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CASE STUDY # 148

BHARAT PETROLEUM CORPORATION LIMITED

2G 1G Bio Ethanol Refinery Project

Abstract

India's transition towards cleaner energy systems requires solutions that simultaneously address energy security, environmental protection, agricultural waste management and rural economic development. Bharat Petroleum Corporation Limited (BPCL) has responded to this challenge through the establishment of India's first integrated 2G 1G Bio-Ethanol Refinery at Bargarh, Odisha. Developed under the Pradhan Mantri JI-VAN Yojana, the project constitutes a pioneering effort to convert agricultural residues and surplus grain into renewable ethanol through an integrated biorefinery model. Spread across 70 acres with an investment of ₹1,775 crore, the refinery combines 100 KL/day of second-generation (2G) ethanol production from rice straw and 100 KL/day of first-generation (1G) ethanol production from rice grain. The project addresses the persistent challenge of stubble burning, creates a sustainable biomass economy, supports India's Ethanol Blending Programme (EBP) and contributes to national decarbonisation goals. Through innovative technology integration, a strong biomass supply chain, Zero Liquid Discharge (ZLD) systems and circular economy practices, the refinery establishes a replicable model for advanced biofuels in India.

Introduction

India generates enormous quantities of agricultural residues annually, much of which is either underutilised or burnt in fields, contributing significantly to air contamination and greenhouse gas emissions. Simultaneously, the country faces rising energy demand, reliance on imported fossil fuels and the need to meet ambitious ethanol blending targets under the National Biofuel Policy.

BPCL conceived the Bargarh Integrated 2G–1G Bio-Ethanol Refinery as a strategic intervention that could simultaneously address environmental, economic and energy-related concerns. Located in Baulsingha Village, Odisha's Bargarh district, the project adopts advanced second-generation ethanol technology using rice straw, with conventional first-generation ethanol production using broken and surplus rice grains. This merging strengthens operational flexibility, ensures year-round utilisation and improves financial viability compared with standalone 2G facilities.

The project encountered significant challenges during implementation, including disruptions from the COVID-19 pandemic, supply chain limitations and the need to redesign its architecture. BPCL responded by transitioning from a Lump Sum Turnkey (LSTK) model to an Engineering, Procurement, Construction and Management (EPCM) model, enabling greater control and flexibility. Mechanical completion was achieved in March 2025, followed by commissioning of the 1G plant on 6 October 2025 and the 2G plant on 19 March 2026. The result is a first-of-its-kind integrated biorefinery that converts agricultural waste into clean fuel while creating new opportunities for farmers, rural entrepreneurs and local communities.

The Problem Statement

India's agricultural economy produces vast quantities of crop residues every year. In many regions, particularly paddy-growing areas, farmers often resort to stubble burning as the most economical way to clear fields for subsequent cultivation. While expedient, this practice contributes to severe air pollution, greenhouse gas emissions, soil degradation and adverse public health outcomes. The challenge has persisted despite multiple policy interventions because economically viable alternatives for residue utilisation have remained limited.

At the same time, large volumes of biomass resources remain underutilised although they have potential as renewable feedstock for biofuel production. This underutilisation represents a lost opportunity for both environmental and ecological improvement and rural income generation. Farmers often receive little or no economic value from crop residues, while the nation continues to rely heavily on imported fossil fuels.

India's Ethanol Blending Programme has emerged as a critical pillar of national energy policy. However, achieving ambitious blending targets calls for substantial increases in domestic ethanol production. Reliance solely on conventional feedstocks poses limitations on food security, feedstock availability and sustainability. Consequently, advanced second-generation biofuels derived from agricultural residues have grown progressively significant.

Yet, 2G ethanol technologies face their own challenges. High capital costs, technological complexity, feedstock variability, enzyme performance uncertainties and commercial-scale operational risks often affect financial viability. Standalone 2G facilities may also struggle with seasonal feedstock availability and inconsistent utilisation rates. These problems require innovative models that combine technological improvement with operational and economic sustainability.

The need, therefore, was for an integrated solution that could address stubble burning, generate farmer income, strengthen energy security, improve environmental outcomes and demonstrate the commercial viability of advanced biofuels within a scalable and sustainable framework.

Strategic Vision

BPCL's vision was to create a first-of-its-kind integrated biorefinery that would serve as a national yardstick for sustainable fuel production and circular economy methods. The project sought to demonstrate that agricultural residues could be transformed from an environmental liability into a valuable economic resource while simultaneously contributing to India's clean energy transition.

The strategic objective extended beyond ethanol production. BPCL aimed to establish a comprehensive ecosystem encompassing biomass aggregation, farmer participation, technological innovation, circular resource utilisation and rural economic development. By integrating 1G and 2G technologies within a single facility, the organisation sought to overcome the financial and operational limitations of standalone advanced biofuel plants while guaranteeing year-round plant utilisation. The long-term vision was to create a scalable model that could be replicated across other agricultural regions of India, supporting the nation's E20 ambitions, Net Zero 2070 commitments and broader energy security goals.

Solutions Stack

The Bargarh Bio-Ethanol Refinery was developed as an integrated technological and operational ecosystem designed to maximise resource utilisation and sustainability.

The facility combines 100 KL/day of 2G ethanol production and 100 KL/day of 1G ethanol production within a single integrated complex. The 2G plant utilises approximately 480 tonnes of rice straw per day, producing 100 KL of ethanol at a yield of approximately 16.5 percent on a weight basis. The 1G facility processes approximately 230 tonnes of broken or surplus rice grain per day, generating 100 KL of ethanol at a yield of approximately 34.5 percent . This dual-feedstock approach secures functional flexibility and stable production throughout the year.

The second-generation process employs advanced technologies, including enzymatic hydrolysis, co-fermentation, distillation and dehydration. Rice straw undergoes wet washing, milling, pre-treatment and hydrolysis before fermentation and ethanol recovery. By-products, including lignin, technical alcohol, fusel oil, raw carbon dioxide, ash, mud and sludge, are systematically recovered and utilised within the broader circular economy framework.

The first-generation process involves grain storage, pre-cleaning, milling, liquefaction, fermentation, distillation and dehydration. Valuable by-products such as Distillers Dried Grains with Solubles (DDGS), technical alcohol, fusel oil and carbon dioxide contribute additional economic value while enhancing resource efficiency.

A defining feature of the project is its emphasis on circular economy principles. Lignin-rich residues generated during 2G processing are utilised for steam generation, reducing dependence on fossil fuels. Carbon dioxide generated during fermentation is recovered and commercialised through a dedicated CO_2 liquefaction facility implemented under a Build-Own-Operate-Transfer (BOOT) model. The facility is designed to recover approximately 50,000 tonnes of CO_2 annually, transforming emissions into a valuable commercial product.

Sustainable environmental management has been integrated throughout the project design. The refinery operates under a Zero Liquid Discharge (ZLD) philosophy. Environmental monitoring is supported through Continuous Ambient Air Quality Monitoring Systems (CAAQMS), Continuous Effluent Quality Monitoring Systems (CEQMS) and Continuous Emission Monitoring Systems (CEMS). More than 10,000 trees have been planted around the facility as part of a comprehensive green belt development programme.

An equally important component of the solution is the biomass supply chain. The refinery requires approximately 850 tonnes of rice straw per day, sourced from nearly 100,000 acres per season.

BPCL developed a Hub-and-Spoke supply chain model involving biomass supply chain entities, Farmer Producer Organisations (FPOs), local entrepreneurs, women's self-help groups and individual farmers. Biomass collection centers, storage depots, baling infrastructure and transportation systems were established to ensure consistent feedstock availability while creating new income opportunities for rural communities. Approximately 200,000 acres of rice fields are baled annually to support plant operations.

Outcomes

The most important achievement is the successful commissioning of India's first integrated 2G 1G bio-refinery, demonstrating the commercial-scale viability of advanced biofuel technologies. The project establishes a proof-of-concept for integrating conventional and advanced ethanol production within a single operational environment. The environmental benefits are substantial. The facility contributes to greenhouse gas reductions estimated at 60-70 percent compared with conventional fuels. By utilising agricultural residues that would otherwise be burnt, the project directly addresses air pollution associated with stubble burning. Recovery of approximately 50,000 tonnes of CO_2 annually, extensive water reuse exceeding 85 percent and Zero Liquid Discharge operations further strengthen environmental performance.

The project has generated meaningful socio-economic benefits. During construction, it created employment for more than 1,800 workers daily. Operationally, the refinery and associated logistics ecosystem support approximately 725 jobs, of which nearly 85 percent are local employments. The biomass supply chain is expected to generate indirect employment opportunities for around 1,200 rural individuals. Additionally, the project has fostered entrepreneurship among approximately 250 local entrepreneurs, farmers and women's self-help groups.

Farmer livelihoods have improved through the creation of an organised market for agricultural residues. Rice straw, previously treated largely as waste, has become a source of supplementary income. The biomass procurement ecosystem strengthens existing institutions such as FPOs, Primary Agricultural Credit Societies (PACS), farmer groups and self-help groups while promoting rural economic activity.

The project also contributes significantly to national energy security. By producing 200 KL/day of ethanol through integrated operations, the refinery strengthens domestic ethanol availability for the Ethanol Blending Programme.

Highlights

- Bharat Petroleum Corporation Limited (BPCL) established India's first integrated 2G 1G Bio-Ethanol Refinery at Bargarh, Odisha, as a model for renewable fuel production and rural economic development.
- Built with an investment of ₹1,775 crore, the refinery produces 200 KL/day of ethanol: 100 KL/day from rice straw (2G ethanol) and 100 KL/day from surplus rice grain (1G ethanol).
- The project addresses stubble burning by utilising approximately 850 tonnes of rice straw daily, turning agricultural residue into clean fuel while supporting a more organized biomass economy.
- The facility incorporates advanced enzymatic hydrolysis, co-fermentation, carbon recovery, and circular-economy practices, including the recovery of 50,000 tonnes of CO2 annually and the utilisation of lignin residues for energy generation.
- Operating under a Zero Liquid Discharge (ZLD) framework, the refinery achieves over 85 percent water reuse and supports environmental monitoring and green-belt development.

Conclusion

The BPCL Integrated 2G 1G Bio-Ethanol Refinery at Bargarh represents a landmark achievement in India's clean energy transition. By integrating advanced biofuel technology with circular economy principles, the project demonstrates how environmental challenges can be transformed into economic opportunities. Agricultural residues that once contributed to pollution now serve as valuable feedstock for renewable fuel production, creating benefits for farmers, rural communities, industry and the nation.

With an investment of ₹1,775 crore, a combined production capacity of 200 KL/day, annual recovery of 50,000 tonnes of CO_2, water conservation exceeding 85 percent and a biomass ecosystem spanning 200,000 acres of paddy fields annually, the project establishes a yardstick for sustainable development in India. Its success demonstrates the viability of integrated 2G 1G biofuel systems and provides a replicable blueprint for future biorefineries nationwide.

As India advances toward E20 blending targets, Net Zero commitments and a circular low-carbon economy, the Bargarh Bio-Ethanol Refinery stands as an example of how innovation, sustainability, inclusion and integration can join forces to create national value.

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