Biomanufacturing: Pioneering Sustainability Through Biotransformation

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Abstract

The article explores the transformation of the ethanol industry towards sustainability through biotransformation, biomanufacturing, and renewable chemicals, highlighting the role of biorefineries in shaping a greener future.

Introduction

The ethanol industry sector, once dominated by traditional petroleum-based processes, is now undergoing a remarkable transformation. The article delves into the evolving world of fuel ethanol, emphasizing the pivotal roles of biotransformation, biomanufacturing, and the promise of renewable chemicals.

Bioethanol as a Fuel

One of the most well-established applications of bioethanol is its use as a fuel additive in gasoline.

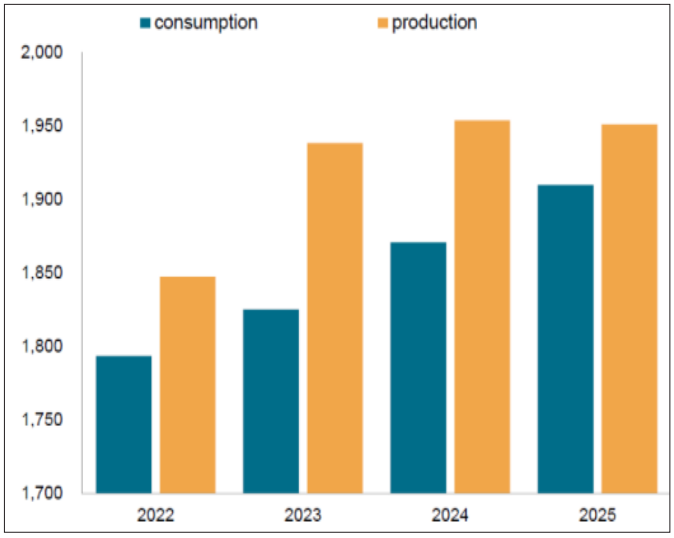

Fig 1: Global fuel ethanol (thousand barrels/day)

Blending bioethanol with gasoline not only reduces greenhouse gas emissions, but also enhances octane ratings, leading to cleaner combustion and improved engine performance. **Figure 1** illustrates the global consumption/production of bioethanol as a fuel, showcasing its steady growth over the years.

However, advancements in bioethanol technology have expanded its role beyond conventional fuel applications. Sustainable Aviation Fuel (SAF), for instance, is garnering significant attention as a means to decarbonize the aviation sector.

Bioethanol-derived SAF offers a promising solution due to its compatibility with existing aircraft engines and infrastructure.

Bioethanol as a Feedstock

Bioethanol serves as a precursor for the production of various renewable materials, offering sustainable alternatives to traditional petroleum-based products. One notable example is bioplastics, which can be synthesized from bioethanol through fermentation or chemical processes. These bioplastics exhibit similar properties to conventional plastics, but with the added benefit of being biodegradable and derived from renewable resources, thus mitigating plastic pollution and resource depletion. **Figure 2** illustrates the global production capacities of bioplastics between 2022-2027.

Additionally, bioethanol-derived chemicals find applications in industries ranging from

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pharmaceuticals to cosmetics. Ethanol amines, for instance, are vital components in the production of various personal care products and detergents. By replacing petroleum-derived chemicals with bioethanol equivalents, companies can reduce their carbon footprint and reliance on finite fossil resources.

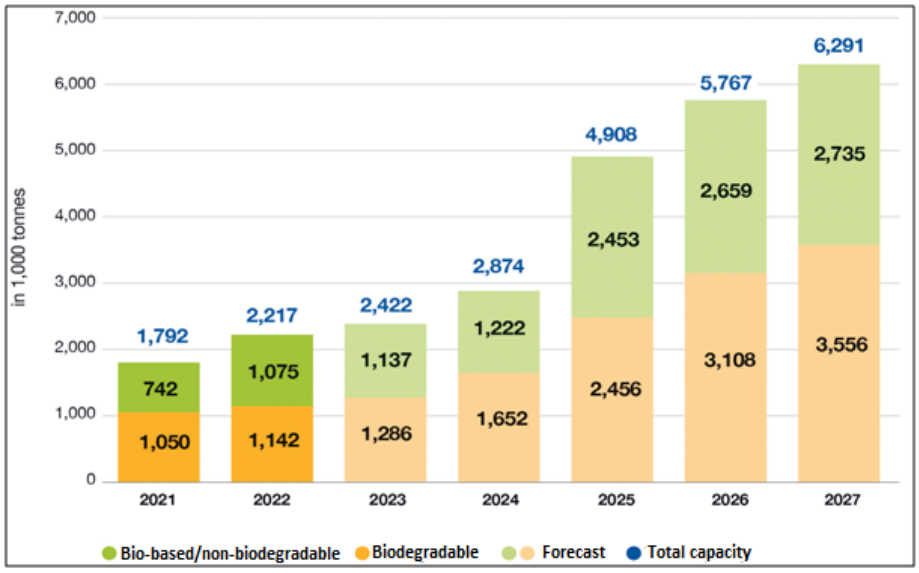

Fig 2: global production capacities of bioplastics between 2022-2027

Biomanufacturing Facility

A biomanufacturing facility is a specialized facility where biological products are manufactured on a large scale. These facilities are designed to produce a wide range of products, including biopharmaceuticals, vaccines, enzymes, and bio-based materials. Biomanufacturing processes typically involve the use of living organisms, such as bacteria, yeast, or mammalian cells, to produce the desired products through fermentation, cell culture, or other bioprocess techniques.

Biomanufacturing facilities require highly controlled environments to ensure the safety, purity, and efficacy of the products being produced. They are equipped with state-of-the-art equipment and technology for fermentation, purification, and other manufacturing processes. Quality control measures are also implemented throughout the production process to maintain product consistency and meet regulatory standards.

Most organic compounds and polymers are still produced from petroleum and other fossil fuels. Biomass-based chemicals and materials will be essential in the shift from the fossil-based economy to the bio-based circular economy. Formation of Biomanufacturing hubs will help mitigate climate change.

Need for the Biomanufacturing Facility

- Strategy for ensuring the long-term economic and environmental sustainability
- Does not contribute to carbon dioxide in the atmosphere in contrast to fossil fuels
- To reduce the emission of greenhouse gases
- An over-dependency on fossil fuel imports
- Reducing chemical waste and the emission of hazardous by-products
- Diversify feedstock sources that support the nation's industrial base
- "Safe by Design" processes and products
- Recycling-friendly chemicals and materials save money, resources, and energy
- Deployment in rural areas will stimulate regional and rural development

Essential Sections of a Biomanufacturing Facility

The biomanufacturing pilot facility can be divided into different sections as follows:

- **Feedstock handling and preparation section**

Sometimes feedstocks need to be pre-treated before sending it for the fermentation process. Feedstocks are typically fractionated/processed into several important intermediates. In most cases, the intermediates will be a heterogeneous mixture of chemicals rather than a single, well-defined substance that can be further processed into the final marketable products. Slurry preparation as well as enzyme hydrolysis can be part of this section.

- **Fermentation section**

This section will have a sterile fermentation facility with two fermentation lines. All aerobic, microaerobic, and fed-batch, continuous fermentations can be

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carried out in simple stir tank fermenters. These tanks are suitable for both acid and base fermentation. This section can also include seed train.

- **Chemical reaction section**

If the product of interest involves chemical or catalytic reactions, this part can be plugged in as needed.

- **Downstream procession section (DSP)**

Unit operations carried out after fermentation to increase the quality of the end product are considered part of the downstream processing phase. This section should be flexible and can be modified as per the product requirement. The DSP section will have equipment for solid/liquid separation, chromatography, nano MF/NF, evaporation, distillation, drying, etc.

- **Storage and utility section**

This section will be used to store all chemicals, raw materials, and ready products. These materials can be stored for up to 15 days.

- **Effluent Treatment Plant (ETP) Section**

An ETP is a system built to clean up wastewater from industries so it can be reused or safely dumped. Different treatment levels and mechanisms can be used to treat various impurities in the wastewater such as suspended solids, organic matter, toxic and non-toxic materials, and inorganic compounds.

Transforming the Ethanol Industry by Biomanufacturing through Biorefineries

The concept of the biorefinery involves the integration of various biomass conversion processes to produce a wide range of valuable products, akin to the conventional petroleum refinery but using renewable biomass as the feedstock. Biorefineries aim to efficiently utilize biomass resources by extracting multiple products, including biofuels, biochemicals, biopolymers, and other biobased materials, while minimizing waste and environmental impact.

Initially, conventional biorefineries were limited to the processing of sugary and starchy feedstocks that produced a limited product basket of fuels and materials, eg. sugar, power, paper, bioethanol, starch, edible oil, and biofertilizers. By leveraging the latest technological developments, advanced biorefineries are now able to process lignocellulosic feedstock like agricultural waste, forestry residues, or energy grasses. The advanced biorefineries produce additional products like low-carbon alcohols, sustainable aviation fuel, marine biofuel, Biochemicals, Biopolymers, Bio composites, Lignosulfonate, Bio-Bitumen, etc.

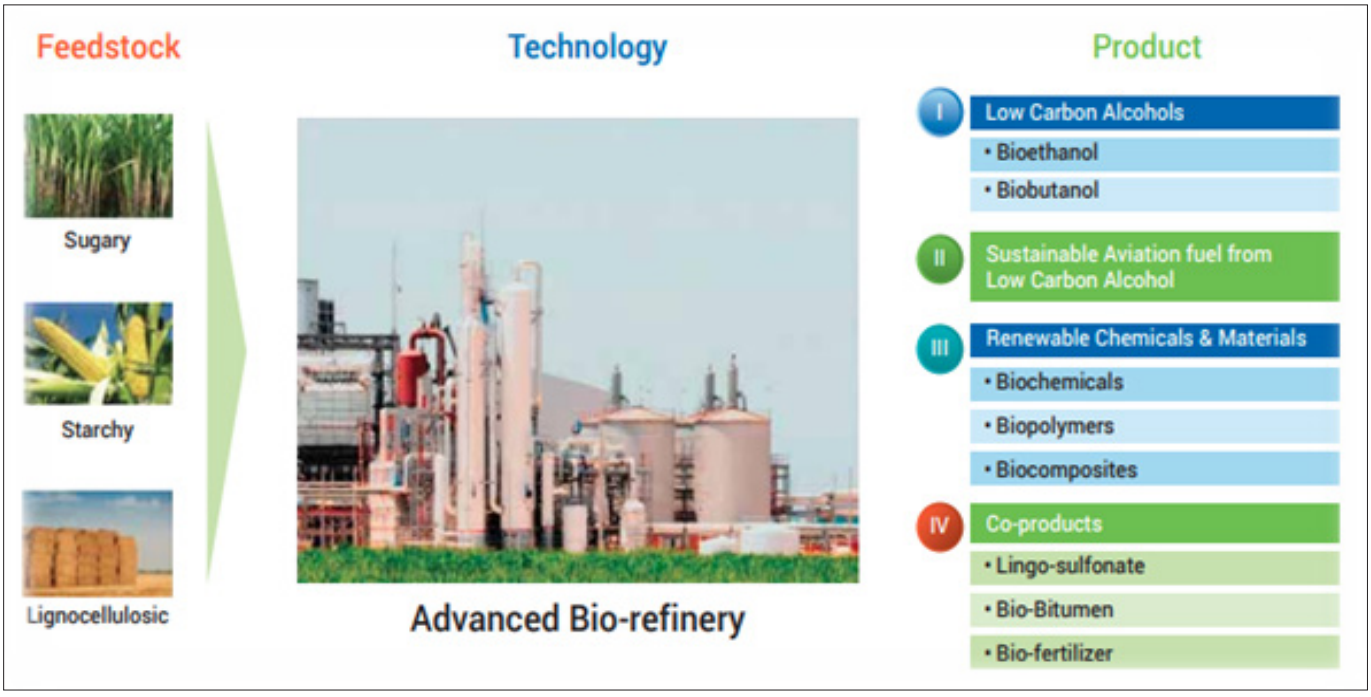

Fig 3: Advanced biorefinery

Advanced Biorefinery Complex

On the back of rich experience in Feedstock-Technology-Product (FTP), Praj has developed a

concept of an advanced biorefinery complex. Here lignocellulosic feedstocks are processed to produce mixed sugar streams and lignin-rich cake. Mixed sugars streams undergo fermentation to produce ethanol or renewable chemicals and materials or both. Ethanol produced can be further processed into Sustainable Aviation Fuel (SAF). Alternately ethanol can also be converted into other derivatives such as acetaldehyde, mono ethylene glycol, etc. Further processing of lignin rich cake can yield variety of value-added products like bio-bitumen, lignosulfonates, marine biofuels.

Advanced Biorefinery Complex: Sustainable Biomanufacturing

In a world threatened by climate change, meeting nationally determined contributions as sustainable climate action is imperative. Mainstreaming bioeconomy that positively impacts environment conservation is a promising solution. Advance biorefineries will play a crucial role in achieving sustainability growth by facilitating energy transition, employment generation, and strengthening the role in various sectors, including transportation and materials production. This evolution underscores the importance of biotransformation, biomanufacturing, and the potential of renewable chemicals in shaping a greener future. The concept of the biorefinery further advances the sustainability of bioethanol production by integrating various biomass conversion processes to produce a wide range of valuable products.

From feedstock selection to process integration and product diversification, biorefineries optimize resource utilization while minimizing waste and environmental impact. Evaluation of biorefineries' sustainability encompasses environmental, economic, social, and technical aspects, utilizing tools such as life cycle assessment and techno-economic analysis.

India's BioE3 Policy exemplifies a strategic approach to biomanufacturing, aiming to drive green growth and socioeconomic development through innovation and collaboration. The Interim Budget 2024-25 proposes a new scheme of bio-manufacturing and bio-foundry which will provide environmentally

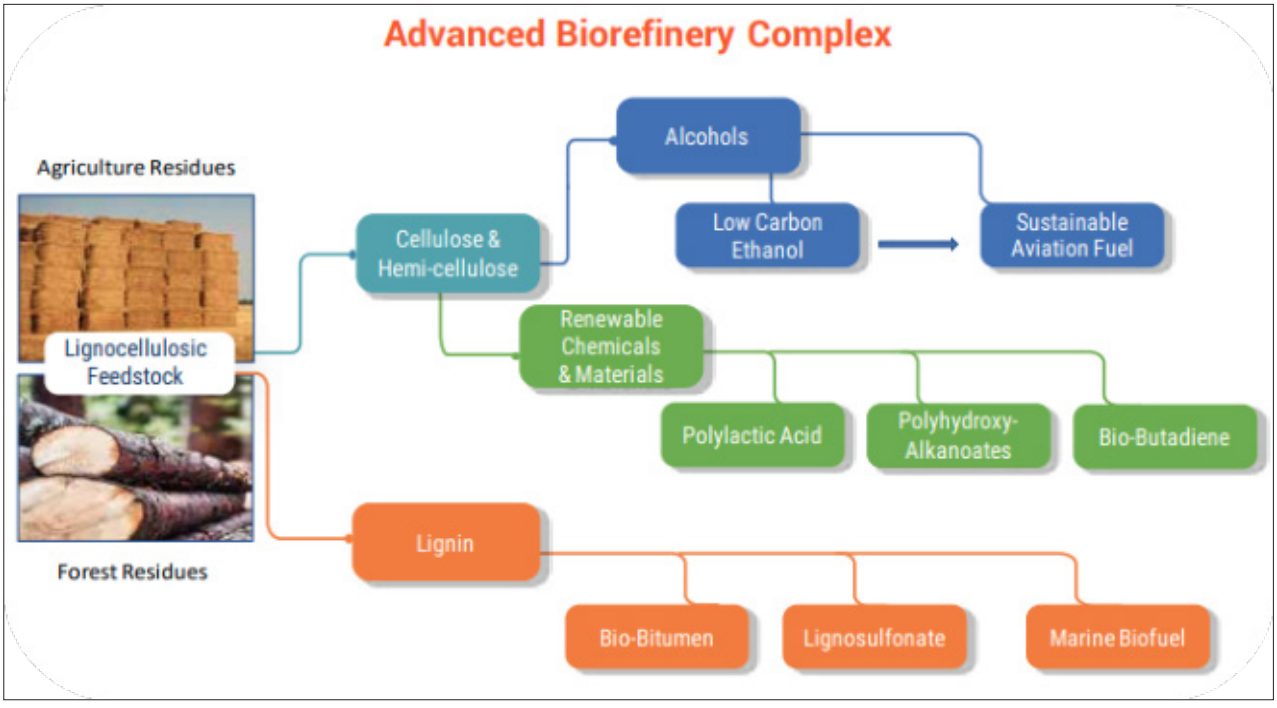

Fig 4: Advanced biorefinery complex

economy.

Conclusion

The ethanol industry has undergone a remarkable transformation, shifting towards sustainable practices and renewable resources. Bioethanol, once primarily used as a fuel additive, now plays a pivotal friendly alternatives such as biodegradable polymers, bioplastics, biopharmaceuticals, and bio-Agri-inputs. By fostering high-performance biomanufacturing and integrating biotechnology with various sectors, India aims to accelerate its transition towards a sustainable bioeconomy, while prioritizing biosafety,

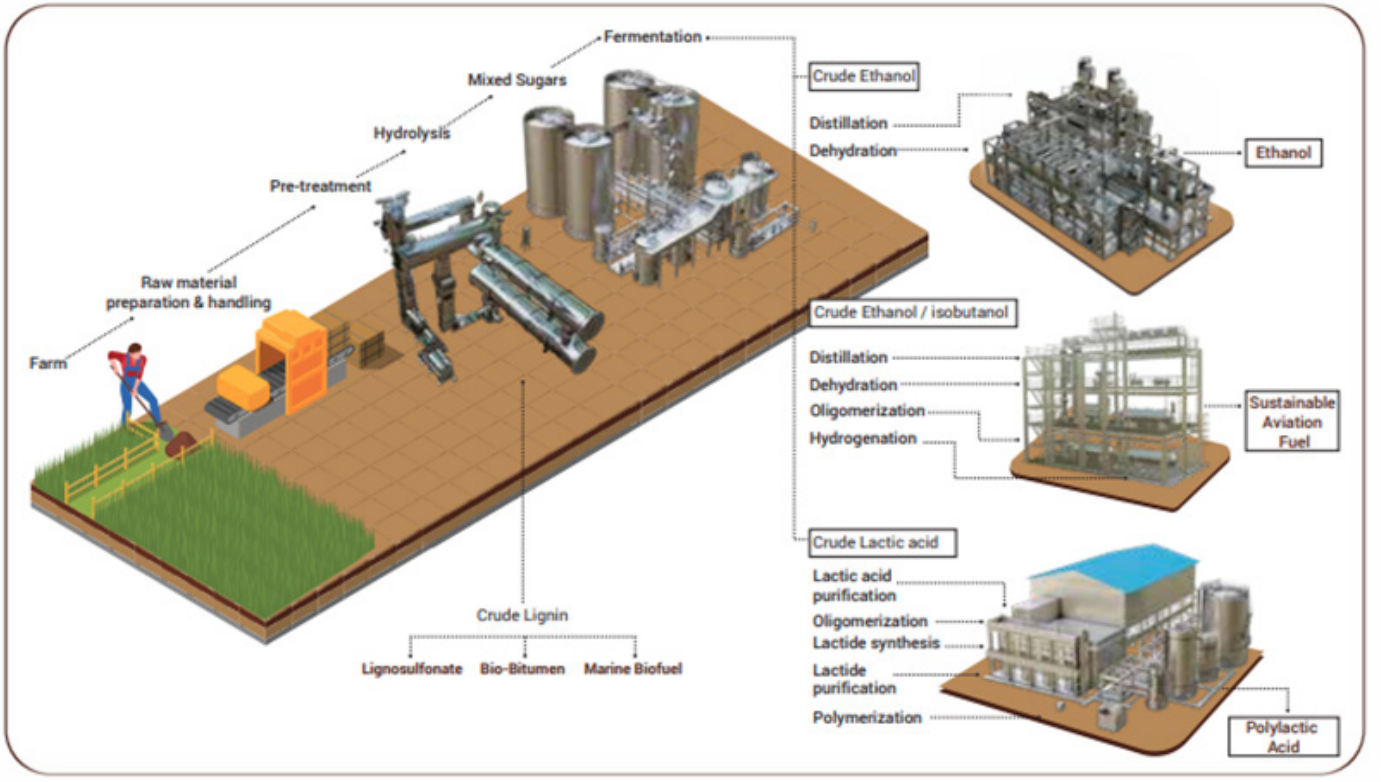

Fig 5: Sustainable Biomanufacturing

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ethics, and equitable access.

In conclusion, the ethanol industry's transformation towards sustainability under sco-res the critical role of biotransformation, bioma nufacturing, and renewable chemicals in driving global efforts towards a greener, more sustainable future. Through continued innovation, collaboration, and strategic policy initiatives, the ethanol industry can further advance sustainability and contribute to the transition towards a bio-based circular economy.

Editor's Note: *Praj has achieved success in the bioeconomy by capitalizing on its expertise in Feedstock-Technology-Product (FTP). This expertise has enabled the development of innovative technology solutions like Bio-Mobility™ for decarbonizing transportation and Bio-Prism™ for recycling carbon in renewable chemicals and materials. Over four decades, Praj has honed its understanding of various bio-based feedstocks and developed advanced technology solutions to process them, resulting in the production of biofuels and renewable chemicals and materials.*