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Ethanol Blending in Rice (*Oryzae sativa* L.)

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Introduction:

The global demand for renewable energy has accelerated the exploration of bioethanol as a sustainable alternative to fossil fuels. Ethanol blending in transport fuels reduces greenhouse gas emissions, enhances energy security, and supports climate mitigation goals. Traditionally, sugarcane and maize have been the dominant feedstocks, but rice particularly surplus grains, broken rice, and rice straw has emerged as a promising option due to its abundance in Asia (Awasthi *et al.*, 2020). Rice straw, a major agricultural residue, contains a complex lignocellulosic matrix suitable for bioethanol production. Pretreatment methods such as acid or alkaline hydrolysis and steam explosion improve cellulose accessibility, followed by enzymatic hydrolysis using cellulases and amylases to release fermentable sugars. Fermentation with *Saccharomyces cerevisiae* or engineered yeasts then converts these sugars into ethanol under controlled anaerobic conditions (Soleymani *et al.*, 2021). Broken rice, with its high starch content, is particularly efficient for hydrolysis, yielding glucose that can be rapidly fermented (Verma *et al.*, 2021).

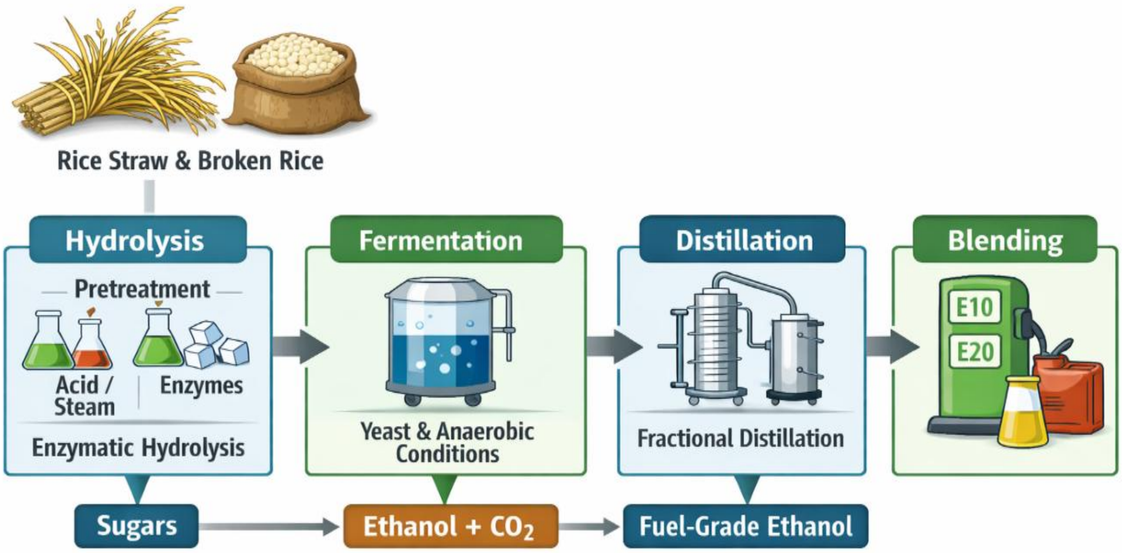
Economically, rice-based ethanol offers dual benefits. It reduces environmental pollution by utilizing agricultural residues that would otherwise be burned, while simultaneously providing farmers with additional income streams. This supports rural development and creates new agro-industrial opportunities. Environmentally, rice ethanol contributes to lowering greenhouse gas emissions, aligning with both European Union and Indian biofuel targets (Morales *et al.*, 2015).

India's National Biofuel Policy and the ambitious E20 blending target by 2025–26 emphasize diversification of feedstocks beyond sugarcane, positioning rice residues as a strategic resource (Okolie *et al.*, 2021). Thus, ethanol blending in rice represents a nexus of agricultural sustainability, energy security, and rural development. However, challenges related to food security, supply chain logistics, and technological costs must be addressed to ensure balanced and sustainable implementation.

1. **Rice as Feedstock:**

A. **Raw Material Potential**

- **Rice grains**: Rich in starch, easily hydrolyzed into fermentable sugars.
- **Rice husk & straw**: Lignocellulosic biomass with cellulose (34–47%), hemicellulose (19–27%), and lignin (5–24%) content, making them suitable for second-generation bioethanol.



- **Availability**: Global rice production exceeds 700 million tonnes annually, ensuring abundant supply for industrial use.

B. **Conversion Efficiency**

- **Enzymatic hydrolysis**: Advances in pretreatment and enzyme technology have boosted sugar yields from rice straw.
- **Bioethanol yield**: Studies report ethanol yields of **350–400 litre per tonne of rice grain**, while rice straw conversion efficiency depends on pretreatment methods (acid/alkali).

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- **Challenges**: High lignin content reduces hydrolysis efficiency; pretreatment requires significant energy input.
- **Sustainability**: Using non-edible fractions (husk, straw) avoids competition with food security.

2. **Technological Processes**

I). Hydrolysis

Breaks down rice straw and starch into fermentable sugars.

- **Pretreatment**: Acid/alkali hydrolysis or steam explosion to disrupt lignocellulose.
- **Enzymatic hydrolysis**: Cellulase and amylase convert cellulose and starch into glucose.
- Broken rice is easier to hydrolyse due to high starch content.

II). Fermentation

Biological Conversion

Microorganisms convert sugars into ethanol under controlled conditions.

- Use **Saccharomyces cerevisiae** or engineered yeasts.
- Maintain anaerobic environment with optimal pH and temperature.
- Produces ethanol and CO_2 as primary outputs.

III). Distillation

Purification

Separates ethanol from fermentation broth to achieve fuel-grade purity.

- Employ fractional distillation to isolate ethanol.
- Remove water and impurities for >99% purity.
- Final product blended with petrol (E10, E20).

3. **Economic Aspects**

Ethanol blending from rice offers significant economic potential for both farmers and the national energy sector. The process transforms agricultural residues and surplus grains into a renewable fuel, creating a **circular economy** that benefits rural communities and reduces import dependency.

a. Production Costs

- The major cost components include **pretreatment**, **enzymatic hydrolysis**, and **distillation**.
- Enzyme procurement and energy consumption during distillation are the most expensive stages.

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- Technological advancements like improved enzyme efficiency and integrated biorefineries are gradually lowering these costs.

b. Farmer Benefits

- Farmers can sell **broken rice, surplus grains, and rice straw**, which otherwise have low market value.
- This provides **additional income streams** and reduces residue burning, improving soil health and air quality.
- Contract farming and decentralized bioethanol units near rice-producing regions enhance local employment and rural development.

4. Government Subsidies

- India's **National Biofuel Policy (2018)** and subsequent updates offer **capital subsidies**, **interest subvention**, and **tax incentives** for ethanol plants using non-sugar feedstocks like rice.
- The **Public Sector Oil Marketing Companies (OMCs)** purchase ethanol at fixed remunerative prices, ensuring market stability.
- These incentives encourage private investment and help achieve the **E20 blending target by 2025–26**.

5.Environmental Impact

Ethanol blending from rice contributes significantly to **environmental sustainability** by reducing emissions, utilizing agricultural residues, and promoting cleaner energy alternatives.

a. Emission Reduction

- Ethanol is an oxygenated fuel that ensures **more complete combustion**, lowering carbon monoxide (CO), hydrocarbons (HC), and particulate matter emissions.
- Replacing petrol with **E10 or E20 blends** can reduce greenhouse gas emissions by up to **35–50%**, depending on feedstock and process efficiency.
- Using rice straw for ethanol prevents **open-field burning**, a major source of air pollution and smog in northern India.

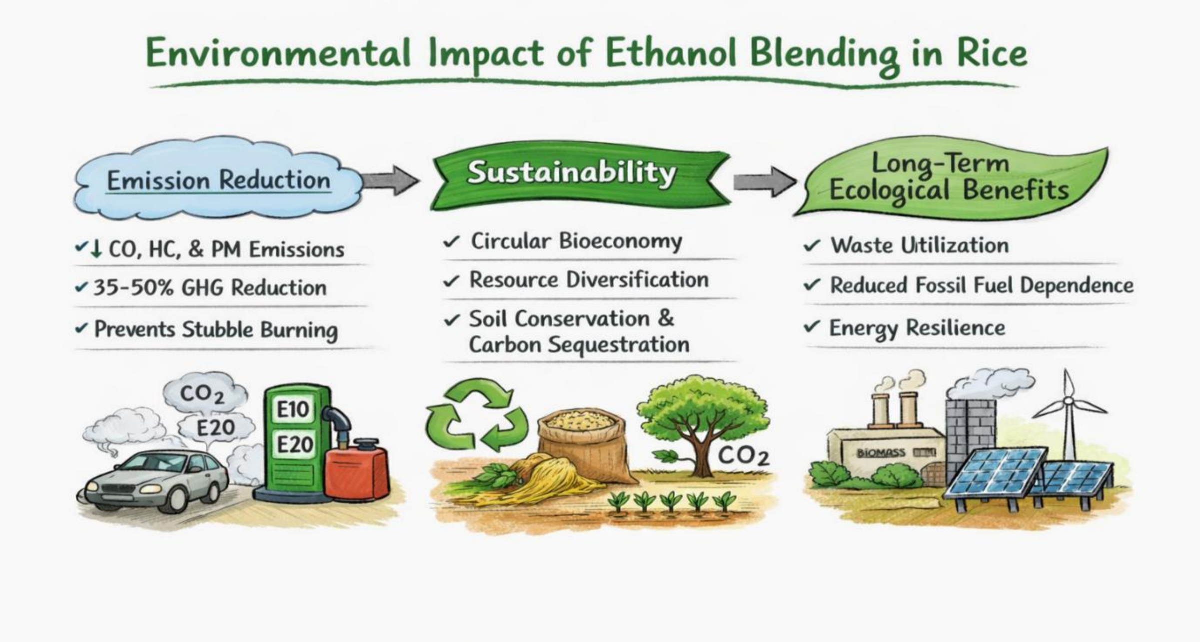
b. Sustainability

- Rice-based ethanol supports a **circular bioeconomy**, converting waste biomass into renewable energy.
- It reduces pressure on food-grade crops like sugarcane and maize, ensuring **resource diversification**.

- The process promotes **soil conservation** by discouraging residue burning and encourages **carbon sequestration** through sustainable agricultural practices.
- Lifecycle analyses show that bioethanol from rice residues has a **lower carbon footprint** compared to fossil fuels, aligning with India's **Net Zero 2070** target.

c. Long-Term Ecological Benefits

- Encourages **rural waste management** and **biomass valorization**.
- Reduces dependency on non-renewable resources.
- Enhances **energy resilience** while maintaining ecological balance.



6. Policy Framework for Ethanol Blending in Rice

Ethanol blending in rice operates within a **national and global policy framework** that promotes renewable energy, agricultural sustainability, and emission reduction.

a. National Initiatives

- **National Biofuel Policy (2018)**: Encourages ethanol production from non-food feedstocks like rice, maize, and agricultural residues.
- **Ethanol Blending Programme (EBP)**: Targets **E20 blending by 2025–26**, aiming to reduce crude oil imports and carbon emissions.
- **Food Corporation of India (FCI)**: Supplies surplus rice for ethanol production under government approval.
- **Financial Incentives**: Includes interest subvention, capital subsidies, and assured procurement by **Oil Marketing Companies (OMCs)**.
- **State-Level Support**: States like Uttar Pradesh and Bihar promote rice-based ethanol plants through local bioenergy missions.

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b. Global Initiatives

- **Brazil's Ethanol Programme**: Pioneer in sugarcane-based ethanol, achieving up to **E27 blending**.
- **United States Renewable Fuel Standard (RFS)**: Mandates blending of bioethanol from corn and cellulosic biomass.
- **European Union Biofuel Directive**: Promotes advanced biofuels from agricultural residues, aligning with **carbon neutrality goals**.
- **International Collaboration**: India partners with countries like Brazil and the U.S. for technology transfer and sustainable biofuel development.

7. Challenges

Ethanol blending from rice faces two major challenges: **food security** and **supply chain issues**.

- **Food Security**: Rice is a staple food for millions, and diverting it toward fuel production risks shortages or price inflation. Ensuring only surplus rice and broken grains are used is critical to avoid undermining nutritional security.
- **Supply Chain Issues**: Collecting rice straw is logistically complex due to scattered fields and seasonal availability. Storage, transportation, and processing infrastructure remain underdeveloped, raising costs and inefficiencies.

8. Future Prospect

Rice-based ethanol blending holds promise for India's energy security and surplus grain management. Future prospects include achieving E20 targets, expanding use of surplus rice stocks, and advancing rice straw technologies. However, sustainability requires reducing the high water footprint and shifting toward non-food feedstocks to balance food security and climate goals.

Conclusion

Ethanol blending from rice presents a **balanced pathway** toward sustainable energy and agricultural development. On one hand, it reduces emissions, utilizes surplus grains and residues, and provides farmers with new income opportunities. On the other, challenges such as **food security** and **supply chain inefficiencies** must be carefully managed to avoid negative impacts. A forward-looking approach should integrate **biotechnological innovations**, efficient logistics, and strong policy safeguards. Encouraging decentralized biorefineries, farmer participation, and government support will ensure both energy security and rural prosperity. Thus, rice-based ethanol can become a cornerstone of India's clean energy transition while maintaining ecological and social balance.

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