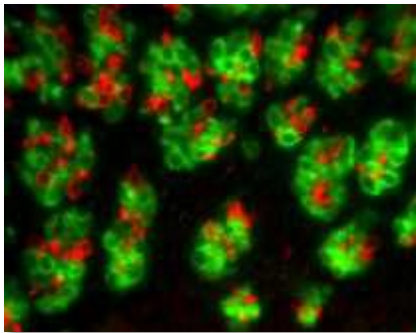
Dow may obtain up to 20 million gallons of Solazyme's oils for use in dielectric insulating fluids and other industrial applications in 2013 and up to 60 million gallons in 2015.

New Flavor Ingredients Help Reduce Sugar While Maintaining the Taste Consumers Desire

High sugar consumption is a primary cause of obesity, which has been linked to increased risks for diabetes, heart and respiratory diseases, cancers, and mortality. Although many consumers would like to decrease their sugar intake, some find products with lower sugar or an “artificial sweet taste” unappealing.

Senomyx has used its proprietary technologies to discover and develop a new flavor ingredient that allows manufacturers to reduce the sucrose (table sugar)

content of food and beverage products by up to 50 percent while maintaining the taste of natural sugar.



Senomyx pioneered the use of taste receptors for the discovery of new flavor ingredients. Proteins on the tips of sweet taste cells, for example, function as receptors that bind sucrose and other sweeteners. Using high-throughput screening, Senomyx identified and optimized a new flavor ingredient that also binds to the receptor, reducing the amount of sucrose needed to create a sweet taste sensation.

Firmenich SA, a leading global ingredients supply company, is conducting pre-commercialization activities with Senomyx’s first enhancer for sucrose, which is applicable for virtually all food product categories and selected beverages. Senomyx is also working to develop additional sucrose enhancers as well as flavor ingredients that enable the reduction of fructose, a key component of high fructose corn syrup. In addition to decreasing calorie content, reducing sugar and fructose during processing has a positive impact on sustainability and costs, including lowered water usage and transportation expenses.

More Efficient Meat and Egg Production That Improves the Environment

Many livestock animals need phosphorus for healthy growth and reproduction. But poultry and swine cannot digest approximately 70 percent of the phosphorus that is naturally contained in feed ingredients such as grains, soy beans and their by-products. In order to satisfy the animals' nutritional requirements, producers traditionally have added expensive sources of inorganic phosphorus to their feed, although this supplementation significantly increases feed costs. The cost of animal feed is a major economic factor for poultry and swine producers.



Verenium developed Phyzyme® XP phytase in collaboration with Danisco Animal Nutrition to improve the digestibility of phosphorus and other nutrients naturally contained in animal feed. This provides producers with the opportunity to reduce feed costs, by reducing usage of inorganic phosphorus, while maintaining poultry and swine growth.

Phyzyme® XP phytase is highly efficient at releasing phosphorus, calcium and other nutrients from naturally occurring animal feed ingredients. Animal trials have shown that Phyzyme® XP phytase offers superior performance compared to competitor phytases.

Undigested phosphorus excreted by poultry and swine frequently runs off into streams, rivers and oceans, increasing water pollution. More and more, governments are mandating limits on the amounts of phosphorus released into the environment. By using Phyzyme® XP phytase, producers can reduce the amount of phosphorus excreted into the environment and safeguard water supplies.

Reducing Waste on Grocery Store Shelves

Consumers look for freshness when they are choosing among bakery products in a supermarket or corner store. How do they test for it? They squeeze the products. It's the moment of truth when a product feels markedly fresher than others – not just the first day, but also for several days afterward.

Genencor enzyme technologies help bakeries around the world distinguish their products at the markets. By altering the molecular structure of starch, the enzyme has a strong effect on retrogradation – the main contributor to the staling process. POWERFresh® Bread and POWERFresh® Special are bakery enzymes that ensure shoppers get the freshest quality products.



Developed together with the baking industry, this advanced technology makes it possible to extend shelf life while maintaining superb eating quality. Combined with competitive cost-in-use, these enzymes provide a powerful competitive edge.

Specifically, this technology helps solve some of the most pressing issues facing the baking industry, such as short shelf-life, fast-fading resilience, and dry, crumbling structure. For bakeries, fewer crumbs mean enhanced efficiency and production cost savings. For consumers, the enzyme means that sliced bread does not break when they butter it, and that the hot dog bun does not break into two.