

Second-Generation Biofuel: Isobutanol Producing Biocatalyst

Gevo, Inc.

345 Inverness Drive South
Building C, Suite 310
Englewood, CO 80112
Telephone: (303) 858-8358
<http://www.gevo.com>

Environmental Problem

Because of the current political instability in oil-producing nations, concerns about global warming, and a call for domestic energy resources, development of an economically viable and environmentally friendly fuel alternative is needed. The EPA has established the requirement for reformulated gasoline (the Clean Air Act) and the Renewable Fuel Standard (Energy Independence and Security Act of 2007). Ethanol, which is readily produced by yeast, can be used for reformulated gasoline and to meet the Renewable Fuel standard. However, the amount of ethanol that can be blended in gasoline is limited by the EPA, at the moment to 10%. Unless there is a considerable increase in the share of flexible fuel vehicles and/or a substantial increase in gasoline consumption, the opportunity for ethanol blending has reached its maximum limit (the “blend wall”).

An intriguing alternative to ethanol is isobutanol, which has wide uses in the solvents and plastics markets and is a second generation biofuel that can be easily blended into gasoline and currently is approved to 16%. Isobutanol also can be converted into hydrocarbons to make “green gasoline,” diesel, and jet fuel. It has similar physical and chemical properties to gasoline; it has a high octane number, low Reid vapor pressure (RVP) and 25% greater en-

ergy density than ethanol. Products made from isobutanol have a reduced carbon footprint and other environmental performance features compared to materials derived from crude oil; however, producing isobutanol involves a more complex chemical process than ethanol production.

SBIR Technology Solution

With support from EPA’s Small Business Innovation Research (SBIR) Program, Gevo launched a project to identify rate-limiting steps in the isobutanol pathway in yeast. This effort resulted in the development of genetic and biochemical assays to characterize each of the enzymes involved in the production of isobutanol in yeast. The development of a yeast-based biocatalyst provides an advantage because of its higher tolerance to isobutanol and long history of accepted industrial use. Gevo used synthetic biology and metabolic engineering to develop its biocatalyst to make isobutanol at high concentrations and yield. Gevo’s current generation biocatalyst operates on fermentable sugars. Future generation biocatalysts are in development for mixed sugars from biomass, so that when the conversion technology is commercially available, Gevo could be able to produce cellulosic butanol.

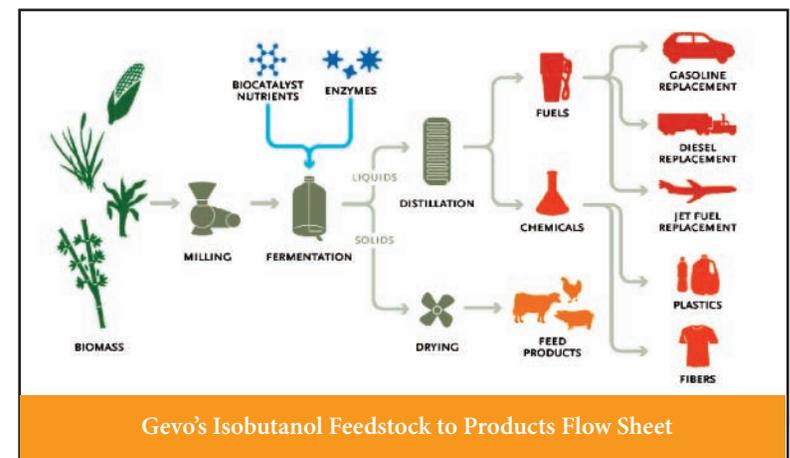
Although isobutanol is a naturally occurring alcohol, high concentrations inhibit the growth of microorganisms. To operate its fermentation at optimum conditions for the biocatalyst, and within the process conditions found in ethanol plants, Gevo developed a unique separation technology. The solution uses a process innovation for continuous separation of the

isobutanol as it is produced. In addition, Gevo has developed and demonstrated the technology to convert isobutanol into hydrocarbons using known chemistry. The hydrocarbons then are blended in proportions that should be able to meet all ASTM standards for fuels.

The development of a yeast biocatalyst is an integral part of Gevo’s “retro-fit” model for the commercial production of isobutanol. Ethanol is produced using yeast in a well designed, energy-efficient, fermentation-based process that has steadily evolved during the past 30 years. Gevo intends to retrofit existing ethanol plants to produce isobutanol by replacing the biocatalyst and adding Gevo’s Integrated Fermentation Technology™ (GIFT™). To accomplish this, Gevo’s isobutanol biocatalyst must be able to perform under the same conditions and match the yield and productivity metrics for ethanol fermentation.

Commercialization Information

In alliance with ICM, Inc., Gevo successfully retrofitted a 1-million-gallon per year commercial demon-



Gevo's Isobutanol Feedstock to Products Flow Sheet



stration facility in St. Joseph, Missouri, the first successful retrofit of an ethanol plant to produce isobutanol. Gevo also launched Gevo Development, LLC to finance and develop a group of biorefineries based on retrofitting existing ethanol plants. These plants can be retrofit using GIFT™ to produce isobutanol for sale to refinery and chemical customers. Gevo is the first company to demonstrate an ethanol plant retrofit to commercial scale production of isobutanol.

Gevo has purchased an ethanol production facility in Luverne, Minnesota. This plant is expected to provide 18 million gallons per year of production capacity for chemicals and fuels customers. Engineering for the mechanical retrofitting of the plant has begun and isobutanol production is expected to begin early in 2012. Commercial scale production is projected to ramp up to a projected 400 million gallons of capacity by 2014. Gevo is focusing on traditional ethanol plants, but its technology also could convert cellulosic sugars. Once cellulosic conversion technology is available, Gevo could produce cellulosic isobutanol from biomass.

Company History and Awards

Gevo, Inc. was founded in 2005 by three California Institute of Technology researchers to develop an advanced biofuel that could sustainably and effectively replace petrochemical products. In addition to its EPA SBIR award, Gevo also received a National Science Foundation SBIR award to produce renewable isobutanol for both the transportation fuel market and the chemical market. Gevo's investors include Khosla Ventures, Virgin Green Fund, Burrill & Company, Malaysian Life Sciences Capital Fund, the French oil and gas company Total, Osage University Partners, and Lanxess. Gevo's partners

include: Cargill, for collaboration in the development of its biocatalyst for cellulosic conversion; ICM, Inc., which will serve as the exclusive North American engineering, procurement, and construction contractor for the retrofit of ethanol plants

utilizing GIFT™; and UCLA, which has granted Gevo an exclusive license for use of UCLA's method for modifying microorganisms for use in biofuel development.

SBIR Impact

- Isobutanol is a renewable “drop in” biofuel with a 25% greater energy density than ethanol.
- Gevo is developing a yeast biocatalyst to make isobutanol at high concentrations and yield. Existing ethanol plants can be retrofit to produce isobutanol, which significantly reduces the initial capital investment compared to capital costs for a new site.
- Gevo began operations at a 1-million-gallon per year commercial demonstration facility in St. Joseph, Missouri. Commercial scale production should commence in 2012, with a projected 400 million gallons of capacity by 2014.
- Gevo's technology also could be capable of converting cellulosic sugars. When cellulosic conversion technology is available, Gevo plans to produce cellulosic isobutanol from biomass.

