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From Farm Waste to Farm Wealth: Sustainable Solutions for Agricultural Residues

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Every harvest leaves behind not only the crop but also large quantities of residues, including straw, husks, stalks, peels, shells and manure. Open burning, dumping or abandonment has long been the usual means of disposal. India generates an estimated 500 to 620 million tonnes of agricultural waste each year (Priya *et al*., 2025), and global food loss and waste amounts to about 1.3 billion tonnes annually, roughly one-third of the food produced for human consumption (Capanoglu *et al*., 2022). Agricultural residues are increasingly recognised as an untapped pool of biomass that can be converted into bioenergy and bio-based products within a circular economy (Gontard *et al*., 2018). Converting farm waste into farm wealth therefore offers environmental, economic and social benefits (Priya *et al*., 2025).

Agricultural Waste: Definition and Composition

Agricultural waste or called agro-waste, refers to residues generated by agri. operations and processes. It includes crop residues such as straw, stalks, leaves and husks; animal manure and slaughterhouse waste; agro-industrial waste such as bagasse and rice husk from mills; and processing waste such as fruit and vegetable peels, seed shells and juice pulp (Sharma & Paul, 2024). Cellulose and lignin together make up 85–90% of the dry matter of agricultural residues, and the material is coarse and low in protein and fat (Sharma & Paul, 2024). Residual resources accounted for about 50% of the fresh weight of harvested crops in 2012, which indicates the scale of this resource (Gontard *et al*., 2018). The type and quantity of waste available also vary with region, crop, farming practice and climate (Priya *et al*., 2025).

Environmental and Economic Significance

If left unmanaged, agricultural and food waste harms air, water and public health. Indiscriminate burning of straw and livestock dung in rural areas has caused a range of environmental problems (Sharma & Paul, 2024), and food waste in landfills generates gases such as methane and hydrogen sulphide (Capanoglu *et al*., 2022). The contribution of food waste to greenhouse gas emissions is estimated at about 3.3 billion tonnes of carbon dioxide per year, and its global cost at approximately 1,000 billion US dollars annually (Capanoglu *et al*., 2022). The food lost or wasted each year could provide a 2,100 kcal daily diet for two billion people, while an estimated 690 million people suffered from hunger in 2019 (Capanoglu *et al*., 2022). Waste generation is also geographically uneven. Regions specialising in livestock production accumulate large manure loads, with associated odour, bacterial contamination and greenhouse gas emissions, whereas

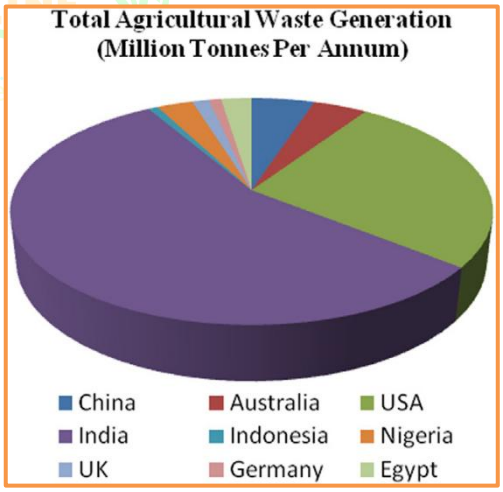


Figure 1: Agricultural Waste Generation in Selected Countries (Million Tonnes per Annum)
Note: Data from Priya *et al.* (2025, Figure 6.1).

regions devoted to crop production experience depletion of nutrients and organic matter (Gontard *et al*., 2018). Among the countries compared in Figure 1, India generates about 620 million tonnes of agricultural waste from roughly 180 million hectares of agricultural land, whereas the United States generates about 292 million tonnes from more than 410 million hectares (Priya *et al*., 2025). India therefore produces more than twice as much waste from less than half the agricultural area, which indicates considerable potential for valorisation.

Pathways for Converting Waste into Wealth

A wide range of conversion routes exists, from simple on-farm practices to advanced laboratory technologies, and the choice of route depends on the residue, the desired product and the resources available (Priya *et al*., 2025). Most routes begin with size reduction by chopping, grinding or milling, which increases the surface area accessible to enzymes, microbes and heat (Priya *et al*., 2025). Six principal pathways are summarised below.

1. **Bioenergy.** In anaerobic digestion, microbes break down manure and crop residues in the absence of oxygen to produce biogas, which typically contains 40–65% methane by volume and can be used for cooking, heating or electricity generation; the residual digestate is a nutrient-rich manure (Priya *et al*., 2025). Rice husk, straw and bagasse can be compressed into pellets or briquettes that substitute for coal and firewood (Priya *et al*., 2025). Pyrolysis, in which biomass is heated at 300–800 °C in the absence of oxygen, yields biochar, bio-oil and combustible gases (Priya *et al*., 2025).
2. **Soil amendments.** Composting and vermicomposting, in which earthworms degrade organic material, convert crop residues and dung into organic manure (Priya *et al*., 2025). Biochar can improve soil quality and increase crop yields, and banana peels have been used to produce a potassium-rich biofertiliser (Priya *et al*., 2025). Digestate from biogas plants is likewise reused as a renewable fertiliser (Gontard *et al*., 2018).
3. **Livestock feed and mushroom production.** Silage production involves chopping residues such as maize stover and wheat straw, packing them tightly under anaerobic conditions and allowing lactic acid bacteria to ferment them, which yields nutritious livestock feed that can be stored for months or even years and is particularly valuable when forage is scarce (Sharma & Paul, 2024). Rice straw is also an important substrate for cultivating button and oyster mushrooms in Asia (Sharma & Paul, 2024).
4. **Building materials.** Rice husk, owing to its heating value and silica content, is used in Portland cement, porous silicate building blocks, insulating slabs and lightweight concrete (Sharma & Paul, 2024), and paddy husk ash has been used in lightweight clay bricks (Priya *et al*., 2025). Particle boards made from coconut husk show greater resistance to termites and wood-rotting fungi, and combining coconut husk and coir fibre with Portland cement produces strong building panels (Sharma & Paul, 2024). Reeds, stalks and straw are likewise used to make low-cost housing and wall panels (Sharma & Paul, 2024).
5. **Bioplastics and green chemicals.** Cellulose from corn cobs has been used to produce bioplastics (Priya *et al*., 2025). In general, agricultural waste is pretreated, converted to monomers such as lactic acid and polymerised into polylactic acid, a widely used bioplastic suitable for films, packaging and disposable cutlery (Sharma & Paul, 2024). Microbial conversion offers further products: *Aspergillus niger* can produce citric acid from grape pomace, and *Monascus purpureus* can produce a red pigment from sugarcane bagasse (Priya *et al*., 2025). Gontard *et al*. (2018) noted that only about 3% of chemicals and 2% of polymers were bio-based, which indicates considerable scope for growth.
6. **Functional food ingredients.** Peels, stems, seeds and pomace from food processing are rich in polyphenols and other bioactive compounds with antioxidant properties (Capanoglu *et al*., 2022). Extraction techniques such as ultrasound-assisted and supercritical CO_2 extraction, together with nano-encapsulation, are used to recover these compounds and improve their stability for use in functional foods (Capanoglu *et al*., 2022). Examples include caffeine extraction from coffee husk and improved lycopene bioaccessibility in tomato pomace (Capanoglu *et al*., 2022).

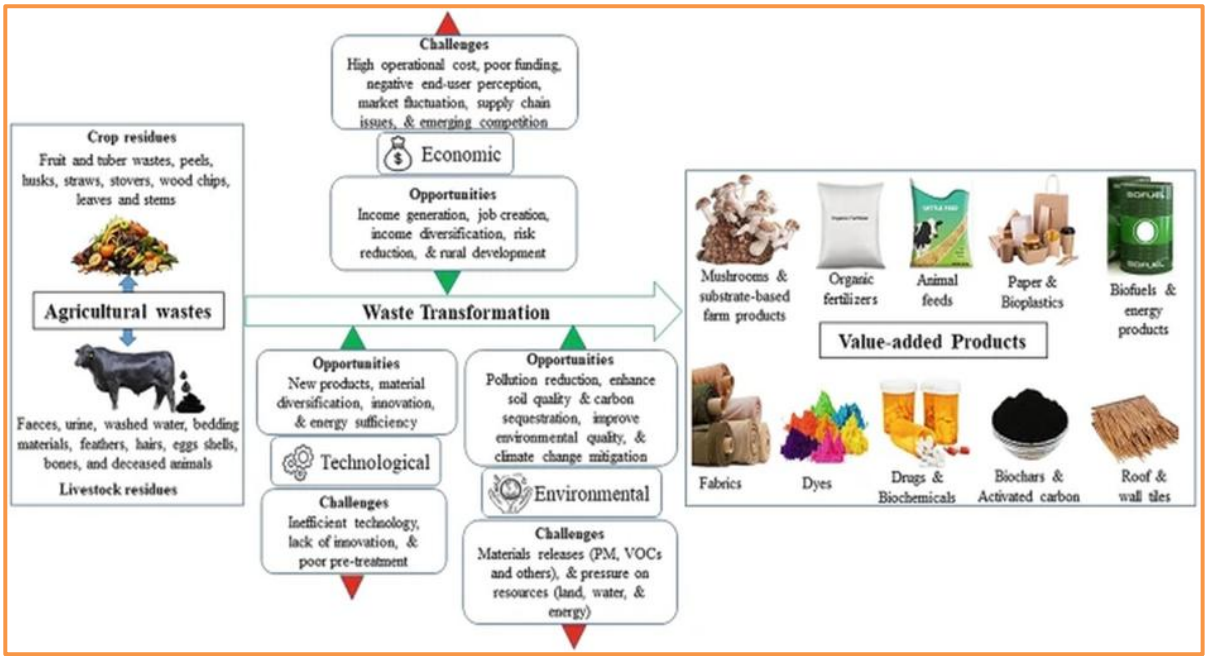


Figure 2: Transformation of Agricultural Wastes into Value-Added Products
Note: Adapted from Springer Nature (ISBN 978-3-031-91209-2).

Case Study: From Weed to Wealth in Assam

In Assam, water hyacinth (locally known as Pani Meteka) reproduces rapidly, often obstructs slow-moving streams and was long regarded as waste (Sharma & Paul, 2024). The Assam State Rural Livelihood Mission initiated an intervention in which women of self-help groups produce purses, table mats, handbags, laptop bags and yoga mats from the plant, and six of these products have been registered on the Government e-Marketplace (Sharma & Paul, 2024). The products were showcased at a home furnishings fair in Osaka, Japan, in July 2019, and a bulk order for yoga mats ahead of International Yoga Day 2019 was completed within 20 days (Sharma & Paul, 2024). The initiative is known as Weed to Wealth and illustrates how an overlooked biomass can support rural livelihoods (Sharma & Paul, 2024).

The Biorefinery Approach

Gontard *et al*. (2018) describe cascading biorefinery approaches in which agricultural residues pass through successive conversion processes that yield high-value chemicals, bio-based materials and bioenergy, with the digestate from anaerobic digestion returned to farmland as fertiliser. Anaerobic digestion is among the most mature of these technologies, although its performance varies with feedstock, geography and season (Gontard *et al*., 2018). The same review emphasises industrial ecology, in which neighbouring agricultural and industrial value chains exchange materials and knowledge on a local basis, so that the waste of one operation becomes the raw material of another (Gontard *et al*., 2018).

Barriers to Adoption

Several barriers limit adoption. Processing equipment can be costly to install and maintain, and small-scale farmers often lack access to suitable equipment and technical expertise (Priya *et al*., 2025). Anaerobic digestion is limited by low conversion yields for lignin-rich feedstocks, low economic value, and problems of feedstock supply and digestate handling and storage (Gontard *et al*., 2018). Some technologies also remain inefficient: direct combustion converts only 20–40% of the energy in biomass, and bio-oil from pyrolysis suffers from corrosion and stability problems (Priya *et al*., 2025). Overcoming these barriers requires a multidisciplinary approach that combines technology, policy, community engagement and sector collaboration (Priya *et al*., 2025).

Roles of Stakeholders

- **Farmers:** replacing open burning with composting, biogas generation or the sale of residues as raw material (Priya *et al*., 2025; Sharma & Paul, 2024).

- **Researchers and entrepreneurs:** developing cost-effective, eco-efficient cascading conversion processes and biogas plants that can adapt to local and seasonal waste streams (Gontard *et al*., 2018).
- **Policymakers:** supporting local synergies between agricultural and industrial value chains and enabling collaboration across sectors (Gontard *et al*., 2018; Priya *et al*., 2025).
- **Consumers:** reducing household food waste, which accounted for 61% of the 931 million tonnes of food waste generated in 2019 (Capanoglu *et al*., 2022).

Conclusion

Agricultural residues represent a substantial but underused resource. Pathways ranging from biogas, composting and silage to building materials, bioplastics and functional food ingredients can reduce environmental pollution, create employment and support economic development (Priya *et al*., 2025). Realising this potential requires cooperation among farmers, researchers, industry and policymakers, supported by local value-chain integration and appropriate technologies (Gontard *et al*., 2018; Priya *et al*., 2025). A change in perspective, from regarding crop residues as undesired waste to treating them as integral components of agricultural production, is essential for a circular and sustainable food system (Gontard *et al*., 2018; Sharma & Paul, 2024).

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