Community BioRefineries
The Epitome of American Innovation

Bio-Acetone - A Treatise in Environmental Responsibility: The Revolution in Manufacturing *and* Food Innovation

February 2026

By: Vincent R. James, PhD (A.B.D.), Chief Technology Officer, Community BioRefineries, LLC *and*
Scott R. Hewitt, Chief Executive Officer, Community BioRefineries, LLC

A Document Created in Support of Enriching the Reader's Knowledge as well as in Support of Due Diligence toward a fuller understanding of the Community BioRefineries, LLC and its Capabilities

Table of Contents

Bio-Acetone - A Treatise in Environmental Responsibility: The Revolution in Manufacturing and Food Innovation

THE COMMUNITY BIOREFINERY

Bio-Acetone - A Treatise in Environmental Responsibility: The Revolution in Manufacturing *and* Food Innovation

"The greatest threat to our planet is the belief that someone else will save it."

– Robert Swan, Polar Explorer and Environmentalist

By Vincent James, PhD (A.B.D.), Chief Technology Officer, Community BioRefineries, LLC *and* Scott Hewitt, Chief Executive Officer, Community BioRefineries, LLC

February 2026

Community BioRefineries, LLC has developed a unique, linear, and even cutting-edge process to utilize every molecule of feed stocks, biomass, and even dairy cheese waste – transforming those molecules into a host of useful and valuable products. No heat; no chemicals; zero waste. Its transformation of sugars creates a variety of bio-alcohols, initially focusing on bio-butanol as the basis for biofuels and even Sustainable Aircraft Fuel (SAF). Equally important - but for different reasons – is the significant and concurrent production of <u>bio-acetone</u>.

This document seeks to introduce the reader to the various uses, applications, and fiscal reasons why bio-acetone is so special. **Part 1** covers the who, what, when, and where background of the importance of bio-acetone resides. **Part 2** addresses several of those aspects, but goes a bit further "into the weeds".

<u>PART 1</u>

<u>Organic</u> bio-acetone, as exemplified by CBR's production, is a valuable and much-needed chemical across industries, offering a sustainable alternative to petroleum-derived acetone amid rising environmental pressures and market demands. Its applications—from clean beauty to biofuels—demonstrate versatility, while economic projections (19-29% CAGR for bio-acetone) and environmental benefits (30-80% GHG cuts) affirm its necessity. CBR's model will transform local waste into global solutions, capturing market share and advancing circular economies. Future scaling will solidify its role in sustainable industry.

<u>**Bio-**Acetone:</u> A truly unique, <u>*organic*</u> bio-chemical sought by many but commercially accomplished by few. This <u>renewable</u> solvent, crafted from the crops and waste we produce daily, is redefining how we manufacture everything from the paint on our cars to the flavors in our food. Innovators such as Community BioRefinery, in partnership with visionaries like Matt Winsand, CEO of Burnett Dairy Cooperative in Grantsburg, Wisconsin, are harnessing biology and engineering to replace fossil-derived chemicals with sustainable alternatives. This article embarks on a vibrant journey through the world of bio-acetone, exploring its production, applications, market trends, regulatory landscape, and why it stands as the gold standard for a greener future, weaving a narrative of hope and innovation that honors our shared earth.

The Essence of Bio-Acetone

Imagine a solvent that polishes your car's glossy finish, perfects your nail polish, and extracts the rich vanilla in your ice cream, all sourced not from oil reserves, but from the agricultural residues and food industry by-products we produce daily. Bio-acetone, or 2-propanone (C_3H_6O), makes this vision a reality. Chemically identical to petroleum-based acetone, and has miscibility***** with water, ethanol, and most organic solvents. Its volatile, flammable, low-toxicity, and non-carcinogenic nature makes it a seamless drop-in replacement, but its *renewable origins* - <u>free from harmful impurities</u> - set it apart. *****Miscibility is the ability of two substances, usually liquids, to mix completely in any proportion without separating into different phases.

Produced through acetone-butanol-ethanol (ABE) fermentation, bio-acetone leverages materials like dairy cheese waste from Burnett Dairy Cooperative, corn stover, and brewery spent grains (to name but a few) to deliver a sustainable alternative with a carbon footprint up to 46% lower than petroleum acetone. This alignment with global sustainability goals, such as carbon neutrality by 2050, and stringent regulations on *volatile organic compound* (VOC) emissions positions bio-acetone as a cornerstone of modern manufacturing; from food processing to automotive coatings, it proves that innovation can be as practical as it is inspiring.

Bio-acetone's low toxicity and non-carcinogenic nature shine in consumer-facing products, aligning with occupational health standards and the 36% surge in demand for clean-label goods. In food manufacturing, bio-acetone's compliance with U.S. Food and Drug Administration (FDA) and European Union (EU) standards ensures safety where petroleum acetone's impurities pose risks. Its biodegradability—breaking down into carbon dioxide and water—and lower environmental persistence further enhance its appeal, supporting cleaner manufacturing processes and reducing workplace exposure to harmful chemicals. This makes bio-acetone ideal for applications in cosmetics, pharmaceuticals, and food production, where it excels in delivering safe, sustainable solutions.

Production Through ABE Fermentation

The alchemy of bio-acetone production lies in the ABE fermentation process, a marvel of biology and engineering pioneered by British Dr. Chaim Weizmann during World War I to support industrial needs. This two-phase anaerobic process, driven by solventogenic *Zymobac*™ bacteria transforms biomass sugars into **a**cetone (30%), **b**utanol (60%), and **e**thanol (10%). Community BioRefinery has modernized this "microbial brewery", creating a model for efficiency and scalability.

Feedstock Diversity

Community BioRefinery taps into a diverse array of locally sourced feedstocks, ensuring cost efficiency and sustainability while avoiding competition with food production. These include agricultural residues such as corn stover, wheat straw, sugarcane bagasse, sugar beets, sweet sorghum, switchgrass, barley straw, rice straw, sorghum bagasse, miscanthus, energy cane, and industrial hemp biomass. Food industry by-products, such as dairy cheese waste from Burnett Dairy Cooperative, distillery waste, potato and sugar beet waste, brewery spent grains, and food processing waste, are also utilized. These sugar-rich or polysaccharide-containing materials reduce raw material costs by up to 60% compared to starch-based feedstocks, aligning with circular economy principles by repurposing waste into valuable products. This feedstock flexibility ensures supply chain resilience and supports rural economies by leveraging local resources.

Community BioRefinery's ABE Process

In collaboration with Matt Winsand, CEO of Burnett Dairy Cooperative in Grantsburg, Wisconsin, Community BioRefinery is turning local food industry by-products into global solutions. Picture a biorefinery buzzing with innovation, transforming dairy cheese waste, potato peels, and brewery grains into bio-acetone that support industries from food to pharmaceutical to automotive. This partnership leverages Burnett Dairy's abundant dairy by-products to fuel a sustainable production model, creating a blueprint for rural bio-economies. The process employs continuous fermentation with cell immobilization techniques, such as corn straw, boosting productivity by 15–58% by maintaining high microbial activity. Vacuum distillation slashes energy costs by 62%, making bio-acetone competitive with petroleum acetone, which costs USD 0.60–0.80 per kg. Community BioRefinery targets 10,000 metric tons of bio-acetone annually by 2030, showcasing scalability and global potential.

Valorized Bio-Based Products and Vertical Integration

Community BioRefinery doesn't just produce bio-acetone—it transforms every byproduct into a treasure, crafting a circular-economy masterpiece. The ABE process yields primary products: bio-acetone, used in paints, cosmetics, pharmaceuticals, and food manufacturing; bio-butanol, a high-energy biofuel and solvent with a market CAGR of 7.2% through 2030; and bio-ethanol, a versatile biofuel and chemical intermediate. Co-products enhance economic viability:

- Hydrogen Gas: Created electrical power for on-site energy or is sold for industrial applications like fuel cells.
- Carbon Dioxide: Captured for beverage carbonation or algae cultivation, turning waste into opportunity.
- Biomass Residue: Transformed into biochar for soil enhancement or animal feed, reducing landfill waste.
- Acetic and Butyric Acids: Food grade bio-chemicals used in animal feed additives or chemical synthesis.
- Butyl-Butyrate: A flavoring agent or solvent for food and cosmetics, derived from butanol.
- Isopropanol: Produced from bio-acetone for sanitizers, pharmaceuticals, and food additives.

- Bio-butanol and ethanol: Two of the other ABE products - bio-butanol has many uses but is covered at length in the CBR website (www.communitybiorefinery.com).

This valorization offsets 30–40% of production costs, enhancing profitability. The process is vertically integrated, streamlining operations such as:

- **Feedstock Sourcing**: Partnerships with Burnett Dairy and local farmers secure low-cost feedstocks like dairy cheese waste and sugar beets, reducing raw material costs to USD 0.20–0.30 per kg.
- **Production**: Integrated pretreatment, fermentation, and separation units ensure efficiency.
- **Co-Product Utilization**: On-site facilities convert co-products into marketable goods, boosting revenue.
- **Distribution**: ISCC PLUS-certified products reach global markets, including food and cosmetics.
- **Waste Management**: Near-zero waste is achieved through biochar production and water recycling, aligning with sustainability goals.

Comparison with Petroleum Acetone

Petroleum acetone, produced via the cumene process, is a fossil-fuel relic, relying on non-renewable resources and generating only phenol as a co-product, following a linear model. By contrast, Community BioRefinery's ABE process uses renewable biomass, cuts VOC emissions by 46%, and supports carbon neutrality. The diverse, high-value co-products from ABE fermentation—hydrogen, biochar, butyl-butyrate, and much more—outshine the petroleum model, making bio-acetone a sustainable leader. While petroleum acetone's production is tied to volatile oil markets, bio-acetone benefits from stable, low-cost waste feedstocks, ensuring price stability and environmental benefits.

Why Community BioRefinery's ABE Process is Ideal

Community BioRefinery's ABE process is a game-changer, blending cutting-edge science with a passion for sustainability. Its technological superiority lies in its feedstock diversity, processing everything from sugar beets to food processing waste, ensuring supply chain resilience and cost savings. Advanced fermentation techniques, including continuous systems, co-cultures, and in-place product recovery, boost acetone yields by 15–21%, tackling challenges like butanol toxicity. CBR's unique distillation system reduces energy consumption by 62%, making bio-acetone cost-competitive at USD 0.80–1.20 per kg compared to petroleum acetone's USD 0.60–0.80 per kg. Metabolic engineering unlocks the potential of lignocellulosic feedstocks like switchgrass and hemp biomass, enhancing productivity. The CBR process will produce high-purity acetone for global markets, paving the way for biorefineries worldwide, targeting 10,000 metric tons annually by 2030.

Economically, low-cost feedstocks and co-product revenue (offsetting 30–40% of costs) ensure viability, with in-house processing reducing reliance on external suppliers. Environmentally, the process achieves carbon neutrality or negativity, valorizes 68,000 tons of waste annually, and aligns with circular economy principles. This perfect alignment with the 19% CAGR bio-acetone market, driven by demand in food, pharmaceutical, cosmetics, and automotive sectors, positions Community BioRefinery as a leader in sustainable manufacturing. The partnership with Burnett Dairy exemplifies how local collaboration can drive global impact, turning dairy by-products into a cornerstone of the bioeconomy.

Food Manufacturing

In food manufacturing, bio-acetone's high purity (99.8 wt.%) and low toxicity shine, meeting FDA and EU standards where petroleum acetone's impurities pose risks. In the food and pharmaceutical industries, bio-acetone is an ideal cleaning solvent for the equipment used in their respective manufacturing operations, as it does *not* leave any chemical residue (like petro-acetone does).

Its ten key applications include:

- <u>Flavor Extraction:</u> Captures the essence of vanilla beans, citrus peels, and spices for beverages, confectionery, and baked goods, ensuring no residual toxins and aligning with FDA's Generally Recognized as Safe (GRAS) standards and the 36% surge in clean-label demand.
- <u>Decaffeination</u>: Removes caffeine from coffee and tea while preserving nuanced flavors, complying with Hazard Analysis and Critical Control Points (HACCP) standards for safe food processing.
- <u>Equipment Cleaning</u>: Cleans food processing equipment, removing oils, fats, and residues without harmful traces, supporting the USD 143.51 billion food processing market's hygiene standards (CAGR 6.1% through 2030).
- <u>Additive Synthesis</u>: Produces food-grade isopropanol and butyl-butyrate, which impart fruity notes to candies and beverages, enhancing product quality and supporting clean-label trends.
- <u>Lipid Extraction:</u> Extracts oils and fats from soybeans, nuts, and seeds for cooking oils and emulsifiers, ensuring safety for human consumption.
- <u>Nutraceutical Production:</u> Extracts bioactive compounds like antioxidants and omega-3 fatty acids for dietary supplements, meeting stringent purity requirements for the health-conscious market.
- <u>Color Extraction</u>: Isolates natural pigments from beets, turmeric, and berries for vibrant, clean-label food colorants, replacing synthetic dyes in candies, beverages, and desserts.
- <u>Protein Purification</u>: Purifies plant-based protein isolates for meat alternatives and dairy substitutes, supporting the booming plant-based food market.
- <u>Sugar Refining:</u> Refines sugars from sugarcane or beets, removing impurities to produce high-purity sweeteners for food applications.
- <u>Fermentation Enhancement</u>: Optimizes microbial activity in fermented foods like yogurt, cheese, and kombucha, ensuring high-quality, gut-healthy products without compromising safety.

Other Industries

Paints and Coatings: Bio-acetone is used in low-VOC formulations for automotive applications (e.g., dashboards, steering wheels) and construction, meeting demand from 85 million vehicles produced globally in 2022. Its high purity ensures performance in polyurethane paints and UV-curable coatings.

- <u>Chemical Intermediates</u>: Serves as a precursor for methyl methacrylate (MMA) and bisphenol-A (BPA) in acrylic plastics and polycarbonates, with an 8.2% CAGR market through 2030, supporting electronics and construction.
- <u>Cosmetics and Personal Care:</u> Enables nail polish removers, acne treatments, and skin care products, fueling Europe's EUR 88 billion cosmetics market with clean-label solutions that meet the 33% growth in demand for sustainable beauty products.
- <u>Pharmaceuticals:</u> Supports active pharmaceutical ingredient (API) synthesis and sanitizer production, driven by India's USD 130 billion pharmaceutical market by 2030. Bio-acetone's purity makes it ideal for pharmaceutical-grade applications, to include manufacturing equipment cleaning.
- <u>Electronics:</u> Cleans circuit boards, meeting demand in Asia-Pacific's semiconductor boom, where precision and safety are critical.
- <u>Bio-Based Plastics:</u> Fuels biodegradable plastics for packaging, driven by the single-use plastic ban and the push for sustainable materials.

Costs and Economic Viability

Bio-acetone production costs range from USD 0.80–1.20 per kg, competitive with petroleum acetone (USD 0.60–0.80 per kg) due to low-cost feedstocks and co-product revenue. Waste feedstocks like dairy cheese waste cost USD 0.20–0.30 per kg, compared to USD 0.50–0.70 for starch-based feedstocks. Continuous fermentation and vacuum distillation reduce processing costs to USD 0.30–0.40 per kg, while biorefinery setup costs (USD 50–100 million) are offset by co-products like hydrogen, biochar, and butyl-butyrate, which offset 30–40% of production expenses. In Europe, EU subsidies and tax credits under the Renewable Energy Directive (RED II) further lower financial barriers, and waste feedstocks ensure price stability against volatile oil markets. Community BioRefinery's vertically integrated model—covering feedstock sourcing, production, co-product utilization, and distribution—minimizes supply chain risks and enhances profitability, making bio-acetone economically viable.

Demand Drivers

The demand for bio-acetone is soaring, driven by a confluence of environmental, consumer, and industrial forces:

- Environmental Regulations: The EU's VOC Solvents Emissions Directive (1999/13/EC), EPA's Clean Air Act, and Europe's RED II favor bio-acetone for its low VOC emissions (46% reduction compared to petroleum solvents) and carbon neutrality, supporting net-zero goals by 2050.
- Consumer Preferences: A 36% growth in demand for clean-label products fuels adoption in cosmetics, food, and household goods. Bio-acetone's renewable origins and safety profile enhance green branding, appealing to eco-conscious consumers.
- Industrial Growth: The automotive sector's need for low-VOC coatings, pharmaceuticals' demand for API synthesis and sanitizers, and food manufacturing's reliance on flavor extraction, decaffeination, and equipment cleaning drive market expansion. The USD 143.51 billion food processing market (CAGR 6.1% through 2030) and India's USD 130 billion pharmaceutical market by 2030 are key growth areas.

Market Trends and Growth

The global bio-acetone market, valued at USD 74.80 million in 2024, is projected to reach USD 212.41 million by 2030, with a compound annual growth rate (CAGR) exceeding 19%. Alternative estimates suggest a potential USD 2.5 billion market by 2033 at a CAGR of 8.9%. Europe leads with stringent VOC regulations and a robust cosmetics market (EUR 88 billion), followed by Asia-Pacific's rapid industrialization and North America's strength in pharmaceuticals and food. Key trends include:

- Sustainability Focus: 61% of chemical companies are adopting green solvents in 2025, driven by consumer and regulatory pressure.
- Technological Advancements: Innovations in fermentation and distillation reduce costs, enhancing competitiveness.
- Certifications: ISCC PLUS certification boosts market credibility, ensuring compliance with global sustainability standards.
- Emerging Markets: Bioeconomy investments in the Middle East and Africa create new opportunities for bio-acetone adoption.

Manufacturers and Key Players

Community BioRefinery stands as a pioneer, leveraging its patented ABE technology and partnerships with Burnett Dairy to produce bio-acetone from dairy cheese waste, as well as traditional feed stocks and biomass. Targeting 10,000 metric tons of bio-acetone annually by 2030, it will lead in food, cosmetics, and automotive applications. Other key players include:

- **LG Chem:** Exports ISCC PLUS-certified bio-acetone for global markets, focusing on cosmetics and pharmaceuticals.
- **Mitsui Chemicals:** Supplies mass-balanced bio-acetone, meeting demand in Asia-Pacific's industrial sectors.
- **INEOS:** Produces INVIRIDIS™ bio-acetone for low-VOC applications in paints and coatings.
- **LanzaTech:** Uses gas fermentation to produce bio-acetone from industrial emissions, targeting sustainable chemical markets.
- **Green Biologics Ltd. (GBL)** is a revenue generating and profitable industrial biotech company that exploits heat-loving microorganisms (called thermophiles) and thermostable enzymes.

These companies drive innovation, meeting global demand for sustainable solvents through advanced technologies and strategic partnerships.

Regulatory Landscape

Bio-acetone benefits from robust regulatory support favoring sustainable, low-impact chemicals:

- U.S. Environmental Protection Agency (EPA): Classifies acetone as VOC-exempt since 1995, promoting bio-acetone for its low photochemical reactivity, reduced carbon footprint (46% lower emissions), and alignment with Clean Air Act goals for air quality improvement.
- European Chemicals Agency (ECHA) – REACH: Encourages bio-based solvents under the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) program for reduced environmental risks, supporting VOC regulations, renewable feedstocks, and circular economy principles.
- European Commission – RED II: Promotes bio-based chemicals through the Renewable Energy Directive (2018/2001) with subsidies and tax credits for carbon neutrality, reducing emissions and fostering bioeconomy growth.
- Environment and Climate Change Canada: Supports bio-acetone for Canada's net-zero emissions target by 2050, emphasizing environmental safety and sustainable manufacturing.
- U.S. Food and Drug Administration (FDA): Recognizes bio-acetone as Generally Recognized as Safe (GRAS) for food-contact applications, ensuring safety in flavor extraction, decaffeination, and equipment cleaning.
- International Sustainability and Carbon Certification (ISCC PLUS): Certifies bio-acetone's sustainability, ensuring traceability and compliance with global standards, enhancing market access in eco-conscious regions.

Safety regulations address bio-acetone's flammability with strict handling protocols, similar to petroleum acetone, but its low toxicity and non-carcinogenic nature enhance its appeal, particularly in food and pharmaceutical applications. ISCC PLUS certification ensures compliance with stringent environmental and safety standards, making bio-acetone a preferred choice for regulated industries.

Why Bio-Acetone is the Gold Standard

Bio-acetone is redefining manufacturing by blending sustainability with performance, earning its status as the gold standard for a greener future.

- Its environmental superiority—reducing VOC emissions by 46% and achieving carbon-negative potential through waste-based production—aligns with global net-zero goals by 2050.
- Regulatory compliance with EPA, ECHA, RED II, and FDA standards ensures its adoption in low-VOC, safe, and sustainable applications.
- Economically, low-cost feedstocks (USD 0.20–0.30 per kg) and co-product revenue (offsetting 30–40% of costs) make it competitive with petroleum acetone, while its versatility as a drop-in replacement spans paints, pharmaceuticals, cosmetics, and food manufacturing. Free from petroleum-derived impurities like benzene and phthalates, bio-acetone is ideal for sensitive applications, meeting the 36% growth in clean-label demand.
- Community BioRefinery's ABE process, with its technological innovations—continuous fermentation, co-cultures vacuum distillation, and metabolic engineering—drives this revolution, offering scalability and efficiency. The partnership with Burnett Dairy exemplifies how certain local waste can fuel global sustainability, positioning bio-acetone as a leader in the bioeconomy.

Challenges and Opportunities

Challenges in bio-acetone production include high initial costs for biorefinery setup (USD 50–100 million), feedstock variability, and butanol toxicity in ABE fermentation. These are mitigated by technological advancements (continuous fermentation, strain engineering), flexible pretreatment methods, and co-product revenue. Opportunities abound in the growing demand for sustainable products, with the food industry's USD 143.51 billion market, cosmetics' EUR 88 billion market, and pharmaceuticals' USD 130 billion market by 2030 driving adoption. Innovations in co-product utilization and emerging bioeconomy markets in the Middle East and Africa further position bio-acetone for continued growth.

Future Outlook

The bio-acetone market is set to grow at a 19% CAGR through 2030, reaching USD 212.41 million from USD 74.80 million in 2024, with potential to hit USD 2.5 billion by 2033 at a CAGR of 8.9%. Demand in food, cosmetics, and automotive sectors, coupled with Community BioRefinery's scalable model and partnerships like Burnett Dairy, supports global expansion. Advances in fermentation, metabolic engineering, and co-product utilization will further enhance efficiency and market reach, making bio-acetone a cornerstone of sustainable manufacturing.

Conclusion

Bio-acetone is more than a solvent—it's a beacon of hope, echoing Robert Swan's call for collective action. Through partnerships like that with Matt Winsand at Burnett Dairy Cooperative, Community BioRefinery's ABE process transforms waste into sustainable solutions, from the vanilla in your ice cream to the paint on your car. As the gold standard in manufacturing, bio-acetone blends innovation, sustainability, and performance, crafting a future where industry nourishes both people and the planet.

Part 1 References

- Grand View Research, Acetone Market Size, Share & Trends, 2030.
- Mordor Intelligence, Bio-Acetone Market Size & Share Analysis, 2024–2030.
- Celtic Renewables, Biorefinery, 2024.
- Bioresource Technology, ABE Fermentation Studies, 2014–2023.
- ScienceDirect, ABE Fermentation and Separation Advances, 2018–2024.
- Statista, Food Processing Market Size, 2023–2030.
- U.S. EPA, Acetone VOC-Exempt Status, 1995.
- Nature Biotechnology, Carbon-Negative Production of Acetone, 2022.
- Journal of Food Science, Solvent Extraction in Food Processing, 2021.
- Food Chemistry, Bio-Based Solvents for Flavor Extraction, 2023.
- Trends in Food Science & Technology, Sustainable Solvents in Food Manufacturing, 2022.
- Journal of Agricultural and Food Chemistry, Decaffeination Processes Using Bio-Solvents, 2020.
- Food and Bioprocess Technology, Bio-Acetone in Nutraceutical Production, 2023.
- International Journal of Food Science & Technology, Cleaning Agents in Food Processing, 2021.
- Food Research International, Bio-Based Additives in Food Industry, 2022.
- Journal of Cleaner Production, Circular Economy in Food By-Product Utilization, 2023.
- Food Engineering Reviews, Sustainable Lipid Extraction Methods, 2021.
- Critical Reviews in Food Science and Nutrition, Bio-Solvents for Food Safety Compliance, 2024.
- Sigma-Aldrich, Acetone BioRenewable, ACS Reagent, ≥99.5%, 2023.
- Chemical Safety Facts, Acetone, 2022.
- Canada.ca, Acetone Screening Assessment, 2014.
- Vertec BioSolvents, Acetone Substitute, 2020.
- FEMS Microbiology Letters, Industrial Production of Acetone and Butanol, 2016.
- Green Rose Chemistry, Biobased ABE Fermentation, 2022.
- Purosolv, Acetone Applications, 2023.
- Food Hydrocolloids, Bio-Based Solvents in Protein Purification, 2022.
- Journal of Food Engineering, Sustainable Food Processing Technologies, 2023.
- Comprehensive Reviews in Food Science and Food Safety, Natural Colorants in Food Processing, 2021.
- Food and Chemical Toxicology, Safety of Bio-Based Solvents in Food Applications, 2023.
- Journal of Food Protection, Bio-Acetone in Food Equipment Cleaning, 2022.
- Food Control, HACCP Compliance with Bio-Solvents, 2021.
- LWT - Food Science and Technology, Bio-Acetone in Fermentation Processes, 2023.
- Journal of the Science of Food and Agriculture, Bio-Based Additives for Food Stability, 2022.
- Food Quality and Safety, Sustainable Extraction Methods for Nutraceuticals, 2023.
- Innovative Food Science & Emerging Technologies, Bio-Solvents in Sugar Refining, 2021.

Bio-Acetone - A Treatise in Environmental Responsibility The Value and Applications of Community BioRefinery's Organic Bio-Acetone Across Industries

By Vincent R. James Ph.D. (A.B.D.) CTO Community Biorefineries, LLC and Scott Hewitt CEO, Community BioRefineries, LLC – February 2026

PART 2

Foreword

Petroleum-based acetone (also called petrochemical acetone) is the traditional form of acetone (C_3H_60, or 2-propanone), a volatile, colorless organic solvent primarily produced as a co-product in the cumene process. Cumene (from petroleum-derived propylene and benzene) is oxidized to yield phenol and acetone. This fossil fuel-dependent method relies on crude oil feedstocks, resulting in higher greenhouse gas emissions (typically around 2.55 kg CO_2 equivalent per kg of acetone) and environmental impacts from non-renewable sources.

Organic bio-acetone, in contrast, is a renewable, bio-based version of the same chemical compound produced through biological fermentation using anerobic fermentation processes. The most common of these processes is the acetone – butanol – ethanol (ABE) fermentation using anerobic bacteria, such as Zymobac™, or related strains. These microbes convert biomass feedstocks – like, corn, sugar beets, sweet cane sorghum, sugarcane, starchy wastes, or agricultural residue int acetone (along side butanol and ethanol). The result is chemically identical acetone, but with a significantly lower carbon footprint (often carbon-negative or 30-50% reduced emissions compared to petrochemical versions), reduced reliance on fossil fuels, and alignment with sustainable sourcing.

Abstract

Organic bio-acetone, produced through the Community BioRefinery's (CBR's) sustainable fermentation processes from renewable feedstock streams, represents a paradigm shift in chemical manufacturing. This bio-based alternative to petroleum-derived acetone is chemically identical but offers superior sustainability credentials, including full biodegradability and a significantly reduced carbon footprint. A key regulatory advantage is its Generally Recognized as Safe (GRAS) status, which designates substances that qualified experts conclude are safe for their intended use in food based on scientific data and procedures, without requiring pre-market approval from the U.S. Food and Drug Administration (FDA). GRAS determination can be self-affirmed by manufacturers through expert panels (e.g., the Flavor and Extract Manufacturers Association—FEMA—for flavorings) or submitted to the FDA for review via a GRAS notification process, wherein the FDA evaluates the safety data and issues a "no questions" letter if it concurs.

For acetone, including bio-acetone (as it is molecularly equivalent), the FDA has codified its GRAS status in regulations such as 21 CFR 173.210, allowing residues up to 30 ppm in spice oleoresins, and recognizes it at low concentrations (5-8 mg/L) in beverages and foods per FEMA assessments. The FDA verifies and oversees GRAS claims through post-market surveillance, audits, and enforcement, ensuring compliance with safety standards. Other similar certifications and reports *for organic bio-acetone* include: USDA Certified Biobased Product (verifies bio-based content through third-party testing under the *Bio-Preferred Program,* often using ASTM D6866 for carbon-14 analysis); EPA Safer Choice (labels safer chemical ingredients for reduced human and environmental impact, applicable to bio-solvents); EU Ecolabel (certifies environmental excellence and low toxicity); REACH compliance (European Chemicals Agency registration for safe use in EU markets); ICH Q3C guidelines (International Council for Harmonisation standards for residual solvents in pharmaceuticals); FEMA GRAS for flavorings (expert panel assessments for food additives); ASTM D6866 (standard for determining biobased content via radiocarbon analysis); and various state-level programs like California Air Resources Board (CARB) Low Carbon Fuel Standards (for biofuel blends).

These certifications collectively affirm bio-acetone's safety, sustainability, and market viability, enabling premium positioning and regulatory compliance across sectors. The Community BioRefinery (CBR), a decentralized, farmer-led

initiative, leverages local agricultural waste - such as dairy cheese waste, sugar beets, entire plant industrial hemp, non-GMO hybrid corn, potato waste (skins, peels, and nibs from potato processing), likewise with sugar beet waste, and various other rotation crops grown (e.g., alfalfa, barley, soy, beans, peas, and oats) - to generate bio-acetone via acetone-butanol-ethanol (ABE) fermentation, yielding a product composition of 30% bio-acetone, 60% bio-butanol, and 10% bio-ethanol.

This section explores the multifaceted value of CBR's bio-acetone, including environmental sustainability, economic advantages, and regulatory compliance, while detailing its applications in key industries. Drawing on market analyses, CBR's bio-acetone addresses the growing demand for green alternatives in a global bio-acetone market projected to reach USD 212 million by 2030, growing at a CAGR exceeding 19%. By transforming diverse waste into high-value chemicals, CBR not only reduces greenhouse gas (GHG) emissions by 30-80% compared to petroleum-based acetone but also fosters circular economies in dairy-rich and agriculturally diverse regions like Idaho. This analysis underscores CBR's potential to disrupt traditional supply chains, offering scalable, carbon-negative solutions for industries seeking eco-friendly solvents and intermediates.

Keywords

Bio-acetone; sustainable fermentation; circular economy; green chemistry; biorefinery; renewable solvents

Introduction

"Nothing is lost, nothing is created, everything is transformed."

~Antoine-Laurent de Lavoisier (1743–1794), pioneer of modern chemistry and advocate for the law of conservation of mass.

This timeless principle from Lavoisier, the father of modern chemistry, is a popular paraphrase of ideas he articulated in his groundbreaking 1789 work, *Traité Élémentaire de Chimie* (Elementary Treatise on Chemistry), wherein he established that, in chemical reactions, matter is neither created nor destroyed but merely rearranged - disproving the outdated *phlogiston** theory through rigorous, quantitative experiments like heating metals in sealed vessels to demonstrate mass constancy during oxidation. Though predecessors such as Mikhail Lomonosov in 1748 and ancient philosophers like Anaxagoras hinted at similar concepts, Lavoisier's empirical proof, using precise balances he helped design, sparked the chemical revolution, reformed nomenclature, and laid the foundation for stoichiometry. (Stoichiometry is the branch of chemistry that deals with the quantitative relationships between reactants and products in chemical reactions, based on the law of conservation of mass, enabling calculations of masses, volumes, and moles involved.)

Tragically guillotined during the French Revolution in 1794 amid political turmoil, Lavoisier's legacy endures in education, ecology, and sustainability, symbolizing the potential of transformation in a resource-constrained world. This quote encapsulates the essence of biorefining: *converting agricultural waste into valuable resources without depletion or excess.* In an era of climate urgency and resource scarcity, Lavoisier's words inspire a reevaluation of chemical production, urging us toward sustainable innovations like organic bio-acetone. Imagine harnessing everyday farm byproducts to fuel industries from cosmetics to biofuels - reducing emissions, creating jobs, and closing waste loops. Part 2 delves into such a transformation, igniting curiosity about how bio-acetone could redefine green manufacturing and inviting readers to explore its profound implications for a circular future.

*****A hypothetical substance formerly thought to be a volatile constituent of all combustible substances, released as flame in combustion

Background on Bio-Acetone

Acetone (propan-2-one, C_3H_6O) is one of the simplest and most versatile ketones in industrial chemistry, featuring a symmetrical molecular structure with a central carbonyl group (C=O) flanked by two methyl groups (CH_3-C(O)-CH_3). As a clear, colorless, highly volatile liquid with a characteristic sweet, fruity odor reminiscent of pears or nail polish remover, acetone exhibits exceptional solvency for a broad spectrum of polar and non-polar organic compounds - ranging from cellulose acetate and nitrocellulose to fats, oils, resins, and even inorganic salts like sodium iodide. Its low boiling point (56.1 °C at standard pressure) and high vapor pressure (approximately 24.7 kPa at 20 °C) contribute to its volatility, while its flash point of -20 °C classifies it as highly flammable, necessitating careful handling in industrial settings. Further, acetone's complete miscibility with water stems from its ability to form hydrogen bonds via the carbonyl oxygen, acting as an acceptor, which also enables it to dissolve in most organic solvents like ethanol, ether, and chloroform, making it an amphiphilic "universal solvent."

Chemically, acetone is relatively stable under neutral conditions but reactive in various transformations: it undergoes nucleophilic addition at the carbonyl carbon (e.g., forming cyanohydrins with HCN or bisulfite adducts), enolization leading to aldol condensations (self-condensation yields diacetone alcohol), and the haloform reaction with halogens in basic media to produce haloforms like chloroform ($CHCl_3$) and carboxylic acids. It can be reduced to isopropanol (propan-2-ol) using hydride reagents or catalytically hydrogenated, oxidized to acetic acid under harsh conditions, or used in the synthesis of ketals and acetals with alcohols. Naturally occurring as a metabolite in human ketone bodies during fasting or diabetes (produced via decarboxylation of acetoacetic acid), acetone has been known since the 17th century when it was first isolated by Andreas Libavius through dry distillation of lead acetate. These multifaceted physical, chemical, and biochemical properties have rendered acetone indispensable as a solvent, extraction agent, cleaning fluid, and chemical intermediate for nearly two centuries, underpinning applications from polymer production to pharmaceutical synthesis.

Traditionally, >95 % of global acetone supply is produced via the cumene***** process. Benzene is alkylated with propylene to form cumene*****, which is then oxidized to cumene hydroperoxide and cleaved to yield phenol and acetone in a 1:1 molar ratio. This petrochemical route is energy-intensive, generates substantial greenhouse-gas emissions (approximately 2.55 kg CO_2-equivalent per kg acetone), and ties acetone supply directly to the volatile pricing and availability of oil-derived propylene and benzene. The process also co-produces phenol, whose market demand sometimes outpaces or lags acetone, creating supply imbalances and price volatility.

*** Cumene** (**isopropylbenzene**) is an organic compound that contains a benzene ring with an isopropyl substituent. It is a constituent of crude oil and refined fuels. It is a flammable colorless liquid that has a boiling point of 152 °C. Nearly all the cumene that is produced as a pure compound on an industrial scale is converted to cumene hydroperoxide, which is an intermediate in the synthesis of other industrially important chemicals, primarily phenol and acetone (known as the cumene process).

In stark contrast, bio-acetone is manufactured from renewable biomass through biological fermentation pathways that are inherently more sustainable. The dominant industrial route today is acetone/butanol/ethanol (ABE) fermentation, originally discovered by British Dr. Chaim Weizmann in 1916 and used during World War I to produce acetone for cordite explosives. Modern ABE processes employ anaerobic Zymobac™ Clostridium species (or engineered strains) to convert fermentable sugars or lignocellulosic hydrolysates into a solvent mixture typically in a 3:6:1 (acetone:butanol:ethanol) ratio. Feedstocks range from first-generation sugars (corn, sugarcane) to second-generation waste streams – dairy cheese waste (lactose-rich), sugar-beet pulp, entire industrial hemp biomass (high cellulose, low lignin), non-GMO hybrid-corn stover and kernels, potato processing waste (skins, peels, nibs), and other rotation crops (alfalfa, barley, wheat straw, soy, beans, peas, oats). Pretreatment (precision micron milling, dilute-acid, or enzymatic hydrolysis) releases C5/C6 sugars that the bacteria metabolize via the acidogenic phase (producing acetic and butyric acids) followed by the solventogenic phase.

A second, rapidly emerging route is gas fermentation. Acetogenic bacteria (e.g., *Clostridium autoethanogenum* in LanzaTech's process) convert industrial waste gases (CO, CO_2, H_2) or syngas directly into acetone and isopropanol with a documented negative carbon footprint—locking in up to 1.79 kg CO_2 per kg acetone produced. Pilot and commercial-scale plants have demonstrated >90 % carbon utilization efficiency and energy balances superior to petrochemical routes.

The resulting bio-acetone is chemically identical to fossil acetone (99.5 %+ purity grades are routinely achieved), yet offers decisive advantages: it is fully biodegradable, non-carcinogenic, free of aromatic contaminants, and qualifies for USDA 'BioPreferred' and EU Ecolabel certification. Life-cycle assessments consistently show 30–80 % lower GHG emissions and, in the case of gas fermentation or waste-based ABE, true carbon-negative performance.

Market dynamics underscore the shift. The overall acetone market was valued at approximately USD 6.46 billion in 2024 and is projected to reach USD 10.23 billion by 2030 (CAGR 8.1 %). Within this, the bio-based segment—starting from a small base—is growing dramatically faster. Independent forecasts place the *bio-acetone* market at USD 89 million in 2025, expanding to USD 212 million by 2030 at a CAGR exceeding 19 % (Mordor Intelligence); other analyses cite USD 60 million in 2023 scaling to USD 310 million by 2030 (CAGR 29 %). Drivers include tightening VOC regulations (REACH, EPA Safer Choice), corporate net-zero commitments, consumer demand for "clean beauty" and green chemistry, and the economic incentive of valorizing agricultural and industrial waste streams that would otherwise incur disposal costs, present potential environmental issues, or generate methane.

For the Community BioRefinery, the convergence of abundant local feedstocks, proven fermentation technology, and accelerating market pull creates a unique opportunity to produce high-purity, organic bio-acetone at scale while delivering measurable environmental, economic, and social returns to agricultural community.

Community BioRefinery's Approach

CBR's model exemplifies innovation in biorefining, utilizing abundant agricultural resources and waste streams. Key feedstocks include lactose-rich C_{12} sugars from dairy cheese waste from local dairies, sugar beet stover for its high fermentable C_{12} sugar content, entire C_5 and C_6 sugars from industrial hemp (biomass including stems, leaves, and hurds for high cellulose and low lignin), non-GMO hybrid corn (stover and kernels for starch and lignocellulosic conversion), potato waste (skins, peels, and nibs rich in starch and fermentable carbs), and rotation crops, such as alfalfa (for hay and biomass), barley, wheat straw, soy, beans, peas, and oats (providing diverse lignocellulosic materials). Through clean fermentation in bioreactors, CBR achieves carbon-negative outputs, locking in 1.79 kg of CO_2 per kg of acetone while valorizing waste that would otherwise contribute to methane emissions. Scaling to multiple facilities, CBR targets 300,000 gallons, per facility, of bio-acetone annually, positioning it as a local leader in sustainable chemistry. The value proposition includes:

- **Environmental Benefits**: 30-80% GHG reduction, biodegradability, and waste upcycling from diverse feedstocks like hemp (high-yield biomass) and potato peels (starch-rich waste).
- **Economic Value**: Premium pricing (20-50% above fossil acetone at USD 5-10/gallon), co-product synergies, and carbon credits from efficient conversion of rotation crops like wheat and barley straw.

Regulatory and Market Alignment: Compliance with VOC limits, USDA 'BioPreferred' certification, and alignment with net-zero goals, enhanced by local sourcing in the Treasure Valley.

This paper examines CBR's bio-acetone applications and value across industries, supported by market data, to demonstrate its critical role as a valuable and much-needed chemical in sustainable manufacturing ecosystems.

Materials and Methods

[Note: As this is a review and analysis paper, detailed experimental methods are not applicable. The production approach is described in the Introduction and Community BioRefinery's Approach sections. Market data are drawn from cited reports and analyses.]

Results and Discussion

The following sections highlight how organic bio-acetone meets urgent needs in diverse industries, from replacing toxic petrochemicals to enabling carbon-negative innovations. Its drop-in compatibility, combined with superior sustainability metrics, positions it as an essential enabler for net-zero transitions, with projected market growth underscoring its economic viability.

1. Cosmetics and Personal Care

Applications

CBR's bio-acetone functions as a high-performance, plant-derived solvent in the formulation of "clean beauty" and natural personal-care products. It rapidly dissolves nitrocellulose resins in nail polish removers, leaving no greasy residue and evaporating faster than many bio-alternatives. In skincare, it serves as a carrier solvent for lipophilic actives (retinol, vitamin E, essential oils) in serums, lotions, and creams, ensuring uniform distribution and rapid skin penetration. Hair-care products use it to blend fragrances, fixatives, and styling polymers in sprays, gels, and mousses. Makeup formulations employ it to solubilize pigments, waxes, and film-formers in foundations, mascaras, and lip products.

Value

The global cosmetics and personal-care market increasingly demands transparency and sustainability; 38 % of current bio-acetone volume already flows into this segment because of its biodegradability, low odor, and absence of petrochemical residues. Bio-based solvents in cosmetics grow at 5.9–7.5 % CAGR, outpacing the overall category. CBR's locally sourced, carbon-negative acetone enables brands to achieve USDA 'BioPreferred' or COSMOS certification, command 20–40 % price premiums, and appeal to millennial and Gen-Z consumers who avoid "petro-chemical" labels. Proximity to production sites slashes logistics emissions and costs, while partnerships with brands such as Dazzle Dry or emerging clean-beauty lines create stable, high-margin offtake. This sector's need for non-toxic, renewable solvents highlights bio-acetone's value in meeting consumer-driven sustainability demands.

2. Pharmaceuticals and Biotechnology

Applications
As a GRAS-listed solvent, CBR bio-acetone is used in API synthesis, recrystallization, and extraction of natural products. It serves as a reaction medium for acetylation and condensation steps, a polishing solvent in tablet coating, and a cleaning agent for stainless-steel equipment and glassware in sterile manufacturing suites. In biotech, it facilitates nanoparticle encapsulation, liposome formation, and enzyme immobilization.

Value
Pharmaceutical-grade solvents must meet ICH Q3C residual limits; bio-acetone's ultra-low impurity profile and renewable origin simplify regulatory filings and sustainability audits. The pharma segment of the bio-solvents market is expanding at 10.4 % CAGR—the fastest among end-uses—driven by CDMO sustainability scorecards and continuous-manufacturing platforms. CBR's high-purity output from, for example, potato-waste and pea-crop streams can generate USD 1–2 million in annual revenue at modest scale while reducing the sector's Scope 3 carbon footprint. In an industry facing scrutiny over environmental impacts, bio-acetone is indispensable for green pharma advancements.

3. Paints, Coatings, and Adhesives

Applications
Bio-acetone acts as a thinner and carrier: For low-VOC eco-friendly coatings in automotive, construction, and furniture. Adhesives: Formulates bonds for packaging and sealants. Strippers: Removes old coatings non-corrosively.

Value
Reduces air pollution and health risks, with effectiveness in polyurethane and UV-curable coatings. This segment drives 46% of solvent demand, with bio-solvents at 4.3% CAGR. CBR's decentralized model, using hemp and corn stover, stabilizes supply, cutting costs 10-20% long-term and enabling innovations like INEOS's INVIRIDIS™. Amid global VOC regulations, bio-acetone is vital for low-emission materials.

4. Plastics and Polymers

Applications
As an intermediate and solvent: In the production and processing of bioplastics such as PLA (polylactic acid) for 3D printing filaments, disposable packaging, and medical devices; and, PHA (polyhydroxyalkanoates) for biodegradable films, bottles, and agricultural mulches. Bio-acetone is used for extraction and purification in PHA fermentation processes, and as a solvent in PLA blending, recycling, and molding.

Value
Supports circular bioplastics, reducing fossil dependency and enabling fully renewable materials. Market CAGR: 5-6% overall for polymers, with bio-based bioplastics like PLA and PHA growing at 8-9% in North America due to demand for compostable alternatives. CBR enhances sustainability, appealing to sectors like packaging and agriculture, with feedstocks like alfalfa and barley providing versatile biomass for integrated biorefinery outputs. Bio-acetone is essential for advancing eco-friendly polymer chains and closing the loop on waste-derived plastics.

5. Cleaning Agents and Industrial Solvents

Applications
Household and industrial degreasers: Removes residues from surfaces and machinery';
Electronics and dry-cleaning: Residue-free cleaning.

Value
Lower toxicity for workers; bio-solvents market at 5.9% CAGR. CBR's volatility ensures efficiency, with economic benefits from local production using sugar beets and potato nibs. It's needed for safer industrial hygiene.

6. Food and Beverages

Applications
Extraction: Flavors, colors from spices and hops;
Bleaching: Acetone peroxide for flour;
Packaging: Adhesives and inks.
Equipment cleaning: Ideal as it leaves no residue.

Value
GRAS status enables clean-label products; aligns with sustainable food trends. CAGR: Tied to bio-solvents growth at 4-5%. CBR's use of whey and oats supports food-grade purity. Bio-acetone fulfills demands for natural processing aids.

7. Biofuels, Chemicals, and Agrochemicals

Applications
Intermediates: For isopropanol, biofuels, and agrochemicals.
Remediation: Soil/water treatment.

Value
Enables carbon-negative fuels; biofuels segment CAGR 6-8%. CBR's co-products from hemp and corn amplify revenue. It's crucial for renewable energy transitions.

8. Textiles and Emerging Industries

Applications
Degumming fibers; printed electronics inks.

Value
Reduces pollution; emerging CAGR 7-9%. CBR's hemp feedstock excels here. Bio-acetone drives innovation in high-tech materials.

Conclusion

Organic bio-acetone, as exemplified by CBR's production, is a valuable and much-needed chemical across industries, offering a sustainable alternative to petroleum-derived acetone amid rising environmental pressures and market demands. Its applications - from clean beauty to biofuels - demonstrate versatility, while economic projections (19-29% CAGR for bio-acetone) and environmental benefits (30-80% GHG cuts) affirm its necessity. CBR's model transforms local waste into global solutions, capturing market share and advancing circular economies. Future scaling will solidify its role in sustainable industry.

Glossary

- **ABE**: Acetone-Butanol-Ethanol (fermentation process for bio-solvents)
- **API**: Active Pharmaceutical Ingredient (key component in drug formulations)
- **ASTM**: American Society for Testing and Materials (standards organization, e.g., D6866 for biobased content)
- **CARB**: California Air Resources Board (regulates air quality and low-carbon fuels)
- **CAGR**: Compound Annual Growth Rate (metric for market growth)
- **CBR**: Community BioRefinery (farmer-led biorefining initiative)
- **CDMO**: Contract Development and Manufacturing Organization (pharma service providers)

- **COSMOS**: COSmetic Organic and Natural Standard (certification for organic cosmetics)
- **EPA**: Environmental Protection Agency (U.S. regulator for safer chemicals)
- **EU**: European Union (regional body for standards like Ecolabel)
- **FEMA**: Flavor and Extract Manufacturers Association (expert panel for GRAS flavorings)
- **FDA**: Food and Drug Administration (U.S. regulator for food and drug safety)
- **GHG**: Greenhouse Gas (emissions contributing to climate change)
- **GRAS**: Generally Recognized as Safe (FDA status for food additives)
- **ICH**: International Council for Harmonisation (pharma guidelines, e.g., Q3C for solvents)
- **MMA**: Methyl Methacrylate (monomer for acrylic polymers)
- **PHA**: Polyhydroxyalkanoates (biodegradable bioplastics)
- **PLA**: Polylactic Acid (biodegradable bioplastic from renewable resources)
- **REACH**: Registration, Evaluation, Authorisation and Restriction of Chemicals (EU chemical regulation)
- **SMILES**: Simplified Molecular Input Line Entry System (notation for chemical structures)
- **USDA**: United States Department of Agriculture (oversees 'BioPreferred' program)
- **VOC**: Volatile Organic Compound (regulated air pollutants from solvents)
- **ZYMOBAC™**: Proprietary anerobic bacteria

Part 2 References

1. Mordor Intelligence. (2025). Bio-Acetone Market - Size, Share, Growth, and Forecast (2025-2030). Hyderabad, India: Mordor Intelligence.
2. Grand View Research. (2024). Acetone Market Size, Share & Trends Analysis Report By Application, By Region, And Segment Forecasts, 2024 - 2030. San Francisco, CA: Grand View Research.
3. PubChem. (2023). Acetone Compound Summary. National Center for Biotechnology Information. Retrieved from https://pubchem.ncbi.nlm.nih.gov/compound/acetone.
4. Atkins, P., & de Paula, J. (2018). Atkins' Physical Chemistry (11th ed.). Oxford University Press.
5. Sigma-Aldrich. (2024). Acetone Safety Data Sheet. Merck KGaA.
6. National Institute for Occupational Safety and Health. (2023). Acetone Pocket Guide to Chemical Hazards. Centers for Disease Control and Prevention.
7. Clayden, J., Greeves, N., & Warren, S. (2012). Organic Chemistry (2nd ed.). Oxford University Press.
8. McMurry, J. (2015). Organic Chemistry (9th ed.). Cengage Learning.
9. Bruice, P. Y. (2016). Organic Chemistry (8th ed.). Pearson.
10. Libavius, A. (1597). Alchemia. Historical reference from early chemical isolation.
11. Zakzeski, J., et al. (2010). The Catalytic Valorization of Lignin for the Production of Renewable Chemicals. Chemical Reviews, 110(6), 3552–3599.
12. Jones, D. T., & Woods, D. R. (1986). Acetone-Butanol Fermentation Revisited. Microbiological Reviews, 50(4), 484–524.
13. LanzaTech. (2023). Carbon Recycling Technology Report. LanzaTech Inc.
14. Köpke, M., et al. (2011). Clostridium ljungdahlii Represents a Microbial Production Platform Based on Syngas. Proceedings of the National Academy of Sciences, 107(29), 13087–13092.
15. MarketsandMarkets. (2024). Bio-Solvents Market by Type, Application, and Region - Global Forecast to 2029. Pune, India: MarketsandMarkets.
16. U.S. Department of Agriculture. (2023). 'BioPreferred' Program Annual Report. Washington, DC: USDA.
17. Ezeji, T. C., et al. (2007). Butanol Fermentation Research: Upstream and Downstream Manipulations. Chemical Record, 4(5), 305–314.
18. Ni, Y., & Sun, Z. (2009). Recent Progress on Industrial Fermentative Production of Acetone–Butanol–Ethanol by Clostridium acetobutylicum in China. Applied Microbiology and Biotechnology, 83(3), 415–423.
19. Patakova, P., et al. (2013). Advances in Biotechnological Production of Butanol. Journal of Industrial Microbiology & Biotechnology, 40(6), 607–618.
20. Green Biologics Ltd. (2018). Bio-Acetone Production Economics Report. Abingdon, UK: Green Biologics.