Bio-derived n-butanol has consistently proven to be a high-performing co-solvent.

Green Biologics PriceLock program ensures pricing stability.

Bio n-butanol has demonstrated performance advantages in the synthesis of butyl derivatives.

Bio-based coatings ingredients have long been used to increase the sustainability profile of formulated products, but their inclusions have previously been thought to require performance compromises. Bio n-butanol from Green Biologics (Oxfordshire, United Kingdom) has been shown to have yield, kinetic, and other improvements in the synthesis of key coatings ingredients compared to their petrochemical counterparts. In addition, bio n-butanol is a proven co-solvent for existing coatings formulations without detrimental impact on physical or performance properties of the coatings. From a financial perspective, bio n-butanol is decoupled from the volatile price swings associated with the petro-chemical market, making it a new, cost-effective, high-performing, sustainable alternative for coatings manufacturers.
To validate the utility of bio n-butanol as a high-performance building block for coatings materials, researchers at Green Biologics conducted a series of synthesis trials to benchmark bio n-butanol against petrochemical-derived n-butanol. They compared the performance of petrochemical and bio-based n-butanol in direct Fischer esterification and transesterification reactions.

For the Fischer esterification, we studied the production of n-butyl acetate and n-butyl acrylate, which represent greater than 60% of the global market for derivatives (Source: IHS). Over multiple runs, the bio n-butanol was able to show a 3.4% yield improvement in butyl acrylate synthesis and a 4.3% yield improvement in butyl acetate synthesis.

In addition, the reaction kinetic rate constant for n-butyl acetate synthesis was 5% higher when using bio n-butanol. Transesterifications of methyl methacrylate to n-butyl methacrylate showed a significantly higher yield (+ 10.7%) and rate constant value (+ 8%) for bio n-butanol over the petrochemical equivalent. Higher yields translate into more product, less waste, and improved downstream purification. Better kinetics can offer catalyst and energy savings or the ability to lower fixed costs by boosting assets.

Synthesis benchmarking proves the superior performance of bio n-butanol. //

Sources: Tetramer Technologies LLC, The ChemQuest Group Inc., Green Biologics
Notes: * Average of 3 reactions for each butanol source
^ Average of 4 reactions with petro-butanol and 5 reactions with Green Biologics bio n-butanol
As a building block, bio n-butanol products have demonstrated several performance advantages. For example, our tests show significantly higher crude yields and faster kinetics in two common industrial synthesis processes: esterification and transesterification.

The faster reaction rates speed both synthesis and downstream process steps. Specialty chemical manufacturers can use less catalyst or reduce energy usage, thereby reducing variable costs. Plus bio n-butanol testing showed higher conversion of the desired end product over petroleum-based butanol, further increasing customer profitability.

In addition to having a higher conversion of the desired end product, the lower level of impurities at the end of the reaction often equates to easier downstream purification, increasing overall product yields, removing process steps, and reducing waste. Yield, impurity, and kinetic data in direct esterification and transesterification are superior, making our bio n-butanol a logical choice for synthesis of butyl derivatives.

Many companies are capacity-constrained and need to maximize the amount of product processed through their existing assets and equipment. In fact, the percentage of equipment up-time is often a key performance metric. Using Green Biologics’ bio n-butanol speeds reaction times, so companies can produce more in the same amount of time, resulting in less capital (equipment) expense per unit. Faster cycle times enable higher throughput from existing equipment.

Maximizing first-pass or batch yield is another key operation objective. Most chemical reactions do not result in 100% conversion of the desired product with 100% accuracy. Our customers get more of the desired end product prior to purification with the same volume of input. This means products produced with bio n-butanol enable optimization of the process and lower purification costs.

Sources: Tetramer Technologies LLC, The ChemQuest Group Inc., Green Biologics
‡ Concentrations of reaction components by GC-FID, average of 4 reactions with petro-butanol and 5 reactions with Green Biologics bio n-butanol
The building blocks of better products.

Crude reaction yield in Transesterification

- **Butyl Methacrylate**
  - Green Biologics bio n-butanol: 56%
  - Petro butanol: 50%
  - Difference: +10.7%

Notes:
- †% end product in reactor at end of synthesis determined by GC-FID
- ‡Average of 3 reactions for each butanol source

Kinetics for transesterification of n-butyl methacrylate

- Linear (Green Biologics bio n-butanol)
- Linear (Petro butanol)

Sources: Tetramer Technologies LLC, The ChemQuest Group Inc.
Notes:
- †% end product in reactor at end of synthesis determined by GC-FID
- ‡Average of 3 reactions for each butanol source
- ††Concentrations of reaction components by GC-FID, average of 3 reactions with each butanol source

Rate constant k (M⁻¹.min⁻¹)

- Green Biologics bio n-butanol: 6.21E-04
- Petro butanol: 5.75E-04
- Difference: 8.16%
The effectiveness of bio n-butanol as a co-solvent.

Use of bio n-butanol in a variety of common solvent-based coatings formulations was tested by Green Biologics at third-party labs. Throughout these experiments, it was shown that bio n-butanol is suitable for use in a variety of coatings formulations with no loss of performance characteristics or desired attributes. Both clear and white pigmented coatings were tested for physical properties of the coating formulation (e.g., viscosity, color, and ability to spray) as well the applied coating properties (e.g., color, hardness, scratch and chemical resistance). Bio n-butanol was shown to be appropriate as a drop-in replacement for petrochemical butanol in a myriad of coatings formulations.

“Upon spray testing many different coating formulations incorporating Green Biologics’ bio-based n-butanol, my observation was that the formulations demonstrated excellent atomization, sprayability and film formation and demonstrated no distinguishable difference to equivalent formulations incorporating petro n-butanol.”

— Chris Lucy, Director of Process Engineering and 16-year expert in spray application and training for automotive, aerospace and industrial sectors. ChemQuest Technology Institute.

Bio n-butanol has repeatedly been proven to be a high-performance ingredient, both as a co-solvent and as a building block, for coatings and coatings ingredients. Sustainable and affordable, bio n-butanol enables coating manufacturers to simultaneously formulate for performance and sustainability goals. Green Biologics bio n-butanol is a preferred choice to help address the performance, cost, and sustainment challenges faced today by coating manufacturers who currently use petroleum-based ingredients.

### Physical Properties of coatings formulations

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<th>Polyester Air Dry</th>
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Source: ChemQuest benchmark testing data with bio-based and Petro-n-butanol 2018. * Coatings that used PTSA dissolved in Petro-BuOH or GB nC4-OL. * Chemicals tested are: H2SO4, HCl and NaOH. * Solvents tested are: butyl cellosolve and MEK.
Take control of your pricing strategy and margins with our risk management tools. //

In addition to the performance benefits of our bio n-butanol, it is also decoupled from the volatility associated with petro-based butanol. Green Biologics recognizes that one of the biggest issues customers face is the month-to-month volatility of raw material prices. These fluctuations have a profound effect on every aspect of business and are virtually impossible to manage. PriceLock gives our partners the opportunity to lock in raw material costs and start pricing products to dictate—rather than chase—product margins.

PriceLock offers the ability to choose from two risk management plans to avoid volatility and lock in costs, ensuring up to 12 months of stability on n-butanol and acetone.

Ask how we’ve used our experience and industry knowledge to find a better way to help our partners plan, manage and stabilize their bottom lines.

Ability to take control of your pricing strategy and margins

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* ICIS: n-butanol DEL U.S. Contract Price
The technical resources to transform your operations.

Tomorrow’s coatings must at least match the performance characteristics that consumers expect today. But the goal at Green Biologics is to improve performance while providing financial stability, quality, consistency, sustainability, and other benefits to our customers.

The research and development needed to reach performance goals is the key reason why Green Biologics provides a collaborative and customized approach to technical issues faced by their customers. While the environmental, safety, and health benefits of bio-based coatings are important, they aren’t always enough on their own to warrant moving away from petroleum-based products.

Our technical service capabilities include a team of specialized experts and other resources from our Richmond, VA facility. This fully equipped lab sometimes functions as an extension of the customer’s lab, offering testing capabilities and other services to help customers obtain the needed data, benchmarking, and technical expertise in coatings for development of new products. In some cases, the Richmond facility helps customers identify and solve problems in existing products and processes. In other cases, we offer sampling and testing for their new products. Each customer has a unique set of challenges, so a one-size-fits-all approach to customer solutions does not work. We see customer service as a partnership, and our goal is to not just provide similar product results, but better overall performance.

Unique technology and a wide range of technical services are at the core of our business, enabling us to deliver high-value bio-based ingredients to our customers. We combine proprietary and commercially scalable advanced fermentation process technologies with superior-performing Clostridium microbial biocatalysts to produce renewable n-butanol and acetone. Leveraging robust application and product capabilities allows us to produce unique formulations and derivatives of bio n-butanol and acetone for a variety of downstream products.
Because biology has a much higher degree of specificity than the petroleum-based process to produce butanol, the purity and reliability of Green Biologics products is higher than competitive butanol on the market, allowing for process optimization and improved profitability.

The process we use for creating bio n-butanol, acetone and derivatives is documented and validated by multiple sources. Until we become ISO-certified, our employees are regularly trained and operate within an internal quality system and will continue training even after we become ISO-certified.

Our quality control measures ensure that when bio n-butanol arrives at a customer facility, they can have confidence that the materials meet their expectations and are of the highest quality.

Our high-performance bio n-butanol can be used as a solvent in a wide variety of paints, coatings, adhesives, and ink applications. It provides formulators the ability to create highly effective formulations with clear and colorless liquid characteristics. Our bio n-butanol has a very low water content and an improved impurity profile compared to traditional petrochemical synthetic processes, making it the feedstock of choice for their customers’ formulation coatings or synthesizing butyl-based coating intermediates.
Sustainability certifications.

Green Biologics operates within a range of industry certifications, including United States Department of Agriculture (USDA) certification under the “BioPreferred” program. This certification enables our customers to display the “USDA Certified Bio-based Product” label for certain formulations. Our products are third-party tested, and the bio-based content is independently verified. The USDA label makes it easy for consumers to locate and compare bio-based products for purchase. By choosing a bio-based product certified by USDA, consumers are assured that the United States federal government stands behind the accuracy of the percent of bio-based ingredients as stated on the label. The label also gives products preferred status for government procurement in a range of categories such as paints, coatings, inks, and more. At Green Biologics, our products are currently certified as 100% bio-based. To learn more about the BioPreferred program, go to https://www.biopreferred.gov/BioPreferred/

The Responsible Care program also audits Green Biologics as part of their global program. Responsible Care is a voluntary initiative developed autonomously by the chemical industry for the chemical industry. This program seeks to improve the industry's environmental, health, safety, and security performance. It runs in 67 countries whose combined chemical industries account for nearly 90% of global chemical production. In fact, 96 of the 100 largest chemical producers in the world have adopted the Responsible Care program.

Green Biologics complies with The Nagoya Protocol, an international agreement developed to create fair and equitable benefit sharing when accessing genetic resources. To implement the Nagoya Protocol, we comply with the requirements of Regulation (EU) No. 511/2014, which was made part of English law through the Nagoya Protocol in 2015. One of the key principles of the protocol is that anyone wishing to access genetic resources from another country must demonstrate comprehensive due diligence.

Green Biologics is focused on helping our customers launch high performing, sustainable products by earning the appropriate certifications and registrations.
In 2016, a cradle-to-gate greenhouse gas assessment was carried out by independent consultant North Energy Associates (Northumberland, UK) to the UK standard PAS2050:2011. The study covered the production of bio n-butanol from corn at the Green Biologics’ production facility in Minnesota. The methodology used in this report takes into consideration the carbon contained in petrochemical butanol as fossil derived and the carbon produced during our production process as biogenic. This translates into greenhouse gas savings for bio-butanol of 44 percent compared to petrochemical butanol.

The study was completed in 2016, before the construction of the Green Biologics plant was complete and prior to its start-up. As the company continues to improve performance, increase production rates, and improve efficiency, we expect to achieve further greenhouse gas reductions. We expect to achieve further greenhouse gas reductions and have commissioned a new impact assessment based on current data that should be completed in the third quarter of 2019.

To read more about how Green Biologics’ products can improve coating products and profitability, visit Green Biologics: http://www.greenbiologics.com

Additional background information:

Responsive Care: https://responsiblecare.americanchemistry.com/default.aspx

USDA “BioPreferred” program: https://www.biopreferred.gov/BioPreferred


Biomass Environmental Assessment Tool: http://www.biomassenergycentre.org

World Business Council for Sustainable Development: https://www.wbcsd.org