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MISSION LiFE & BIOFUELS

31 From Farm to Fuel: The Promise of the Advanced Biorefineries

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Biorefineries play a pivotal role in the global energy transition. By efficiently converting renewable biomass into biofuels, bioplastics, and renewable chemicals, these innovative complexes offer sustainable solutions to climate challenges. In India, abundant feedstock, advancing technologies, and supportive policies position biorefineries as a cornerstone for driving sustainable energy and economic growth.

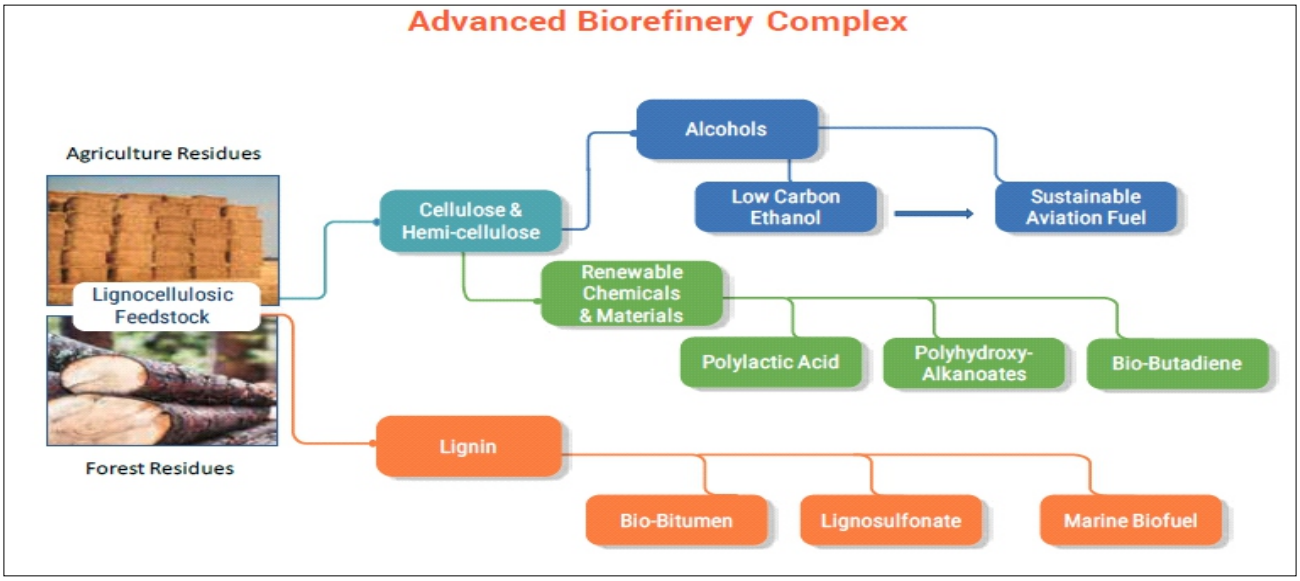
India's Feedstock Potential

India's agricultural abundance positions it as a prime hub for biofuel production, with diverse feedstocks such as sugarcane, corn, vegetable oils, agricultural residues, forest waste, algae, and organic municipal waste. The country produces an estimated 750 MMT of biomass annually, with a surplus of approximately 170 MMT, providing a robust foundation for sustainable biorefinery operations. By leveraging advanced technologies and adopting a single-feedstock, multi-product model, biorefineries can efficiently convert this biomass into biofuels, chemicals, and other value-added products, paving the way for a sustainable and self-reliant energy future.

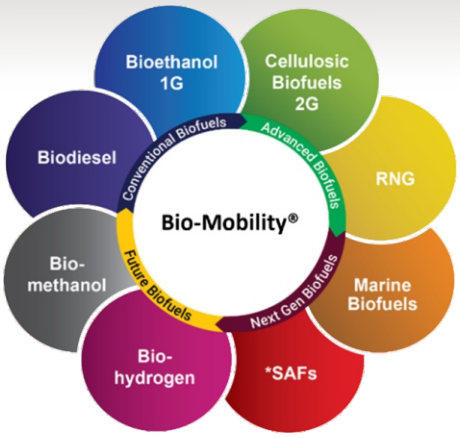
Technology Perspective

The technological landscape for biofuels and biorefineries is rapidly evolving, both in India and globally. Advancements in biotechnology and bioengineering are enabling the conversion of diverse biomass feedstocks into biofuels and value-added products. India leverages its growing R&D capabilities and indigenous technologies to scale sustainable biofuel production. As nations prioritize energy security and carbon neutrality, the synergy of cutting-edge technologies and supportive policies is driving the transition toward a circular, bio-based economy.

Praj is India's leading industrial biotech firm, driven by innovation, integration, and delivery capabilities. Recognizing the global shift towards circular economy and bio-based products, Praj envisions a biorefinery-led future. Praj's product portfolios Bio-Mobility® & Bio-Prism® focus on biofuels & Renewable Chemicals & Materials respectively. With the help of these advanced technology portfolios, fossil fuels and chemicals are replaced with biobased renewable fuels and chemicals.



Biomobility®



In the Bioeconomy space, Praj has pioneered the basket of innovative technology solutions in the form of **Bio-Mobility®.** True to its vision of making the world a better place, Praj continues to pursue sustainable decarbonization mobility sector through circular bioeconomy by deploying its proprietary biofuel technology solutions.

The Bio-Mobility® platform promotes the use of renewable resources to produce low carbon intensity transportation fuel across all modes of mobility (surface, air, and water).

This platform comprises of,

Conventional Biofuels

I. Low carbon bioethanol is produced from sugar and starch-based feedstock like B & C molasses, sugarcane juice, cassava, grain, sugar beet, among others.

II. **EcodiezelTM** - Biodiesel is produced from used cooking oil, palm fatty acid, palm stearin, tallow, etc. using enzymatic technology.

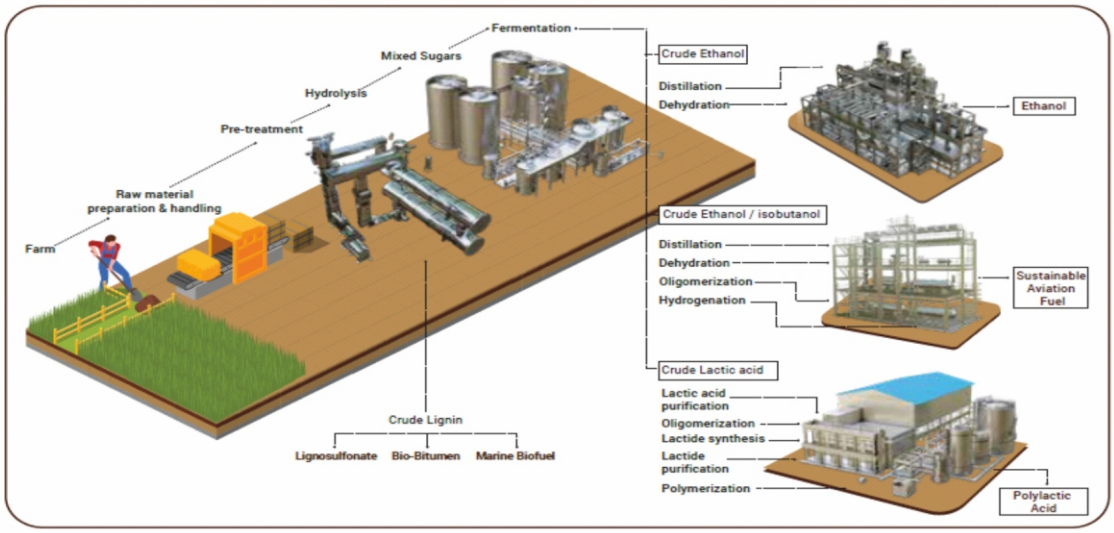
Advanced Biofuels

I. **Ultra-low carbon bioethanol** produced through Praj's proprietary **enfinity®** technology using lignocellulosic residue such as bagasse, corn cob, rice straw, wheat straw, etc. This technology is deployed at commercial scale. Praj is setting up three commercial scale plant with Fortune 500 companies, Indian Oil Corporation Limited (IOCL), Hindustan Petroleum Corporation Limited (HPCL) and Bharat Petroleum Corporation Limited (BPCL).

Ready for Commercialization

Praj Industries in collaboration with IOCL has set up an advanced bioethanol plant in Panipat, India based on its enfinity® technology. The plant will process 200,000 MT of rice straw annually to produce 3 crore litres of ultra-low carbon ethanol. The plant will have several socio-economic and environmental benefits,

- ~1,00,000 farmers to benefit
- ~1,500 jobs in rural area
- ~3,20,000 MT of CO_2 elimination/year which is equivalent to replace ~63,000 cars/ year
- Prevention of stubble burning



II. Byproduct Valorization

Byproduct valorization enhances biorefinery sustainability by converting residues like lignin or fermentation byproducts into high-value products such as bio-based chemicals, materials, or energy. Through advanced technologies this approach reduces waste, diversifies revenue streams, and supports a circular bioeconomy. Alternatively, lignin can be used as fuel in an integrated Combined Heat and Power (CHP) facility as well.

Bio-Bitumen

Praj Industries has developed the Enfimer™ Bio-Bitumen Technology to address the challenges posed by the asphalt industry's reliance on fossil-based bitumen. As bitumen supplies face challenges due to growing demand and improved petrochemical efficiencies, this innovative solution uses lignin, a byproduct from second-generation ethanol or biogas production, as a sustainable binder. Praj's technology produces lignin-based binders from agricultural biomass, contributing to India's sustainability goals and reducing bitumen imports, which currently constitute 50% of national consumption.

Bio-Bitumen blends up to 15%, demonstrated satisfactory physical and rheological performance in trials conducted with CSIR-CRRI. A service road in Gujarat constructed using Bio-Bitumen showed excellent durability, withstanding two years and three monsoon cycles without distress. Based on the success of the service road in Gujarat, Praj Industries in collaboration with CSIR-CRRI constructed a main carriageway of the national highway (4 laning of Madhya Pradesh/Maharashtra border Nagpur section of NH 7; Nagpur Bypass) on 13th-15th December 2024. The initiative was formally inaugurated by the Hon'ble Minister of Road Transport and Highways of India, Shri Nitin Gadkari, on 21st December 2024, marking a transformative step in enhancing India's highway infrastructure. This positions Bio-Bitumen as a viable, eco-friendly alternative for the flexible pavement industry, aligning with global efforts to decarbonize infrastructure development.

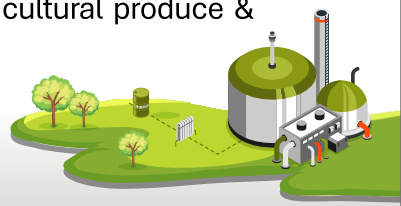
III. Compressed Biogas (CBG) Technologies

Praj has developed RenGas® technology for producing CBG/Renewable natural gas (RNG) from agricultural residues and distillery byproducts. This advanced technology uses a multi-stage anaerobic digestion process to efficiently convert feedstocks like press mud, rice straw, cane bagasse, and distillery waste into high-quality biomethane. RenGas® is designed to handle diverse cellulosic biomass and valorizes solid waste from 1G distilleries, contributing to zero waste discharge. Advanced strategies, such as tailoring microbial consortia and real-time process monitoring through metagenomic studies, are employed to optimize gas production and recycle waste into value-added products.

Next-gen Biofuels

I. Sustainable Aviation Fuel

Sustainable Aviation Fuel (SAF) is a type of biofuel specifically designed for use in aircraft. Unlike conventional jet fuel, SAF is produced from biological resources such as agricultural produce &



residues, waste oils, and algae. One of the significant advantages of SAF is that it can be used in existing aircraft engines without modifications, with up to a 50% blend ratio with conventional jet fuel.

The production of SAF involves converting feedstock into liquid hydrocarbons. According to ICAO's 2022 report, there are nine SAF conversion processes that have ASTM certification for commercial aviation use.

The three most advanced technologies are:

- Alcohol to Jet (ATJ)
- Hydroprocessed Esters and Fatty Acids (HEFA)
- Fischer-Tropsch Process

Praj's ETJ technology

Ethanol to Jet (ETJ) technology, which is essentially the Alcohol to Jet (ATJ) pathway, is a promising pathway for converting ethanol into SAF. Praj Industries is advancing ETJ technology alongside its partners, leveraging its expertise in low (1G) and ultra-low (2G) carbon ethanol. The company offers integrated solutions, including technology, engineering, and modular manufacturing, to support SAF production via the ETJ pathway. Praj's innovations are driving SAF adoption in India.

SAF pilot facility

The bench scale unit is a multipurpose continuous mode facility. Currently, 3 fixed-bed reactors with ancillary equipment are housed in the unit. It was installed and commissioned in the month of October-November 2023. A distillation unit is attached for the purification of hydrocarbons. Catalyst holding capacity is about 5 liters and we can process about 100 liters of feeds in a day. Passing quality SAF is already made from this unit.

Praj Industries' advanced catalysis facility is central to their SAF technology development, supporting a variety of reactions such as hydrogenation, dehydrogenation, and reforming. It enables long-term catalyst testing, crucial for R&D in hydrogen production, bioenergy, and SAF. By combining R&D, bench-scale, and pilot-scale capabilities, Praj provides a comprehensive solution for innovation.

Proven-Ready for commercialization

On May 19th, 2023, Praj Industries marked a major milestone when India's first commercial passenger flight was powered by a blend of domestically produced sustainable aviation fuel (SAF). This achievement was realized through a partnership with Indian Oil Corporation Ltd. (IOCL). Praj produced the SAF at its in-house R&D facility using molasses-based feedstock, which was then blended and tested by IOCL. The SAF was used in an AirAsia India flight (i5-767) from Pune to New Delhi. This milestone underscores Praj's crucial role in advancing sustainable aviation in India.

II. Bio-Hydrogen

Bio-Hydrogen, a clean and renewable fuel source, is produced through the biological conversion of organic matter. With its potential for decentralized production, Bio-Hydrogen is a promising alternative to fossil fuels - particularly diesel and is poised to play a significant role in shaping Bio-mobility.

Bio-Hydrogen from RenGas® using Bio-Chemical production process

Praj Industries' innovative approach for Bio-Hydrogen production involves the conversion of compressed biogas/Renewable natural gas into hydrogen via steam methane reforming (SMR). Praj Industries has leveraged its expertise in CBG production to develop innovative solutions for Bio-Hydrogen generation. By combining its RenGas® technology for CBG production with industry-proven SMR technology, Praj can now offer decentralized modular & containerized, commercial-scale plants for on-site production of Bio-Hydrogen along with Compression, Storage, and Dispensing solutions.

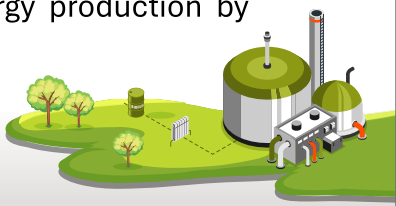
Bio-Hydrogen for Bio-mobility

This integrated approach offers a cost-effective and efficient method for converting biomass into a clean and renewable fuel source avoiding the challenges faced in the transportation of Hydrogen. Bio-Hydrogen from RenGas® can be used in various applications, particularly in the long haul, heavy-duty HICE & HFC powered vehicles, developing Bio-mobility with a more sustainable and decarbonized commercial transportation landscape.

Circular Economy

India's biofuel strategy exemplifies the principles of a circular economy by transforming agricultural residues, waste products, and surplus grains into valuable energy resources. Initiatives like the Ethanol Blended Petrol Programme, Sustainable Alternative Towards Affordable Transportation (SATAT), and the PM JI-VAN Yojana reduce waste, minimize greenhouse gas emissions, and enhance resource efficiency while promoting rural development and job creation.

India's circular economy is uniquely positioned to drive sustainable development, leveraging its vast agricultural feedstock potential and innovative concepts like Farm to Fuel (or Farm to Wheel). With abundant biomass resources, including crop residues, sugarcane bagasse, and other agricultural waste, India can create value-added biofuels, biochemicals, and bioenergy. The Farm to Fuel concept integrates rural development with clean energy production by



converting farm waste into fuels, reducing stubble burning, and generating income for farmers. This approach not only aligns with the global energy transition by reducing dependence on fossil fuels but also promotes carbon neutrality, energy security, and a resilient rural economy.

Policy Perspective

For the biorefinery complex to flourish, a supportive policy environment is crucial. India has been proactive in formulating policies and initiatives to drive the growth of the bioenergy sector:

- Infrastructure and Biomass Supply: Developing infrastructure and a strong biomass supply chain for efficient feedstock movement.
- Pricing Incentives: Stable pricing and incentives for biofuels to reduce fossil fuel dependence.
- Supportive Measures: Blending mandates, tax incentives, and favourable regulations to strengthen the market for biofuels and renewable chemicals.

Socioeconomic Benefits

- Energy Security: Energy security is improved by lessening reliance on imported fossil fuels. Supply risks and geopolitical vulnerabilities can be reduced by using energy from many sources.
- Forex Savings: The indigenous development of biofuels reduces the demand for expensive imported oil.
- Job Creation: The biofuels industry generates employment opportunities in multiple sectors, including agriculture, biomass production, biofuel refining, and distribution. This leads to an increase in employment, particularly in rural areas, which stimulates local economies and sustains livelihoods.

Conclusion

In conclusion, the biorefinery emerges as a transformative force, paving the way for a greener and self-reliant India. By replacing fossil fuels and chemicals with sustainable biofuels, renewable chemicals, and materials, it serves as a catalyst for environmental preservation and mitigates the impact of climate change. The availability and deployment of advanced technologies at a commercial scale position the biorefinery as a viable and practical solution to address our pressing energy and resource challenges.

Most importantly, the biorefinery aligns seamlessly with India's vision of ‘Atmanirbhar Bharat’ (self-reliant India) by fostering indigenous technology development. By harnessing our rich feedstock availability and embracing homegrown innovation, the biorefinery complex empowers the nation to chart a path of economic growth and energy independence.