Stubble Burning and Sustainable Management: A Detailed Report on an End-to-End Packaging Production Pipeline

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March 28, 2025

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1. Introduction

Burning of stubble—the burning of crop residues following the harvesting of grains like paddy and wheat—is a widespread activity in northern India. While the practice facilitates speedy field clearing cost-effectively, it is a significant source of air pollution, land degradation, and public health hazards.

In regions like Punjab, the short gap between paddy harvest and the sowing of wheat compels farmers to burn stubble, thereby perpetuating long-term ecological damage.

The report presents:

1. **A thorough discussion of stubble burning:** Covering seasonality, causes, and consequences, supported by numeric figures and charts.
2. **A comprehensive pipeline solution:** Detailing the process of converting stubble to biodegradable packaging material.
3. **Cost and financial analysis:** Providing an exhaustive breakdown through tables, charts, and morphological charts.
4. **Estimation of overall benefits:** Highlighting the total environmental, economic, and social advantages of our solution.

2. Stubble Burning: Overview, Causes, Effects, and Morphological Chart

Stubble burning is motivation by time pressure and resource shortage. In northern India—particularly in Punjab—farmers only have 1 Month between rice harvesting and sowing wheat. This short window, together with restricted exposure to contemporary residue management technology, compels most farmers to clear stubble. While burning offers an instant solution to field-clearing, it poses serious negative impacts on the environment and public health.

2.1. Seasonal Patterns

- Duration: Burning begins in late **September** and peaks in the first fortnight of **November**.
- Peak Period: Early **November**, with daily farm fires frequently exceeding **3,000**.

2.2. Air Pollution Contribution

- Average Contribution: About **10.6%** of Delhi's $PM_{2.5}$ in late **2024**.
- Maximum Contribution: Up to **35%** on certain days in **2024**.
- Recorded High: **31%** on November 13, 2024.
- Seasonal Impact: Pollution levels exceed **10%** on **58%** of days from October 22 to November 30, 2023.

2.3. Land and Crop Data

- Total Farmland in Delhi: About **53,000 hectares** (2022).
- NCR Region: Significant agricultural lands across Haryana, Uttar Pradesh, and Rajasthan.
- Paddy in Punjab: Nearly **7 million acres** under paddy, producing **22 million tonnes** of stubble annually.

2.4. Land Division Among Farmers

- Marginal Farmers: Less than **1 hectare**.
- Small Farmers: **1–2 hectares**.
- Medium Farmers: **2–4 hectares**.
- Large Farmers: More than **4 hectares**.
- Average Land Size (small farmers in Delhi): Around **1.4 hectares** (2016).

2.5. Stubble Production

- Punjab & Haryana: About **28 million tonnes** of paddy straw annually.
- Unmanaged Stubble: Around **6.4 million tonnes**.

2.6. Current Stubble Management Status

- 54.2% reduction in stubble burning incidents from 2022 to 2023.
- In 2023, 6,391 incidents across Haryana, Punjab, and NCR.

2.7. Economic and Policy Constraints

1. **Economic Constraints**
   - *Cost-Effectiveness:* Burning is cheapest and fastest for field clearing. Alternatives like Happy Seeders cost over Rs. 2 lakh.
   - *Profit Margins:* Even with subsidies, machinery rental costs reduce already thin margins.
2. **Time Pressure**
   - The Punjab Preservation of Subsoil Water Act (2009) delays paddy sowing, leaving only 10–15 days for wheat sowing. Burning is quickest.
3. **Mechanization and Residue Volume**
   - Modern combine harvesters leave behind large residue that is difficult to remove manually.
4. **Lack of Viable Alternatives**
   - Farmers lack awareness of mulching or bio-decomposition.
   - Storage facilities are insufficient for large-scale stubble usage in bioenergy or composting.
5. **Systemic and Policy Challenges**
   - Government subsidies often favor water-intensive rice-wheat systems.
   - Enforcement of burning bans is weak due to political sensitivities.

2.8. Morphological Chart

The morphological chart below outlines various methods for each production step. Our selected options balance cost, efficiency, and quality.

Table 1: Morphological Chart for Composite Board Production

Function	Alt 1	Alt 2	Alt 3	Selected
Raw Material	Rice Straw	Wheat Straw	Bamboo	Rice Straw
Binding Agent	Molasses	Synthetic Resin	Lignin	Synthetic Resin
Fillers	Sawdust	Bagasse	Coconut Coir	Sawdust
Material Prep	Manual Shredding	Automated Shredding	Purchase	Automated Shredding
Mixing	Manual Mixing	Mechanical Mixer	Continuous Mixer	Mechanical Mixer
Forming	Hand Molding	Hydraulic Press	Extrusion	Hydraulic Press
Drying	Sun Drying	Hot Air Oven	Microwave Drying	Hot Air Oven
Cutting	Manual Saw	Laser Cutting	CNC Machine	Manual Saw
Finishing	Sanding	Laminating	UV Coating	Sanding
Final Use	Furniture Boards	Packaging	Acoustic Panels	Packaging
Waste Handling	Open Burning	Composting	Briquetting	Briquetting
Labor	Fully Manual	Semi-Automated	Fully Automated	Semi-Automated

3. Our End-to-End Pipeline Solution

Our proposed solution converts agricultural stubble into eco-friendly, biodegradable packaging materials via an integrated process. Note that for both stubble cutting and transportation, only one machine each is used.

3.1. Pipeline Process

1. **Stubble Removal and Collection:** A single stubble remover machine is used to cut and collect stubble from the fields. This machine is attached to a high-power tractor with a trolley for instant collection and efficient performance. The complete system is offered on a rental basis, alleviating the financial burden on farmers who would otherwise need to invest in expensive machinery. Farmer will get paid for the amount of stubble they give (Rs. 1900/ton as per government rates).Our solution proposes using the stubble removal and collection machine developed by IIT Ropar in 2019, known for its cost-effectiveness and improved work quality.

2. **Processing:** The stubble is processed into fine powder using a chopper/shredder, pulverizer (hammer mill), and vibratory sieve separator. Sieving can be made manual to decrease the investment cost of sieve separator machine. Also a shredder cum pulverizer can be used to further reduce the cost.

3. **Mixing:** The stubble powder is blended with sawdust, slurry, and synthetic resin to form a homogeneous paste.

4. **Molding:** The paste is molded into packaging sheets, boxes, or trays using molding and shaping units.

5. **Drying and Finishing:** The molded products are dried (using industrial dryers or sun drying) and finished with trimming, cutting, and optional surface coating. In rural areas sun drying will

Figure 1: IIT Ropar's stubble-clearing machine with trolley and tractor in action, Source : Hindustan Times

be preferred because of presence of ample sunlight and for keeping the whole pipeline cost efficient.

6. **Quality Control and Packaging:** Final products are tested for strength and moisture before being packaged for sale.

3.2. Pipeline Overview

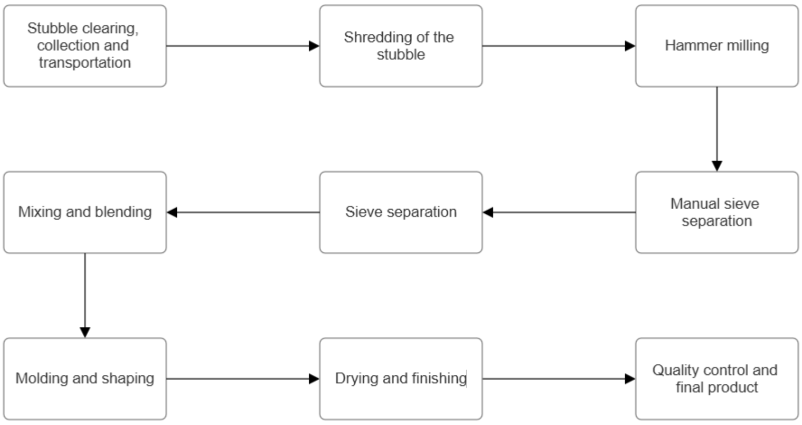

Figure 2: Production Pipeline Flowchart

3.3. Discussion on End Product and Material Properties

mix	Sample	Apparent density (g/cc)	Flexural strength (N/mm2)	Thickness swelling (mm)	Moisture content (%)
Mix1	Rice straw +slurry	0.166	0.056	2	54
Mix2	Rice straw + molasses +saw dust + synthetic resin	0.46	0.096	0	22.2
Mix3	Rice straw + saw dust + slurry	0.26	0.158	0	31.8
Mix4	Rice straw + slurry + synthetic resin	0.13	0.10	1.5	31.5
1	Thermocol	0.0087	0.088	0	0.5% for every 7 days

Figure 3: Proof-of-Concept Mixtures for Packaging Boards, Source : Link

Observations from the Above Image:

- Certain mixes with resin and sawdust show higher flexural strength and lower moisture content.
- Adding slurry or molasses can alter density and swelling properties.
- Thermocol is extremely light but not biodegradable, while stubble-based boards offer an eco-friendly alternative.

These results demonstrate that rice straw-based boards, when combined with suitable additives, can provide mechanical strength and moisture resistance required for packaging applications.

4. Cost and Financial Analysis

4.1. Machinery Requirement and Cost Estimate

Below is a detailed machinery requirement and cost estimate for setting up the stubble-based packaging material production pipeline in India. These prices are approximate and based on market trends.

4.1.1. 1. Stubble Collection and Transport

Table 2: Machinery for Stubble Collection and Transport

Machine	**Purpose**	**Approx. Cost (INR)**
Stubble Remover Machine	Cuts and collects stubble from fields	5,00,000/unit
Trolley Attachment	Collects and stores stubble for transport	1,50,000/unit
High-Power Tractor	Pulls the stubble remover and trolley	12,00,000/unit

Total for Collection: Rs. 18,50,000 per setup

4.1.2. 2. Stubble Processing Unit

Table 3: Machinery for Stubble Processing

Machine	**Purpose**	**Approx. Cost (INR)**
Chopper/Shredder Machine	Cuts stubble into small pieces (2–3 cm)	3,00,000/unit
Hammer Mill / Pulverizer	Grinds stubble into fine powder (100–500 microns)	6,00,000/unit
Vibratory Sieve Separator (Optional)	Filters oversized particles	2,00,000/unit

Total for Processing: Rs. 11,00,000 per setup

4.1.3. 3. Mixing and Blending Machinery

Table 4: Machinery for Mixing and Blending

Machine	Purpose	Approx. Cost (INR)
Batch Mixer / Ribbon Blender	Mixes stubble powder with sawdust & slurry	5,00,000/unit
Resin Binder Sprayer	Sprays synthetic resin uniformly	2,50,000/unit
High-Speed Kneader (Optional)	Helps achieve a uniform paste	3,50,000/unit

Total for Mixing: Rs. 7,50,000 – 11,00,000

4.1.4. 4. Molding and Shaping Unit

Table 5: Machinery for Molding and Shaping

Machine	Purpose	Approx. Cost (INR)
Hydraulic Compression Molding Machine	Presses material into mold shape	12,00,000/unit
Extruder (For Sheet Production)	Produces continuous sheets for cutting	8,00,000/unit

Total for Molding: Rs. 12,00,000 – 20,00,000

4.1.5. 5. Drying and Finishing Unit

Table 6: Machinery for Drying and Finishing

Machine	Purpose	Approx. Cost (INR)
Industrial Dryer / Hot Air Oven	Removes moisture from the final product	6,00,000/unit
Edge Trimming & Cutting Machine	Cuts packaging sheets into uniform sizes	3,00,000/unit
Surface Coating Unit (Optional)	Adds waterproof or protective layers	2,50,000/unit

Total for Drying & Finishing: Rs. 9,00,000 – 11,50,000

4.1.6. 6. Quality Control and Packaging

Table 7: Machinery for Quality Control

Machine	Purpose	Approx. Cost (INR)
Flexural Strength Tester	Tests packaging strength	2,00,000/unit
Moisture Analyzer	Checks moisture content	1,50,000/unit

Total for Quality Control: Rs. 3,50,000

4.2. Overall Investment Summary (Machinery)

Above cost analysis presents an idea where we automate the complete process. Following is the final cost estimation considering complete automated and machinated pipeline.

Table 8: Grand Total for Machinery Setup

Section	Cost Estimate (INR)
Stubble Collection	18,50,000
Processing Unit	11,00,000
Mixing & Blending	7,50,000 – 11,00,000
Molding & Shaping	12,00,000 – 20,00,000
Drying & Finishing	9,00,000 – 11,50,000
Quality Control	3,50,000
Grand Total	**61,50,000 – 75,50,000**

However to reduce the cost we can remove some machinery and make it a manual process. Making these steps manual would not be a big issue since in the villages we can find easy labour and also not much skilling would be required. If skilling is required then that can happen during the job also. Following is the reduced cost removing some extra machinery.

Table 9: Reduced Investment After Cost-Reduction Measures

Section	Reduced Cost (INR)	Savings (INR)
Stubble Collection	17,50,000	1,00,000
Processing Unit	7,50,000	3,50,000
Mixing & Blending	1,50,000 – 5,00,000	Approx. 6,00,000
Molding & Shaping	–	8,00,000
Drying & Finishing	4,00,000 – 12,00,000	Up to 11,50,000
Quality Control	2,50,000	1,00,000
Final Total	33,50,000 – 45,00,000	28,00,000 – 30,50,000

4.3. Cost per Unit and Profitability (Summary)

As discussed, the production cost per 8ft x 4ft board is about Rs. 330, with a selling price of Rs. 450–550, resulting in a profit margin of 26.7%–40%.

5. Ground-Level Implementation

To ensure the successful execution of the composite packaging board production, a well-defined ground-level approach is necessary:

5.1. Farmer Participation and Stubble Collection

- Establish stubble collection networks with farmer cooperatives.
- Provide rental-based stubble collection machinery to minimize investment costs.
- Introduce financial incentives like government subsidies and buyback programs.

5.2. Decentralized Processing Units

- Set up small-scale village-level processing units to reduce logistical expenses.
- Deploy mobile processing units for on-site stubble processing.

5.3. Sustainable Manufacturing and Distribution

- Use renewable energy sources like solar-powered operations.
- Partner with local artisans and manufacturers for packaging and finishing.
- Implement rigorous quality control measures to ensure consistency.

6. Partnering with Brands for Product Adoption

To enhance market penetration, collaborations with businesses and institutions are key:

6.1. Eco-Friendly Packaging Companies

- Engage with brands focusing on sustainability, such as organic food and cosmetics companies.
- Approach firms adhering to Environmental, Social, and Governance (ESG) commitments.

6.2. Government and Institutional Buyers

- Collaborate with municipal corporations and government agencies.
- Propose the adoption of stubble-based boards in public infrastructure and housing projects.

6.3. Retail and E-commerce Companies

- Work with supermarkets and FMCG brands to replace synthetic packaging.
- Partner with e-commerce firms for sustainable transit packaging.

7. Expanding to Different Parts of the Country

To scale the production model nationwide, targeting key agricultural and industrial hubs is crucial:

7.1. Targeting High Stubble-Generation Regions

- Implement production facilities in Punjab, Haryana, Uttar Pradesh, and Bihar.
- Expand to Maharashtra, Madhya Pradesh, and Karnataka for greater impact.

7.2. Regional Customization and Awareness Campaigns

- Adapt products to suit regional packaging needs, such as moisture-resistant variants.
- Conduct educational programs for farmers and entrepreneurs on the benefits of stubble-based packaging.

7.3. Developing Export Potential

- Align production with international biodegradable packaging standards.
- Target European and North American markets facing stringent plastic waste regulations.

8. New Techniques for an Expanded Product Line-Up

To enhance product offerings, advanced manufacturing techniques must be adopted:

8.1. Advanced Molding Techniques for Complex Shapes

- Introduce vacuum forming and CNC cutting for intricate designs.
- Develop 3D-molded packaging for food containers, electronics, and medical supplies.

8.2. Integration of Additional Natural Fibers

- Improve strength by adding bamboo fiber, coconut coir, or hemp reinforcements.
- Experiment with hybrid materials for waterproof and heat-resistant packaging.

8.3. Developing Structural and Industrial Applications

- Manufacture modular furniture, acoustic panels, and construction boards.
- Explore applications in the automobile and aviation industries for lightweight composite materials.

By adopting these strategies, the composite packaging board initiative can evolve into a scalable and sustainable industry, reducing agricultural waste and contributing to the circular economy.

9. Conclusion and Impact

This report captures a holistic solution to transform stubble from farming into sustainable, biodegradeable packing materials. This holistic approach has addressed the burning issues of stubble and enab-les sustainable economic growth.

Environmental Effect: Redirecting stubble from burning will decrease PM2.5 concentrations, greenhouse emissions, and prevent soil nutrients' loss.

Economic Effect: Through transforming stubble into higher-value packing items, the solution generates new farm incomes, conserves waste manage-ment expense, and supports the development of eco-friendly industries. With a cost of production around Rs. 330 per board and selling prices ranging from Rs. 450 to Rs. 550, profit levels can vary between 26.7% to 40%. The break-even is achieved around 17,650 boards and with a capacity of 1,000 boards per month, the payback period stands around 2 years.

Social Impact: Better air quality results in improved public health, reduced healthcare costs, overall socioeconomic improvement in rural society.

Our Pipeline: The entire process involves:

1. Collecting stubble using a stubble remover machine.

2. Transporting stubble with a high-power tractor equipped with a trolley attachment.
3. Processing the stubble into fine powder.
4. Mixing the powder with sawdust, slurry, and resin to form a paste.
5. Molding the paste into packaging products.
6. Drying and finishing the products.
7. Conducting quality control and packaging the final product.

Overall, this integrated approach mitigates the environmental damage caused by stubble burning while creating a sustainable, economically viable model for eco-friendly packaging production.

10. Uniqueness and Patentability

Our solution stands out due to its innovative approach to transforming agricultural stubble into biodegr-capable, eco-friendly packing materials through a combined and sustainable supply pipeline. Its uniqueness is derived from the fact that it addresses three extremely significant problems simultaneously: removing environmental pollution caused by burning of stubble, offering an economical substitute to single- utilize plastics, and awarding economic empowerment to farmers by making specialist machinery accessible to them at a low cost.

10.1. Key Unique Features

1. **Integrated Pipeline Process:**
   - Integrates stubble removal, processing, molding, and finishing into a continuous process.
   - Employs a single, effective stubble removal machine designed by IIT Ropar (2019), with a trolley and high-power tractor for immediate collection.
   - Provides a rental model, reducing the cost burden on farmers.
2. **Eco-Friendly and Sustainable:**
   - Converts agricultural waste into biodegradable and recyclable packaging material.
   - Fosters green practices through prevention of air pollution caused by burning of stubbles.
3. **Cost-Efficient and Scalable:**
   - Offers a cost-effective solution as an alternative to plastic packaging.
   - Highly scalable for use at both small-scale and industrial-scale production levels.

10.2. Patentability

The distinctiveness of our solution is epitomized by the convergence of new machinery usage and material processing methods. The following factors drive its patentability:

1. **Novel Integration:**
   - The combination of a stubble remover with a powerful tractor and trolley for immediate collection is an innovative method that enhances efficiency.
2. **Material Composition:**
   - The composition of the paste from stubble powder, sawdust, slurry, and synthetic resin is optimized for strength, durability, and biodegradability.

3. **End-to-End Solution:**
   - From raw stubble harvesting to completed packaging products, the pipeline provides a comprehensive solution with negligible environmental costs.
4. **Flexibility and Customization:**
   - The molding units have the capability to produce multiple packaging products including sheets, trays, and boxes according to market demands.

The coalescence of eco-friendliness, cost-effectiveness, and innovative engineering provides our so-solution a strong potential for patentability. With the potential to address a significant environmental problem with a scalable and market-aware product, we aim to make a lasting impact in sustainable packaging and agricultural waste control.

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