ISB Bharti Institute of Public Policy

Bamboo for Viksit Bharat 2047

A Roadmap for Sustainable Industrial Futures

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Executive Summary

India holds a unique and strategic position in the global bamboo economy. With nearly 30% of the world's bamboo resources and a remarkable diversity of 136 species, the country is well-equipped to emerge as a global leader in bamboo-based industrialization. The bamboo sector already supports over 8 million artisans and informal workers, playing a significant role in sustaining traditional rural economies. It now presents an unprecedented opportunity to transition into a mainstream engine of sustainable livelihoods, green employment generation, and low-carbon industrial development.

The global bamboo trade, valued at USD 71.63 billion in 2023, is projected to grow at a compound annual growth rate of 6.6%, reaching USD 92.62 billion by 2027. India is well-positioned to capture a larger share of this market. Technological innovations such as second-generation (2G) bioethanol from bamboo biomass, low-silica pulp processing for the paper industry, and pyrolysis techniques for biochar production have significantly expanded the range of industrial applications of bamboo. These include sectors such as clean energy, paper and pulp, steel manufacturing, textiles, construction, and pharmaceuticals. With appropriate policy support, bamboo can transition from being a peripheral natural resource to a core industrial input contributing to both economic competitiveness and environmental sustainability.

However, India's current integration into the global bamboo value chain remains limited. The country continues to import several million tonnes of bamboo annually to meet domestic demand, despite possessing abundant raw material. More than 80% of bamboo growing within India's forested landscapes remains unutilized. This underperformance is primarily the result of fragmented supply chains, insufficient private sector engagement, underdeveloped value addition infrastructure, and a lack of targeted policy mechanisms to integrate bamboo into national industrial priorities. These limitations have prevented the sector from contributing meaningfully to critical national goals, including employment generation, economic diversification, and climate action.

This report presents a comprehensive roadmap to reposition bamboo as a strategic resource for green industrialization and inclusive growth. The first strategic imperative is to strengthen sustainable supply chains. This requires expanding high-quality bamboo cultivation, especially of commercially valuable species such as *Bambusa tulda*, across non-forest areas including degraded lands, farmlands, and agroforestry systems. Simultaneously, it is essential to operationalize community-based and ecologically sound bamboo harvesting from forest areas. Strengthening nursery infrastructure, improving access to certified planting materials, and enhancing agricultural extension services for bamboo-based farming are vital to this effort.

The second imperative is to enable value addition and promote enterprise development across the bamboo value chain. This involves supporting small and medium enterprises (SMEs) engaged in bamboo processing through access to affordable finance, modern machinery, skilling programs, and integration with market linkages. Establishing common facility centres in high-bamboo-density regions, supported by design and technology hubs, can accelerate processing capacity and innovation. Promoting high-value bamboo products for both domestic consumption and export, combined with appropriate quality assurance and certification systems, will enhance the competitiveness of bamboo-based enterprises.

The third imperative is to mainstream bamboo into the country's broader industrial and infrastructure development policies. This includes incentivizing the use of bamboo in government procurement for housing, construction, renewable energy, and public infrastructure, and aligning sectoral mandates under national flagship schemes such as PM Gati Shakti, Make in India, the National Bio-Energy Mission, and the National Bamboo Mission. Encouraging sector-specific fiscal and non-fiscal instruments will be essential to attract private investment, create long-term demand, and stabilize supply-demand dynamics across the bamboo ecosystem.

Based on spatial analyses by the Initiative on Forest Economy at the Bharti Institute of Public Policy, Indian School of Business, the current bamboo distribution in India spans approximately 23.7 million hectares, with 54% located within forest areas. An additional 4.3 million hectares have been identified as suitable for bamboo cultivation, of which 1.8 million hectares lie on farmland. This offers a significant opportunity to expand cultivation, especially in regions dominated by small and marginal farmers, who comprise over 84% of India's agricultural holdings. Promoting bamboo on these lands—without competing with food security—can provide farmers with an additional income stream while contributing to environmental restoration.

Released on the occasion of International Earth Day, this report highlights bamboo's strategic value not merely as a natural asset, but as a vehicle for green industrial transformation, rural prosperity, and climate resilience. With coordinated action across ministries, targeted public investment, and appropriate regulatory support, bamboo can become a cornerstone of India's transition to a climate-smart, self-reliant, and inclusive economy. It offers a compelling opportunity to deliver on national development goals while simultaneously positioning India as a global leader in sustainable, resource-based industrialization.

1 BEYOND SUBSISTENCE:
BAMBOO AS A DRIVER OF ECONOMIC TRANSFORMATION

Globally, bamboo is becoming an important trading commodity due to its increasing demand in its use as raw materials for paper and pulp industry, textile industries to produce soft fabrics, and as construction materials. With advancements in processing technologies, bamboo composites are becoming equally and more durable than hardwood timber such as teak. Value-added products, such as biochar, are rapidly becoming important sources of bioenergy, and bamboo is making way into homes through ecofriendly items, such as toothbrushes, straw, and plates. The potential of bamboo as an alternative fuel to coal and diesel in steel, cement, and thermal power plants is increasing, allowing industries to adapt to this alternative and renewable energy source. The 2G technology used to break the lignocellulosic structure of bamboo to generate ethanol shows promise for its potential to develop blended petrol.

Realising the economic potential of bamboo, several countries are increasing their bamboo production. According to the Food and Agriculture Organization (FAO) Forest Assessment Report for 2020, bamboo is grown in over 132 countries over a total land area of approximately 35 million hectares, a notable increase of almost 50 % since the 1990 assessment. According to the International Network for Bamboo and Rattan (INBAR), global bamboo trade in 2023 was over 73 billion USD, with the largest importers being Europe, North America, and Asia-Pacific. Apart from the economic benefits, bamboos are helping countries achieve several of their international targets, such as the Bonn challenge on restoring degraded forests, where there is a commitment to restore over 350 million hectares globally, carbon sequestration under the Intended Nationally Determined Contribution of the Paris Agreement, achieving the Aichi targets on improving biodiversity under the UN Convention on Biological Diversity, and the UN Sustainable Development Goals.

India is endowed with substantial bamboo resources and has high potential to improve the area under bamboo. Bamboo-based industries, including handicrafts, construction, furniture, and paper production, employ over eight million people in India, making them a vital pillar of rural livelihoods and economic resilience. These industries are especially significant for forest-proximate communities, which often rely heavily on natural resources for subsistence and income. Bamboo cultivation and processing present a sustainable livelihood opportunity that aligns economic development with environmental stewardship. With its rapid growth rate, versatility, and wide range of applications, bamboo offers a renewable alternative to timber and non-renewable materials.

For local communities, especially Indigenous and marginalized groups, bamboo agroforestry not only provides a diversified income stream through harvesting, processing, and manufacturing activities but also strengthens community resilience against economic and climate shocks. The value chain, from cultivation to finished products, opens opportunities for entrepreneurship, skill development, and access to the domestic and export markets. It also reinforces cultural heritage, as the traditional knowledge and craftsmanship associated with bamboo products remain deeply rooted in many communities. Importantly, the role of people—as producers, artisans, traders, or consumers—is central to the success of bamboo-based enterprises.

Sustainably improving bamboo resources in India could achieve multiple outcomes, including (i) improving the local economy, especially of small and marginal farmers and their income; (ii) increasing the industrial use of bamboo and thereby reducing dependency on coal and diesel; (iii) value addition to bamboo help in biochar for agriculture and industries; (iv) decreasing the production costs in textile and pharmaceutical industries; (v) as an alternative to steel in construction materials; (vi) meeting the domestic ethanol production needs without compromising India's food security; and (vii) achieving India's international commitment, such as the Bonn challenge on forest restoration and the Paris Agreement on climate mitigation.

Recognizing the importance of bamboo, the government of India initiated the first phase of the National Bamboo Mission (NBM) from 2006 to 2016, which focused on the propagation and cultivation of bamboo in both forest and non-forest lands. The NBM was then restructured and relaunched in 2018/19 to support the entire value chain, including planting material, plantations, collection, aggregation, processing, marketing, skill

1.1 Bamboo and industries

Bamboo has a wide range of industrial applications, from small-scale industries to large construction industries, and even in the iron and steel industries. Bambusa tulda is used in lumber, Agarbatti sticks, handicrafts, food. Bambusa balcooa is used in construction, scaffolding, ladders, furniture, pulp and paper, food and fodder and Dendrocalamus strictus is used in pulp and paper, construction, furniture, mats, sticks, baskets, household utensils, food processing industries. In the construction industry, bamboo has a range of applications, such as scaffolding, low-rise houses, framing, beams, columns, and roofs, and reinforced bamboo is increasingly being used as a replacement for steel. Bamboo huts and buildings are increasingly preferred in ecotourism destinations and ecofriendly construction. Bamboo contains high cellulose content, solid fibre, good plasticity, and fibre length lies between hardwood and softwood making it suitable making paper. In the food industry, bamboo is used from edible bamboo shoots and fiber for sustainable packaging solutions such as utensils, containers, and tea bags. Bamboo has phenols, flavonoids, and antioxidant properties, and its outer wall has a high silica content, which is used in the pharmaceutical industry. Bamboo-based food products are gaining popularity because of their nutritional and health benefits. While bamboo is used for various industrial purposes, young and pickled shoots, processed bamboo forms, and tea leaves are daily food ingredients across the globe, particularly in East and Southeast Asian countries. Bamboo is also utilized as a seasoning, like bamboo salt and vinegar, and in beverages like bamboo wine. Nutraceutical applications include bamboo fiber powder and silica extract, both of which are known for their digestive and bone health properties.

Food fortification improves the accessibility of bamboo for industrial application by enhancing its nutritional value in processed foods. Bamboo fibre is incorporated into bakery products, like pasta and cereals, to boost dietary fibre intake, while bamboo shoot powder enriches biscuits and energy bars with vitamins, minerals, and antioxidants. Bamboo leaf extract provides antioxidants in beverages, while bamboo silica strengthens bones and joints in fortified water and supplements.

Emerging packaging technologies for bamboo food products enhance their shelf life, freshness, and safety. Active packaging prevents microbial shoot powder enriches biscuits and energy bars with vitamins, minerals, and antioxidants. Bamboo leaf extract provides antioxidants in beverages, while bamboo silica strengthens bones and joints in fortified water and supplements.

Emerging packaging technologies for bamboo food products enhance their shelf life, freshness, and safety. Active packaging prevents microbial growth, nanotechnology-based packaging improves barrier properties, edible coatings extend shelf life, and intelligent packaging uses sensors to monitor the freshness.

Bamboo is an eco-friendly alternative for everyday products, including personal care items, kitchenware, fashion accessories, and office supplies. In personal care, bamboo's natural hypoallergenic, antibacterial, and biodegradable properties make it ideal for products such as toothbrushes, cotton swabs, tissue paper, and baby items. Bamboo-infused items such as soaps and face masks also provide the most beneficial antioxidants to enhance skin rejuvenation. In kitchenware, bamboo offers durable, lightweight options, such as cutting boards, utensils, bowls, plates, chopsticks, and straws, reducing plastic waste. Bamboo also extends to stationery and fashion, with products like notebooks, pens, and laptop stands, as well as clothing such as breathable bamboo socks, t-shirts, and yoga wear.

1.2 Bamboo as Ethanol feedstock and biochar

The government of India is taking significant steps towards securing its energy future by embracing sustainable practices such as ethanol blending. India is the world's third-largest energy consumer and depends on oil imports to meet its growing energy demand. This dependency puts risks on energy security and leads to a substantial outflow of foreign currency. With ethanol blending, India has a promising opportunity to reduce its dependence on imported oil, while addressing environmental concerns. Ethanol, a byproduct of sugarcane processing, can be mixed with petrol, reducing fossil fuel consumption and harmful carbon emissions that contribute to climate change and public health issues.

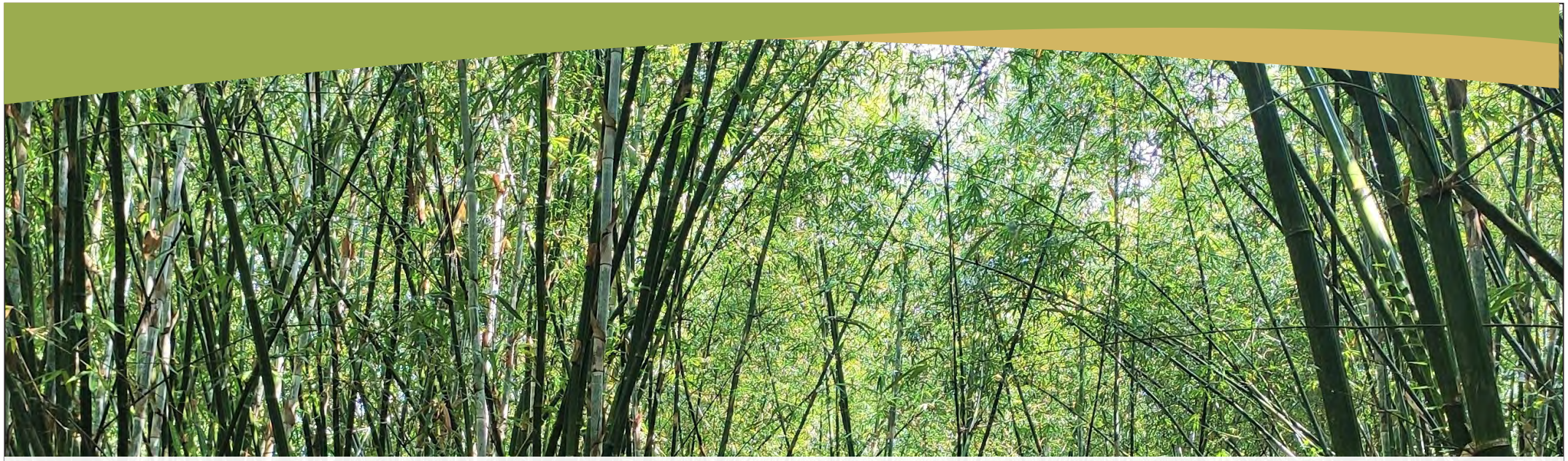
Ethanol is a primary biofuel that is naturally produced through the fermentation of sugars by yeasts or petrochemical processes such as ethylene hydration. The raw materials are largely sugarcane and paddy, and soybean is used to produce biodiesel. However, these crops are essential for ensuring food security. Therefore, alternative sources of ethanol must be explored.

With the advancement of 2G technology, there is scope to reduce dependency on these food crops. Cellulosic or 2G ethanol is produced from the sugar contained in plants (xylose and glucose) instead of the sucrose or dextrose contained in sugarcane or corn. Bamboo as a fast growing provides a perfect alternate for ethanol production using 2G technology without competing with food crops, and bamboo plant could provide continuous supply of biomass and requires less water or fertilizer than other commercial crops.

Bamboo is an extremely efficient biomass source and offers a sustainable alternative to conventional fuels. Its rapid growth and ability to regenerate after harvesting makes it a highly renewable resource. Unlike traditional woody biomass sources that require decades to mature, bamboo reaches maturity within 3–5 years, allowing for annual harvesting.

Additionally, bamboo exhibits low ash content, typically around 3–5 %, and boasts an impressive yield of 25–40 tons per acre annually after 4th year of plantation. With the increasing unpredictability of climate patterns leading to frequent crop failures, bamboo stands out as a hardy crop capable of withstanding erratic weather conditions, while still providing a consistent yield. This resilience makes it a reliable agricultural choice for farmers and an invaluable resource for sustainable energy production.

Biochar is obtained by carbonizing various types of biomass to achieve properties suitable for remediation of degraded soil. Biochar from bamboo composts could help farmers reduce the use of chemical fertilizers while achieving 20-30 % improved crop production. They are also used as activated carbon substitutes in water and air filtration systems to remove heavy metals, toxins, and pollutants, for remediation of contaminated soil (e.g., heavy metals and petroleum Z`hydrocarbons), and for industrial wastewater treatment, as they are effective at adsorbing contaminants such as dyes, phenols, and nutrients from industrial effluents.



1.3 Bamboo for forest restoration, climate mitigation and SDG

Bamboo's rapid growth in short period of time, exceptional mechanical properties, and adaptability across a wide range of climatic and soil conditions make it an ideal species for diverse applications, including bioenergy production, forest landscape restoration, and the reclamation of degraded lands. They have an exceptional ability to adapt to varied climatic and edaphic conditions and can grow in extremely diverse soil conditions, varying from organically poor to mineral-rich. They also have a broad range of moisture tolerance, which makes them an effective tool for reclaiming degraded land.

Bamboo is a valuable plant for restoring degraded lands due to its ability to grow in challenging conditions, prevent soil erosion with its extensive root system, and regenerate quickly. Many countries, including Cameroon, China, Ethiopia, Kenya, Ghana, Madagascar, the Philippines, and Vietnam, have recognized the potential of bamboo for sustainable land management and have incorporated bamboo in their restoration programs.

Additionally, bamboo sequesters carbon at a rate significantly higher than that of many traditional tree species, thus playing a vital role in climate change mitigation. Studies indicate that bamboo plantations can absorb between 17 and 25 tons of carbon dioxide per hectare annually, underscoring their potential to contribute to national and global climate goals.

Notably, one hectare of bamboo can produce up to five times the biomass of many other tree species and sequester three times the carbon compared with traditional softwood plantations. Moreover, bamboo's utility extends beyond ecological benefits; it also supports socioeconomic development. India's natural bamboo landscapes are home to large rural populations and offer a vital source of income and employment in forest-proximate communities.

Since 1988, India has made significant efforts in its forest sector to protect and restore degraded forests and achieve better biodiversity and livelihood outcomes. India also aims to restore approximately 26 million hectares of forests by 2030 under the Bonn Challenge and has committed to sequester approximately 2-3 billion tonnes of carbon through afforestation in the Paris Agreement. India is also signatory to the Kunming-Montreat protocol, which recommends biodiversity conservation, including the creation and management of protected areas while recognizing the rights and needs of indigenous and forest-dependent communities. This requires the sustainable use of forest resources for both the conservation and livelihood needs of forest-dependent communities. India, as per the National Forest Policy 1988, has also set a target of 33 % forest cover.

Bamboo plantation can achieve better afforestation outcomes and provide fodder and fuelwood to local communities. Restoration of existing bamboo clumps can be performed by turning the soil at the roots and cleaning the clumps. Bamboo is a preferred species in watershed development projects for their ability to hold soil together and reduce erosion. Forest health can be improved through active participation of the local community in the conservation and protection of degraded bamboo forests.

Bamboo economy can support in multiple Sustainable Development Goals (SDGs) including: SDG 1 to end poverty in all its forms everywhere, SDG 7 to ensure access to affordable, sustainable, and reliable modern energy services for all, including the aim to double the share of renewable energy by 2030, SDG 8 to promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all, SDG 13 to promote actions at all levels to address climate change and SDG 15 to protect and restore terrestrial ecosystems and halt all biodiversity loss, especially the call for restoration of 15% of all degraded ecosystems by 2030, and increase forest cover and integration of natural resources into planning and development processes.

1.4 Bamboo for poverty alleviation

Over 60 million poor and rural communities are estimated to be highly dependent on these forests for cooking fuel, fodder, and other forest produce for their livelihood. Tribals constitute approximately 8.6 per cent of India's total population, and according to the 2011 census, this was approximately 10.43 crore. More than 50 per cent of the tribal population live in forests and derive their livelihoods from land and forest resources. It has been estimated that nearly 40–60 % of the annual earnings of tribals, especially women, are from the collection and sale of minor forest produce. Some of the poorest in India are tribal and forest-dependent communities in the forest-rich States of Jharkhand, Chhattisgarh, Madhya Pradesh, and Odisha. These tribals, landless farmers, and farmers with small landholdings of less than two hectares and without irrigation facilities seasonally depend on forests for their livelihood. Their dependency on forests includes fuelwood for cooking and fodder for their cattle, and minor forests produce seeds, leaves, and flowers that are collected and sold in the market for their income. However, in many cases, the income from forest supports subsistence only and does not significantly improve their wellbeing or help them out of poverty. In recent years, migration to cities in search of employment opportunities has increased.

Emerging cases of successful bamboo harvesting and livelihood improvements through Community Forest Rights, particularly from Maharashtra, show how bamboo can be used as a resource for poverty alleviation.

“Bamboo has evolved as a low carbon and energy efficient alternate construction material reducing carbon footprints and improving living environment”

- Sanjeev Karpe, Konkan Bamboo and Cane Development Centre

2 BAMBOO SUPPLY

India is endowed with substantial bamboo resources, covering approximately 13 percent of its total forestland. India accounts for approximately 30 % of the global bamboo resources. There are over 148 species in 29 genera of bamboo currently found in India. Most bamboo species are found in the deciduous and semi-evergreen regions of northeastern India and the tropical moist deciduous forests of northern and southern India. They also grow abundantly on farmlands. Bamboos belong to the grass family, and there are three large genera (Bambusa, Dendrocalamus, and Ochlandra) of bamboo found in India.

Dendrocalamus strictus occurs in the plains of South and Central India and dry hilly areas of North India. In Himachal Pradesh, Madhya Pradesh and Maharashtra, Bambusa spp. and D. strictus are found dominant. The main species in Andhra Pradesh, Bihar, Jharkhand, and Uttar Pradesh are B. arundinacea and D. strictus, respectively. D. strictus and B. bamboo are naturally distributed in the sub-Himalayan and Siwalik tracts. In the higher altitudes of Himachal Pradesh and Uttarakhand Drepanostachyum falcatum (local name: Ghal Ringal), Himalayacalamus falconeri (local name: Deo Ringal), Thamnocalamus spathiflorus (local name: Thaam Ringal), Thamnocalamus jaunsarensis (local name: Jamura Ringal) are found in on the hill slopes along with natural belt.

These bamboo species are useful for preventing soil erosion and improving watersheds. In Jammu and Kashmir, D. strictus is restricted to mixed deciduous forests in the outer plains and low-altitude subtropical regions. Melocanna bambusoldes are widely distributed in Assam, whereas B. tulda and B. pallida cover over 70 percent of bamboo forests in Arunachal. Gujarat has B. arundinacea predominantly.

Both the Bambusa and Dendrocalamus have thick walls and are rigid, which helps their use in heavy duty construction works and paper and pulp industries, while the Ochlandra genera bamboos are thin walled and more flexible making them suitable in furniture making.

To understand the supply potential of bamboo, it is important to map bamboo

2.1 Current distribution and potential in India

resources currently available in the country. The Bharti Institute of Public Policy at Indian School of Business conducted a recent study using satellite imageries and ground data points on bamboo plantations from different states in India to map the area where bamboo is currently present in India. Satellite imageries from Sentinel 1 SAR and Sentinel-2 MSI Level-2A were sourced from the Google Earth Engine and training data points were collected from few States, where ISB is working with the forest department and local communities. Spectral indices like NDVI (Normalised differences vegetation index) and the Bamboo index derived from NDVI and Soil Moisture index were used to distinguish bamboo from other vegetation.

Bamboo index is calculated as:

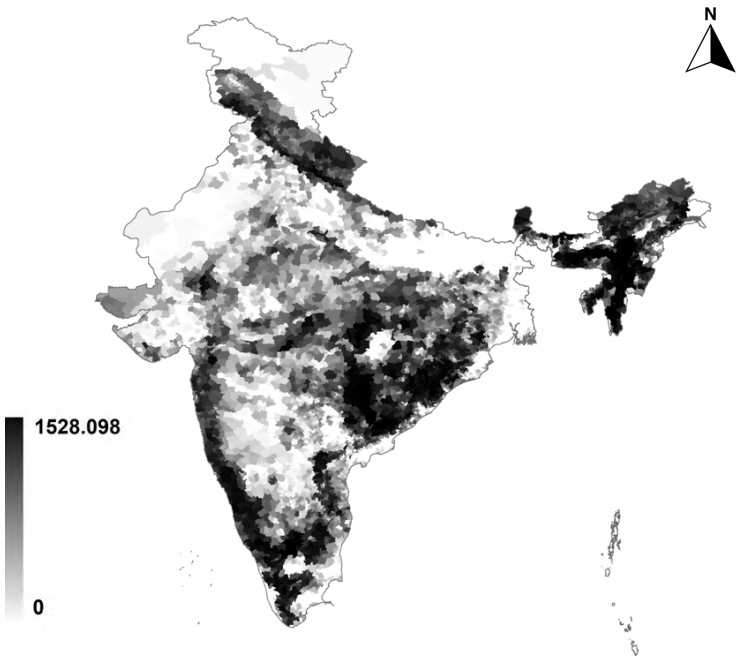
BI = (NDVI-SI)/(NDVI+SI);

Where NDVI is vegetation index and SI as soil moisture index.

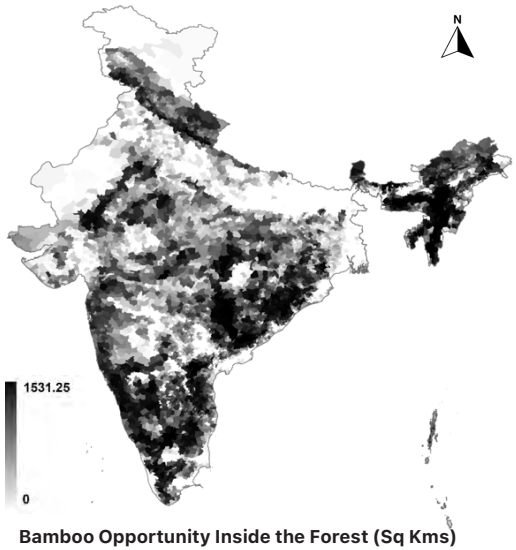
To identify areas suitable for bamboo growth, topographic information, including elevation, slope, and aspect, was extracted from the NASA Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (30m resolution). Soil variables were sourced from SoilGrids250m, whereas climate variables were derived from the Terra Climate dataset. By leveraging ground truth location data for bamboo and other tree species, a Google Earth Engine-based workflow was implemented to extract terrain variables (elevation, aspect, and slope), physiographic features (soil attributes), and climate variables. The spatial extent of bamboo growth suitability was also mapped.

Further prioritization of suitable areas for bamboo growth was provided by the Indian Water Erosion Dataset. These datasets facilitated the identification of locations where bamboo-based restoration interventions could provide immediate ecosystem benefits such as erosion control and carbon sequestration.

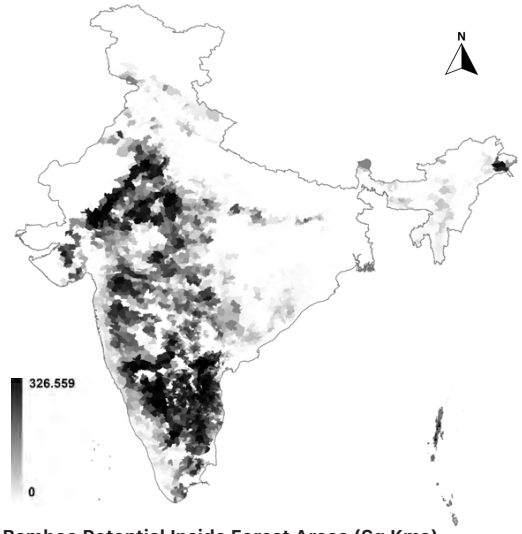
The study estimates the bamboo distribution in India to be around 23.8 million ha, with the northeast region alone having 7.7 million ha. The annual yield of bamboo in India is perceived to be around 0.33 tonnes, which thus would result in about 8 million tonnes of bamboo production per year. The bamboo distribution is 12.2 m ha within forest and 11.4 m ha outside government-owned forest land. The study also estimates about 4.4 million ha of land where bamboo could be grown. This potential within and outside forest land is 2.6 m ha and 1.8 m ha.



Bamboo Presence Inside Forest (Sq Kms)



Bamboo Opportunity Inside the Forest (Sq Kms)



Bamboo Potential Inside Forest Areas (Sq Kms)

2.2 Bamboo from forests

India has approximately 70 million hectares of forest, which is approximately 22 percent of its geographical area. There are three ways to procure bamboo from the forests. The first is through the State Forest Development Corporations that harvest bamboo sustainably as per the working plan of the forest division and auction it at competitive prices; second, the State Forest Department also harvests bamboo through Joint Forest Management (JFM) programs, where the communities jointly manage forests with the State and the benefit of the entire bamboo harvest goes to the communities. The third is through communities with Community Forest Rights (CFR) in forests, where the Gram Sabha holding CFR rights over the forests are entitled to harvest bamboo and sell commercially, and to share the benefits with the members of the Gram Sabha.

Creating a supply chain through communities has the advantage of directly benefiting the livelihood of forest-dependent communities. Forest-dependent communities have long been restricted to access forests and to withdraw forest resources for commercial purposes. The Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006 (hereafter FRA), recognizes and vests two broad types of rights to forestland with forest-dwelling communities: individual forest rights (IFR) and community forest rights (CFR). While IFR secures an individual the right to hold, self-cultivate, and live in forestland under individual or common occupation, CFR provides for rights to the Gram Sabha collectively to sustainably manage forests they have traditionally used, including sustainable harvest of non-timber forest products, including bamboo.

There have been several success stories on CFR and bamboo, with increased incomes from local communities. The success story of Menda Lekha Village is well-documented. Menda Lakha in Maharashtra, was India's first village to secure CFR in 2009, in over 1,800 hectares of forests the communities traditionally used. In 2011, it earned Rs. 1.15 crore from the sale of bamboo alone. Similarly, Padboria village, with approximately 75 inhabitants, nearly 50 km from Gadchiroli, earned Rs. 2.71 crore during 2015-16 from the sale of bamboo harvested from 508 hectares of CFR land it had received in 2012. In Maharashtra, the bamboo forests of Chandrapur and Gadchiroli are managed under different tenurial regimes. Earlier managed under the Zamindari/malguzari system, they were declared as reserve forests and nationalized. Over the last decade, under the Community Forest Resource Rights under FRA (CFR) and PESA, these forests have been handed over to the local community. Of the total bamboo area of 4,749 sq. km. in the state, 71 % (3,354 sq. km.) has been brought under CFR and PESA. Of this area under CFR and PESA, 94 % (3153 sq. km.) is in Gadchiroli district alone.

CFR is currently recognized in around 7 million hectares of forests, which is less than 10 percent of India's forests, while the potential for CFR is estimated to be around 35 million hectares, which could benefit both the bamboo economy and local communities.

2.3 Bamboo from Small and marginal farmers

Currently, there is no clear data on bamboo production in farmlands in India. The Agricultural Census does not specifically collect information on bamboo plantations in farms. However, there is tremendous potential for cultivating bamboo, especially commercially important species, such as *Bambusa tulda*.

The government of India under the NBM has recognized the importance of improving the livelihoods of small and marginal farmers through their participation in the bamboo economy. The National Sample Survey Office, Ministry of Statistics and Programme Implementation, conducted a Situation Assessment Survey of Agricultural Households during the NSS 77th round (January 2019 to December 2019) with reference to the agricultural years July 2018–June 2019 in the rural areas of the country. According to this survey, 89.4 percentage of agricultural households owned less than two hectares of land.

Currently, rainfed agriculture, which is rain-dependent, accounts for 55 per cent of the net sown area (139.42 M ha), and 61 per cent of India's farmer population.

According to the department of agriculture and farmers welfare land use statistics for the year 2022-23.

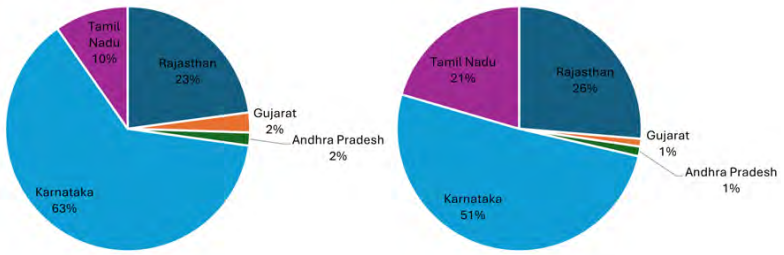
Land use	Area in 1000 hectares
Forest	72021
Area put to non-agricultural uses	27845
Barren & unculturable land	16554
Permanent pastures & other grazing lands	10248
Land under Misc. tree Crops	2992
Culturable Wasteland	11659
Fallow Land Other than Current Fallows	11128
Current Fallow	13498
Net Area Sown	140705

Source: Land Use Statistics at a Glance: 2022-23, Government of India

Culturable Waste Land is the land available for cultivation, whether taken up or not taken up for cultivation once but not cultivated during the last five years or more in succession, including the current year for some reason or another. Such land may be either fallow or covered with shrubs and jungles that are not used.

Fallow Lands other than Current Fallows includes all land, which was taken up for cultivation but is temporarily out of cultivation for a period of not less than one year and not more than five years. Together, these land categories add to about 22.7 million hectares.

Using satellite data and analysis, we found that approximately 1.8 million hectares are suitable for bamboo plantations outside of forests, of which more than 50 % of small and marginal farmers are in Karnataka alone, followed by 26 and 21% in Rajasthan and Tamil Nadu, respectively.



Pie charts on bamboo-SC/ST marginal farmers

Bamboo Plantation in Sindhudurg

Dendrocalamus stocksii known as 'Managa bamboo' in Sindhudurg district is a graceful mid-sized non-thorny bamboo species with loosely spaced solid erect culms ranging from 30-50 mm diameter. This species is mainly found in the Central Western Ghats from Ratnagiri in Maharashtra to Kasargod in Kerala. This species has wide adaptability comes up well in tropical humid, subhumid, and semi-arid conditions under black and red soil conditions. It is grown on farmlands by farmers, mostly on farm boundaries in the coastal districts of Maharashtra, Goa, and Karnataka. This species forms an integral part of home gardens and is usually preferred as a boundary plantation on farms, especially along the West Coast. Offset planting is the traditional, easy, and most common method for planting D. stocksii. Planting offsets provides a high rate of success, but the major drawback is that a well-grown clump from which it is to be taken may yield only 4-5 offsets. Hence, for large-scale plantations, collecting offsets is cumbersome. For practical purposes, propagation through culm cutting appears to be the only feasible technology. Hence, the Konkan Bamboo Development Centre (KONBAC), a private enterprise working with communities, introduced propagation through culm-cutting methods in the region.

Due to KONBAC interventions, the local demand for raw bamboo poles has increased, and traders are forced to continuously increase the price of raw bamboo poles, which now fetches a high price of about INR 50-75 per pole from the farm gate. With this incentive of better prices, it has become a profitable crop, particularly for small farmers with underutilized uplands. For farmers, rice ensures food and bamboo ensures cash support. It starts commercial production from the 4th year after plantation and can yield annually without being destroyed during harvesting, similar to other timber trees. Its short gestation period coupled with low labor and input requirements makes bamboo an ideal crop for small and marginal farmers in Sindhudurg. Small farmers in Sindhudurg are now earning regular and assured income from bamboo at their farm gates. They do not use fertilizers or pesticides and ensure that all leafy biomass fallen on the plantation ground is decomposed into manure. Bamboo plantation contributed to the economic development of the small farmers and contributed significantly to conservation of the biodiversity hot spots of Western Ghats.

2.4 Supply chain constraints

There are three types of bamboo value chains within the country. One is defined as 'social,' which involves communities using bamboo to meet local needs, such as fencing, housing, and utility items. The second method is 'industrial processing,' which involves industrial-scale processing and manufacturing. The third can be considered as 'artisanal' or 'handicraft,' which involves small-scale, craft-based production. The social supply chain meets the bona fide requirements of forest fringe communities. The industrial supply chain primarily meets the requirements of the paper industry, thermal power plants, and small-scale industries.

For example, in Jharkhand, the key constraints and challenges faced by the bamboo supply chain include (i) lack of availability of uniform quality raw material and accessibility for artisans and entrepreneurs, (ii) poor market linkages, (iii) lack of financial support (especially working capital), (iv) lack of harvesting techniques and scientific treatment practices, and (v) absence of value-added products.

The National Bank on Agriculture and Rural Development (NABARD) supports bamboo farmers by enabling or providing credit support to them. NABARD is currently co-funding an integrated bamboo-based enterprise development program in Jharkhand, supported by the SAARC Development Fund through the Foundation for MSME Clusters.

In Assam, Bamboo is available year round. However, supply is lower in the rainy season. Bamboo is harder to harvest and can absorb water, which can lead to cracking when dried, and culms have a higher starch content during this season, which attracts pests. The forests in Assam are controlled by Autonomous District Councils (ADCs). Bamboo is also grown by individual households across the state in small-scale patches or home gardens. Small-scale cultivators sell their products at low prices. Bamboo aggregators are responsible for harvesting and act as intermediaries between farmers and local traders. Local bamboo traders buy aggregated bamboo from different villages and sell it to larger traders. In addition, in a system promoted by the state forest department, bamboo is grown in joint forest management committee (JFMC) plantations owned by the committee, which manages harvest and sale.

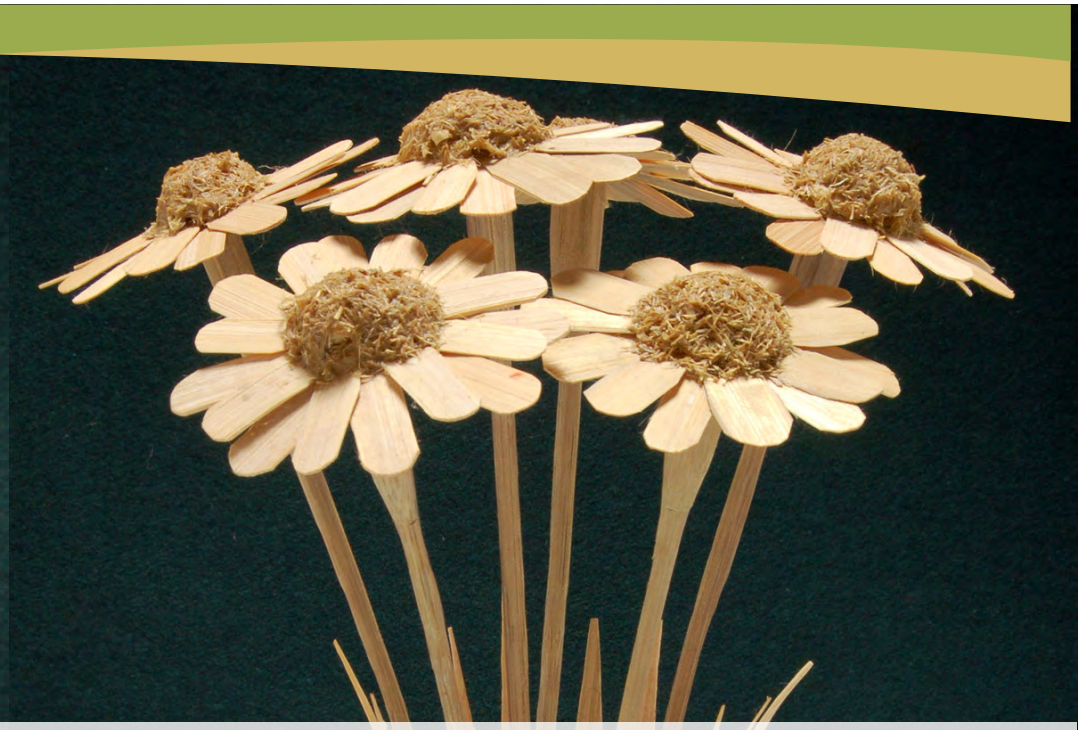
Available bamboo mostly comes from ADCs, bamboo development agencies (BDAs) and homegrown production.

Harvesters collecting bamboo from forested areas often do not have training and collect easier to access bamboo which is not of the best quality. Bamboo in Assam is sold through multiple channels. For example, bamboo bazaars in Barpeta town and the Barpeta Road area sell bamboo to artisans. Also, in Nalbari, local traders sell bamboo at the doorstep.

In Odisha, bamboo grows in forested areas and farmlands along with other crops. In addition, a small amount is produced on plantations by private and homestead growers. The key collectors are from the Odisha Forest Development Corporation (OFDC) or Vana Surakhya Samiti (VSS). The collection and marketing of bamboo from the natural forest is done by the OFDC Ltd. either directly by itself or through the Raw Material Procurer (RMP) as per the decision of the government. To regulate the collection and trade of Bamboo, Odisha Govt has formed a High-Powered Committee. Before the start of the working season (October to June), the high-power committee decides the various modalities for working bamboo coupes in Forest, which include operational cost, royalty to be paid to the government, cost to be paid by the purchaser for silvicultural operation, and commission to be paid to the OFDC Limited.

Chhattisgarh has Mukhyamantri Bans Vikas Yojna to improve its bamboo production. Under this scheme, bamboo planting will be done on non-forest area revenue land, non-forest area–farmers' land, community land, cultivable wasteland, and near canals and ponds. Under this scheme, according to the demands of all categories of farmers/ beneficiaries, bamboo species found in the state and high-quality tissue culture bamboo plants are planted on their farms, private land, and agricultural land. The beneficiary can purchase a maximum of 1,000 high-quality bamboo plants after obtaining permission from the Divisional Forest Officer. Financial subsidy on planting material and fertilizers are provided by the government. Between 2016 and 2023, over eighteen thousand farmers planted over ten lakh saplings of bamboo with financial assistance from the government of Chhattisgarh.

To manage harvesting and sale, 26 bamboo processing centers were established in the state. In Jharkhand, the Jharkhand State Rural Livelihood Promotion Society is the state rural livelihood mission of Jharkhand started with an aim to "improve rural livelihood options and work towards social and economic empowerment of rural poor and women." It works through the institutional structure of SHGs and their federations. Financial inclusion and enterprise promotion are key works of the JSLPS, and bamboo artisans could benefit from it, especially in capacity building and financial linkages. In the state of Tripura, bamboo plantations were taken up in 27 ha of degraded forest land to increase the bamboo production of Bambusa tulda. Bamboo production yielded around 60 lakh rupees in the fifth year. The bamboo product unit can also be set up in the JFMC area, through which JFMC people can produce different bamboo-based products and sell them to private agencies.



2.5 Export-import of Bamboo

Despite having 30 % of the world's bamboo resources, India contributes only 4 % to the global bamboo supply. The market share that India holds today is around 4 %, lower than that in other countries such as China, Vietnam, Thailand, and Cambodia. The total size of the bamboo market was around US$ 72.10 billion in 2019 and is expected to reach at US$ 98.30 billion by 2025, of which China has the largest market share of around 70 %. India is still in the pre-industrial bamboo value chain phase. India exported less than one million USD of bamboo raw materials, while China exported 61 million USD, Viet Nam 7 million USD, Thailand 3 million USD, and Indonesia 1 million USD

According to the International Bamboo and Rattan Organization (INBAR) an independent intergovernmental organisation, the global bamboo market grew from $66.22 billion in 2022 to $71.63 billion in 2023 at a compound annual growth rate (CAGR) of 8.2 %. The bamboo market is expected to grow to $92.62 billion by 2027, at a CAGR of 6.6 %.

In contrast, a study by the Indian Institute of Forest Management in 2020 observed that over 80 % of forest bamboo produced in India was unutilized. Notably, the Indian bamboo industry is currently grappling with extremely high input costs owing to the inadequate utilization of bamboo. In India, bamboo is mostly used in the manufacturing of Agarbatti, wherein a maximum of 16 % is used for manufacturing bamboo sticks, while the remaining 84 % is complete waste. As a result, the Bamboo input cost for Round Bamboo Sticks is in the range of Rs 25,000 to Rs 40,000 per MT as against the average Bamboo cost of Rs 4,000 to Rs 5,000 per MT. The annual demand in India for Agarbatti sticks is estimated to be around 60,000 tons per annum, whereas the demand is met from domestic production of about 3,000 tons, mostly from the northeast region by micro and small enterprises. The deficit is imported from China and Vietnam.

To promote exports, the government has lifted the "export prohibition" on bamboo charcoal, a move that would facilitate the optimum utilization of raw bamboo and higher profitability in the Indian bamboo industry. To reduce imports and create more employment in bamboo-based industries, particularly in the Agarbatti industry, the Khadi and Village Industries Commission, in 2019, requested the Central Government for policy changes in imports of raw Agarbatti sticks and import duty on round bamboo sticks that were heavily imported from Vietnam and China. Subsequently, in September 2019, the Ministry of Commerce "restricted" the import of raw Agarbatti. In June 2020, the Ministry of Finance increased its import duty on round bamboo sticks to over 30 %.

2.6 Bamboo and MSME

The role of Micro, Small, and Medium Enterprises (MSME) sector in India is a vital part of the bamboo economy. Their importance lies in processing bamboo after harvesting and catering to different industrial needs. Value addition also helps to improve the prices of bamboo. Straight poles are required in the construction industry. Similarly, the paper and pulp industry require preprocessed bamboo pulp, and the furniture industry requires bamboo that is treated to prevent insect and fungal damage.

Preprocessing treatments using physical, chemical, and biological techniques can help prevent insect and fungal damage. Pre-processing of bamboo can also involve sizing (cross-cutting) and grading using machines to achieve uniform lengths. Bamboo poles are further processed into three parts- the lower part has high strength and thickness which can be used in wood carving and scaffolding while the middle part has medium strength and thickness that can be used for poles in horticulture and handicraft.

In small industries, pre-processing bamboo involves drying, which can be performed using sunlight or oven heat. After sizing and grading, traders direct culms to different value chains based on their thickness and strength. Construction requires mature bamboo with high wall thickness. Furniture making requires wider pieces with less weight (lower wall thickness). Incense stick-making and bamboo mat-making require high intermodal distances. While scaffolding can require longer pieces, paper mills prefer 8-10 ft long bamboo.

A working paper published by the Foundation for MSME Clusters noted that local traders often buy small quantities of bamboo and perform simple sorting and grading at the village level. They sell bamboo to artisans or to larger traders with depots. The larger traders then sell the bamboo to different industries and bamboo-based manufacturing enterprises (including industrial users, such as paper mills or biofuel producers and artisans), and the construction industry. The yield of round bamboo sticks from bamboo culms varies between 6 % and 12 %. SMEs do not have facilities for waste utilization, resulting in bamboo input prices ranging between Rs25,000 and Rs40,000 per tons as against the bamboo price of Rs2,500 to Rs4,000 per ton. SMEs are unable to invest in the infrastructure required for waste bamboo utilization.

A large amount of bamboo waste is generated during primary and secondary processing of bamboo. Currently, most bamboo waste is not utilized, and thus the cost of bamboo raw material is over three times higher than that of China and Vietnam. Bamboo Charcoal has a good potential for exports and is most suited for waste bamboo utilization. Therefore, China is a major exporter of bamboo charcoal. The price of bamboo charcoal varies between Rs25 and Rs30 per kilogram. Free export of bamboo charcoal should ensure proper bamboo waste utilization, resulting in lower production costs for Indian Bamboo Enterprises.

3 BAMBOO DEMAND

Bamboo is witnessing rising demand across a range of industries, driven by its versatility and sustainability. Major sectors currently utilizing bamboo include thermal and steel plants where it is used as fuel for co-firing, as well as bioethanol production, paper and pulp manufacturing, construction, and the Agarbatti industry. In addition, its applications are expanding into newer domains such as textiles, food products, and pharmaceuticals. One of the most significant emerging uses is in the production of activated charcoal. Globally, the demand for activated bamboo charcoal is growing at an annual rate of 7 %, with the United States experiencing an even faster growth rate of 13 % per year. Producing one ton of activated charcoal requires approximately four tons of raw bamboo, underscoring the scale of resource input needed to meet this rising demand.

3.1 Demand creation through policy mandates

In an ambitious move to promote cleaner energy practices and reduce the dependence on fossil fuels, the Ministry of Power revised its biomass policy in 2023. This revision mandates the co-firing of 5 % biomass in coal-based thermal power plants (TPPs) from the financial year 2024-25, with an increase of 7 % from 2025-26. However, despite this regulatory push, the implementation and impact of biomass integration in thermal power generation has been slower than anticipated, with limited progress observed across the sector.

A crucial development since May 2023 has added momentum to this initiative. The Government officially recognized bamboo as a viable biomass fuel through an addendum. This inclusion is a game-changer owing to its exceptional properties, including high bulk density, superior calorific value, and rapid growth rate, all of which make it an efficient and sustainable fuel alternative.

Bamboo offers a continuous biomass supply when properly managed. Its culms, leaves, branches, and roots can be used as biomass, which makes it a highly resourceful material. Bamboo's high fibre, low ash, and minimal alkali levels make it an excellent source of fuel for power generation and in steel and cement industries. They can be processed into solid, liquid, or gaseous fuels using different processing technologies, each produced for specific use. Technological advancements include pyrolysis and densification of solid biofuels, such as bamboo chips, pellets, briquettes, and charcoal. These fuels can efficiently replace coal and coke, thereby reducing carbon emissions.

Bamboo, as a biogenic alternative, holds immense promise in driving the transition to a low-carbon energy future. Its shorter rotation period, ranging from three to five years, and high biomass productivity make it an optimal species for nature-based solutions. The steel industry is exploring the use of bamboo and other biomass sources, such as biochar, as low-carbon alternatives to coal, with the potential to substitute pulverized coal injected into blast furnaces and reduce carbon emissions. The Steel Authority of India Limited (SAIL) and Tata Steel are exploring the use of biochar as an alternative to fossil fuels. Biochar can be used as a partial replacement for coke in blast furnaces, potentially reducing CO2 emissions by 19-28 %.

The integration of bamboo into biomass blending strategies could significantly reduce India's reliance on coal and other fossil fuels, thereby promoting cleaner energy production. By incorporating bamboo into the fuel mix, the country can make meaningful strides towards a greener and more sustainable energy future, while simultaneously enhancing rural livelihoods through bamboo farming.

The National Thermal Power Corporation (NTPC) has taken a significant step towards sustainable energy by adopting bamboo as a biomass fuel blended with coal in its Solapur Thermal Power Plant. This pioneering decision involved blending up to 30 % bamboo with coal to reduce carbon emissions and promote renewable energy sources. The successful implementation of this model could encourage similar initiatives across other coal-based power plants in India, driving large-scale adoption of bamboo as an energy source.

Although the inclusion of bamboo as a biomass fuel presents a significant opportunity, certain challenges must be addressed for its large-scale adoption:

a. Supply Chain Infrastructure: Developing an efficient supply chain for bamboo procurement, processing, and transportation is critical for ensuring its steady availability for power plants.

b. Technology Adaptation: Thermal power plants must optimize their systems to accommodate bamboo biomass, ensuring seamless blending with coal.

c. Policy and Incentives: Continued government support through incentives, subsidies, and research funding will be crucial for promoting bamboo biomass as a mainstream energy source.

Looking ahead, the expansion of bamboo biomass usage in India's energy sector requires collaborative efforts among policymakers, industry leaders, farmers, and researchers. Investment in research and development can enhance the efficiency of bamboo-based bioenergy production, making it a viable long-term solution to India's energy needs.

The NTPC's decision to incorporate bamboo in biomass co-firing at its Solapur Thermal Power Plant represents a forward-thinking approach to energy production. By leveraging the sustainable properties of bamboo, this initiative sets a precedent for integrating renewable biomass sources into India's energy sector. The benefits extend beyond reducing carbon footprints, including economic upliftment for farmers, conservation of water resources, job creation in villages, and significant contribution to climate change mitigation.

As India continues its transition towards cleaner energy solutions, bamboo has emerged as a strategic resource that aligns with the country's sustainability goals while fostering economic resilience. This initiative exemplifies the synergy between renewable energy adoption and rural development, reinforcing India's commitment to a green future.

By embracing bamboo biomass, India not only reduces its reliance on coal, but also paves the way for an environmentally responsible and economically viable energy landscape for future generations.

Numaligarh Refinery; Source - NRL

3.2 Demand for Ethanol from bamboo

India's Numaligarh Refinery Ltd (NRL), a subsidiary of Oil India, is set to launch the country's first ethanol production unit using bamboo as feedstock. Located in the northeastern state of Assam, this pioneering biorefinery is expected to produce around 50,000 tonnes of ethanol annually—equivalent to approximately 200 kilolitres per day or 6.2 crore litres per year. The project leverages the abundant bamboo resources of Northeast India, which are estimated to be approximately 178 million tons. The refinery will require approximately 0.5 million tonnes of bamboo per year, making it a sustainable and regionally viable initiative. This green fuel venture is being developed through a strategic partnership between NRL, the Finnish clean technology company Chempolis, and the energy solution provider Fortum. In addition to ethanol, the biorefinery also produces valuable by-products such as furfural, acetic acid, liquid CO2, and power, showcasing an integrated approach to bioeconomy development.

3.3 Entrepreneurship - supply aggregation, primary industrial processing

Bamboo-engineered products such as cross-laminated bamboo (CLB), bamboo scrimber, bamboo mat boards (BMB) are developed using advanced manufacturing processes that enhance bamboo's strength, durability, and industrial applications. These processes include preservation and treatment, adhesive application, lamination and pressing.

A furniture manufacturing transforms engineered bamboo products into functional and aesthetically pleasing pieces. Bamboo-based furniture is an accepted choice for indoor and outdoor spaces due to its sustainability and durability. Popular products include chairs, tables, bed frames, shelves and outdoor furniture. Bamboo furniture not only improves the aesthetic appeal, but it is also a green choice for eco-conscious consumers.

Several entrepreneurs have emerged in the bamboo industry. Shri Sanjeev Karpe, who has been in the field of popularising the bamboo for the past 18 years works with almost 10,000 farmers in the Singur district of Maharashtra and is currently working with the farmers of Marathwada and other parts of India.

KONBAC case

Konkan Bamboo Development Centre (KONBAC) started a Bamboo crafts making unit at Kudal in Sindhudurg district of Maharashtra in 2009, which has repositioned bamboo craft products, creating access to new high-value markets. KONBAC developed a strategy that aimed to develop high value-added craft products, including quality control measures, which are products made from graded and treated bamboo. Training was offered to communities in making high-end craft products using tools, machines, and molds developed by Bamboo Studio at the IDC, IIT Mumbai. These trained artisans are now making bamboo craft products, such as bread baskets, serving trays, coasters, lamp shades, and other utilitarian products. More recently, bamboo mats have been widely used as roofing and walling components in resorts and restaurants because of their high quality. People trained by KONBAC were mostly women from traditional bamboo-weaving communities. KONBAC has a buy-back arrangement that provides direct employment to many household-based micro-enterprise female producers. In addition to skill upgrading, training, and market development, artisans are provided with ongoing inputs on design, raw materials, and tools. To ensure that communities receive adequate income, the KONBAC also acts as a facilitator between producers and consumers.

KONBAC tapped the skills of rural youth by training them in making round-pole furniture from bamboo. After the initial training, a few models of furniture were designed, prototyped, and test-marketed in Goa and Mumbai, which are the major commercial markets in the region. Positive feedback from the market with immediate orders requires a production unit for furniture to be set up. The furniture unit uses bamboo treated in a pressure-vacuum treatment plant to protect against termites and borers, which helps extend the life of furniture. Increased lifespan also changed the perception of bamboo furniture among consumers and producers. Trained artisans were given the treated bamboo in a kit form to make the required components per design.

Niche tourism markets have accepted the bamboo furniture produced by KONBAC, and the increase in demand has been steady. KONBAC's bamboo furniture fetches a better price than furniture products from regular commercial enterprises (mostly from the northeast) because of its better quality and finishing. The strategic location of Sindhudurg close to Goa, an international tourist destination, has contributed significantly to expanding the market for bamboo furniture. The smart pricing policies adopted ensure that artisans get the best remuneration possible for their work. Buyers accept the high prices because of the high quality and good finishing of the products. Furniture production does not occur only at factories. The components needed for making furniture, such as bamboo nails, bamboo splits and round bamboo sticks, which form essential inputs for furniture making are produced by the villagers at the household level entirely by women. Women workers regularly supply these materials to the KONBAC through part-time work. Assembly is done partly by the community and the furniture is brought back to KONBAC factory for final assembly and finishing.

KONBAC began a construction enterprise unit to cash in on local market opportunities for resorts, restaurants, and farm houses that were in demand. The establishment of the unit fitted with KONBAC's aim to increase livelihood opportunities for poor rural households by changing the wider perception of bamboo as a low-end, cheap material. By targeting construction, KONBAC aimed to demonstrate the potential of bamboo to be adopted for high-end purposes while also creating considerable employment opportunities for local rural communities. Construction offers several advantages for changing local perceptions of bamboo, as resorts, restaurants, and farmhouses are highly visible products. Instead of bringing larger diameter bamboos for construction from elsewhere, KONBAC used small-diameter bamboo, which is available locally and adopts a technique of joining small bamboos together.

KONBAC provides training to communities for making prefabricated structures. The construction sector is primarily dominated by men at the assembling and erection stage of the house or resort, due to the nature and demand of the work involved. At the same time, women are involved in developing the components needed for construction and creating large-scale employment opportunities at the community level, which is not possible with normal construction methods. Woven mats used for both interior and exterior purpose, bamboo nails and bamboo splints are some of the construction components made by rural women working at home during the time spared from their household activity. The promotion of construction sector in the region has a great potential to arrest the migration of men to urban areas seeking employment opportunities to an extent possible.

KONBAC is presently implementing 'Bamboo craft development cluster' project in Sindhudurg district of Maharashtra under SPURTI, Supported by Khadi & Village Industries Commission, Govt. of India. KONBAC successfully implemented 'Centre for Bamboo Training & product development' project by by National Mission on Bamboo Applications (NMBA) Dept. of science & Technology, Govt. of India. KONBAC also successfully implemented responsibility of setting up of 'Bamboo furniture & interior accessories manufacturing unit' at Lavasa city for Lavasa Corp. Ltd. and Jhadol, Udaipur Dist. of Rajasthan for the ICICI Foundation. KONBAC also successfully implemented responsibility of setting up and running of "Bamboo Based Hygiene Product Manufacturing Unit" a project by National Mission for Bamboo Application (NMBA), Govt. of India. The extensive work done by KONBAC has led to some quality publications, one of the noteworthy among them is 'Breaking Barriers, creating Capital,' published as Monograph by INBAR. KONBAC won the state-level first prize (Vanashree Puraskar) from the Government of Maharashtra to promote bamboo plantations as a commercial farming option for farmers in Maharashtra.

3.4 Industry support

In January 2023, Tata Steel initiated a groundbreaking trial to incorporate biochar as a partial replacement for fossil fuels in blast furnaces. Over the course of a year, the company has successfully substituted approximately 30,000 tons of fossil fuels with biochar, leading to a potential reduction of over 50,000 tons of carbon dioxide emissions annually. This initiative not only underscores Tata Steel's commitment to environmental sustainability but also enhances energy efficiency by partially replacing pulverized coal injection in the steelmaking process. The successful implementation of biochar injection in blast furnaces exceeding 3,000 m2 in volume and achieving production levels of over 9,000 tons per day represents a significant advancement in sustainable steel production.

Rajiv Mangal, Vice President of Safety, Health & Sustainability at Tata Steel, highlighted the broader impact of this development, stating that it opens doors for greater reliance on alternative fuels in the steelmaking process and reiterates the company's dedication to responsible steel production. This pioneering approach positioned Tata Steel as a leader in integrating sustainable practices within the steel industry, setting a benchmark for others to follow.

Similarly, the Steel Authority of India Ltd. (SAIL) has successfully launched the use of biochar at its Rourkela plant, which the company has said to demonstrate its commitment to reducing carbon emissions in steel production. SAIL's Durgapur Steel Plant is testing bamboo biochar as a partial replacement for coke breeze in sintering, with the aim of reducing CO2 emissions by 15-20 %.

The Indian BioChar and BioResources Network is a collaborative platform for individuals and institutions committed to circular agriculture models that significantly reduce greenhouse gas emissions, increase carbon sequestration, and improve farm-related livelihoods in India through efficient use of farm residues and other natural resources. The primary goal is to promote the sustainable and efficient use of farm residues and natural resources to reduce greenhouse gas emissions, enhance soil carbon sequestration, and improve the livelihoods of farming communities. By encouraging the adoption of biochar and other innovative bioresource technologies, the network supports regenerative farming practices that align with the national climate goals. IBBN also facilitates knowledge sharing, research collaborations, and capacity building to scale climate-smart agriculture across the country.

-Global demand: processed bamboo products, green steel, and Carbon Border Adjustment Mechanism.

...ndustry: Source - steelradar.com

3.5 Paper and pulp industry

The paper and pulp industry in India is a significant sector that supports a wide range of industries including packaging, education, newsprint, and hygiene products. It is estimated that approximately 4 million tons of wood is consumed annually. However, bamboo, once a traditional raw material for papermaking in India, currently contributes only a small share to this demand. Historically, bamboo has been extensively used in the industry, but over the years, its share has declined owing to a combination of supply, logistical, and technical constraints.

One of the primary challenges is the geographical mismatch between bamboo-growing regions and the location of major paper and pulp mills. The northeastern states and lower Himalayan belt are the main producers of bamboo, accounting for over 60 % of the country's bamboo resources. In contrast, most paper mills are concentrated in northern and western India, including states such as Uttar Pradesh, Haryana, and Gujarat. This leads to high transportation and procurement costs, making bamboo less competitive than other raw materials, such as eucalyptus or agro-residues.

Another barrier is the technical limitations of bamboo processing. Bamboo has a high silica content, which poses difficulties in pulping and can lead to increased wear and tear of the machinery. This makes it less attractive to mill operators unless specific technological upgrades are made. Additionally, the paper industry faces growing environmental and sustainability pressures to reduce deforestation, improve resource efficiency, and adopt alternative fibers.

Despite these challenges, bamboo holds potential as a renewable, fast-growing biomass that can be integrated into the raw material mix for the pulp and paper sector. With targeted investment in supply chain development, transportation infrastructure, and pulping technology, bamboo could play a more significant role in the future, especially as India moves towards greener industrial practices and circular economy models.

3.6 Bamboo textile and food processing industries

Bamboo textiles are eco-friendly fabrics made from bamboo fibres, known for their softness, breathability, and antibacterial properties. They are widely used in fashion and apparel (socks, underwear, T-shirts, bathing suits), home textiles (towels, bed sheets, pillows, mattresses, blinds, tablecloths), hygiene products (face masks, sanitary napkins, baby diapers), protective gear, and the hospitality sector, thus proving to be a sustainable and versatile choice for eco-conscious individuals. Bamboo is a better alternative to cotton and nylon fabrics.

Bamboo textiles include various fibres such as viscose (soft and silky), lyocell (eco-friendly), linen (durable), cotton blends (strong), and charcoal fabric (antibacterial and odor-resistant), each of them offering unique benefits for clothing, bedding, and hygiene products.

Grasim Industries, a flagship company of the Aditya Birla Group, is India's pioneer in Viscose Staple Fiber (VSF) and has established the world's first bamboo-based rayon-grade pulp plant, demonstrating its commitment to sustainable solutions. It filed the world's first patent for developing pulp (raw material for manufacturing VSF) from mixed hardwood. Later, it established the world's first bamboo-based rayon-grade pulp plant.

As per Market Research Futures analysis, the Bamboo Fiber Market Size was estimated at 5.68 (USD Billion) in 2024. The Bamboo Fiber Market is expected to expand significantly in the coming years, driven by the rising demand for sustainable and eco-friendly materials. In 2023, the market was valued at approximately USD 4.54 billion and is projected to reach USD 12.4 billion by 2032, exhibiting a CAGR of 11.83 % during the forecast period. Key factors contributing to this growth include increasing environmental consciousness among consumers and the growing adoption of bamboo fiber in various industries such as textiles, construction, automotive, and government initiatives promoting sustainability. Recent developments include the launch of innovative bamboo fibre-based products, such as biodegradable packaging and clothing, and strategic partnerships between industry players to enhance production and distribution capabilities.

4

TECHNOLOGY LANDSCAPE AND ADVANCEMENTS IN BAMBOO SECTOR

Recent technological advancements have significantly enhanced the efficiency, scalability, and sustainability of bamboo-based bioenergy production. Catalytic and microwave-assisted pyrolysis are among the most promising innovations. These processes improve both the yield and quality of bioenergy products, such as bio-oil, biochar, and syngas, while offering lower emissions and higher energy efficiency.

Pretreatment technologies play a crucial role in converting bamboo into biofuels such as ethanol. Through hydrolysis, the tough lignocellulosic structure of bamboo is broken down into simple sugars, which are then fermented to produce ethanol. Pretreatments, such as grinding, dilute acid treatment, alkaline treatment, steam explosion, and more advanced methods, such as ionic liquids and deep eutectic solvents, modify the chemical and physical structure of bamboo. This increases the surface area and disrupts the lignin-cellulose bonds, thereby enhancing the efficiency of enzymatic hydrolysis.

Pyrolysis is a thermochemical conversion process that transforms bamboo into high-value products. Different modes of pyrolysis—slow (maximizing biochar), fast (focusing on bio-oil), catalytic (improving oil quality), and plasma-based methods —enable tailored outcomes.

Torrefaction, a milder version of pyrolysis at 200–320°C under low-oxygen conditions, enhances the energy density and combustion efficiency of bamboo, producing a coal-like fuel with better grindability and reduced moisture.

Densification techniques, such as palletization and briquetting, further improve torrefied bamboo by making it easier to handle and transport. Densified bamboo fuels, particularly pellets, are becoming increasingly popular in industrial bioenergy systems.

Anaerobic digestion converts bamboo waste into biogas and compost. With advancements in single- and two-stage digestion systems, this process has become increasingly efficient. Biogas upgrading technologies, such as pressure swing adsorption, membrane separation, and cryogenic methods, help produce high-purity biomethane and liquid CO_2, expanding the potential of bamboo as a clean, industrial-scale energy source.

Bamboo-engineered products- Bamboo requires proper treatment to improve its durability against environmental factors, pests, and decay, especially for industrial applications. Traditional methods such as clump-curing, smoking, soaking, seasoning, and heat treatment are cost-effective and eco-friendly but offer limited protection. Chemical treatments improve bamboo durability, but raise safety and environmental concerns. Among them, boric acid and borax are effective against insects and fungi but have relatively low toxicity.

For long-term preservation, both pressure and non-pressure treatment processes are used. Pressure treatment protects bamboo from adverse conditions and is more effective. Modern pressure techniques, such as the Modified Boucherie Method, involve treating bamboo in closed cylinders under applied pressure or vacuum, ensuring uniform penetration of preservatives while significantly reducing the treatment time. There is also ongoing research focused on using nanomaterials and a combination of traditional and modern techniques to enhance bamboo preservation and develop advanced treatment technologies.

Adhesive application, lamination, and pressing: Modern adhesives, such as high-performance synthetic resins, bio-based adhesives, and nanotechnology-enhanced bonding agents, distribute stress evenly, making bamboo products durable, fatigue-resistant, and moisture-resistant. There is notable increase in research on eco-friendly and formaldehyde-free adhesives increases, their application is becoming an evolving technology, with strict compliance with global safety standards like EU REACH.

Pressing and lamination bond bamboo with adhesives to create larger, stronger panels, beams, and other engineered bamboo products. Processes, such as thermal and vacuum lamination, and pressing techniques, such as high-pressure densification, have enhanced the durability, stiffness, and uniformity of bamboo. These innovations help engineered bamboo products exhibit better mechanical properties than conventional timber, offering greater strength and stability for construction and infrastructure projects.

4.1 Bamboo in Furniture Manufacturing

Furniture manufacturing involves stages, such as (i) designing the furniture model, (ii) selecting and treating the raw material, (iii) cutting and shaping to create single pieces of furniture, (iv) joining using metal fasteners or stitching, (v) surface finishing, and (vi) quality control. Similar to bamboo construction products, emerging technologies for bamboo furniture include the use of automated equipment for stitching, padding, and fabric stretching for upholstered furniture to improve consistency and speed. Some emerging technologies are

CNC cutting: Computer Numerical Control (CNC) machining offers several benefits in modern manufacturing, particularly in enhancing sustainability and efficiency. The use of CNC enables precision cutting to improve energy efficiency by minimizing material waste, optimizing cutting parameters, and refining tool paths, ultimately reducing overall power consumption. Therefore, CNC cutting allows for the precise shaping, sophisticated detailing, and mass production of engineered bamboo products, making it ideal for prefabricated buildings, modular construction, and infrastructure. CNC cutting and shaping for precision manufacturing, increasing production speed, and reducing material waste. Protective bio-coatings application as a part of surface finishing for resistance to wear and tear, making furniture more suitable for long-term use in various environments

Bamboo in Textiles: Enzymatic processing is a sustainable method for extracting high-quality bamboo fibers, replacing traditional chemical processes. Enzymes such as pectin lyase, xylanase, laccase, and cellulase remove impurities and enhance the fiber strength and softness. Innovations in the spinning technology have improved the quality of bamboo textiles. One notable technique is Siro spinning, which involves feeding two separate strands of fiber into the spinning machine simultaneously and twisting them together to produce a single yarn. This method enhances the uniformity and strength of the fiber while reducing linting and contributes to smoother, more durable bamboo fabrics for diverse applications.

Closed-loop production Technology: Closed-loop production systems in bamboo fiber manufacturing are designed to minimize the environmental impact of solvent recycling and reduce emissions. For instance, the Lyocell process employs a closed-loop system that recycles 99.5 % of chemicals, significantly reducing waste and pollution. These systems have lower production costs, making bamboo textiles affordable and accesible for large-scale industrial applications. They ensure compliance with environmental regulations, improve fabric quality, and make bamboo textiles sustainable.

Pulping: Bamboo pulping has evolved through mechanical, semi-chemical, and chemical pulp processes to enhance yield, quality, and sustainability, which often require high chemicals or energy. Among chemical processes, kraft pulping is a common method in the paper industry and is recognized for its ability to remove lignin, produce durable pulp, and support chemical recovery. More sustainable approaches, such as sulfur-free alkaline techniques, organo-solvent pulping, and bio-pulping, provide better fiber separation while reducing the environmental impact. Emerging technologies in bamboo pulping are more efficient and sustainable, as they improve product properties, reduce bleaching costs, and minimize the overall environmental impact. Pretreatment with sodium hydroxide (NaOH) to extract silica and hemicelluloses, or by using desilication agents like aluminum sulfate or sodium aluminate during the pulp cooking process

Bleaching: Bleaching is essential for making bamboo pulp suitable for industrial applications because it enhances brightness and purity but affects the environment. Traditional chlorine-based bleaching generates toxic effluents, such as adsorbable organic halides (AOX), leading to stricter environmental regulations. Emerging advancements in Elemental Chlorine-Free (ECF) and Total Chlorine-Free (TCF) bleaching processes have reduced harmful emissions while preserving fiber strength. ECF replaces chlorine with chlorine dioxide (ClO_2) and removes lignin while maintaining pulp quality. TCF employs oxygen (O_2), ozone (O_3), and hydrogen peroxide (H_2O_2) for a completely chlorine-free process. Ongoing innovations in eco-friendly bleaching processes enhance sustainability, making bamboo pulp more viable for industrial use while meeting global regulatory standards.

Active Packaging: Many technologies covered in previous sections, such as engineered bamboo composites in construction, enzymatic fiber processing in textiles, nanotechnology, biopolymer coatings, and biodegradable adhesives, make bamboo consumer products more durable, eco-friendly, and accessible at an industrial scale. Active and intelligent techniques enhance bamboo-based biodegradable packaging by extending shelf life and ensuring product quality. Active elements, such as oxygen scavengers and antimicrobial agents, preserve food, while biosensors monitor freshness and storage conditions. These innovations make bamboo packaging viable for the food, pharmaceutical, and e-commerce industries, where maintaining the product quality is crucial. Bamboo-based packaging with active elements reduces plastic waste while offering high-performance solutions.

Bio-based Barrier Coatings: Bio-based barrier coatings for bamboo-based packaging improve moisture and grease resistance while maintaining biodegradability, non-toxicity, and structural flexibility, without relying on plastic. These coatings are made from materials such as nanocellulose, biopolymers, and plant-based resins, which aid in recycling and composting bamboo packaging products.

“India taps only one-tenth of its bamboo potential due to lack of facilities for value addition and transportation, as well as low productivity, which is about 2 tons per hectare annually.”

- Sridhar Punati, Chairman of the Bamboo Society of India

Source: The Hindu, 29 June 2024.

5 THE BAMBOO ENABLERS

The lack of organized markets for farm bamboo remains a problem. Those cultivating bamboo are not clear about where it is to be sold or what the prevailing market price is. Additionally, there are no established standards for grading and classification of bamboo.

To create a better demand there is need for support on legal, policy, research and development, and entrepreneurship.

5.1 Green jobs

India has millions of bamboo artisans working in micro-enterprises in remote communities, which suffer from high levels of poverty. These artisans have multiple opportunities to increase their bamboo-related incomes. The products created by these artisans provide functional and decorative uses that could appeal to diverse consumer groups. In addition, these products, which typically use sustainable techniques and materials, can act as replacements for many less sustainable items because bamboo is often more environmentally friendly than other raw materials (e.g., plastic, timber, or metal). Thus, helping India's bamboo artisans expand and improve their production and link to new markets can help reduce poverty and address global environmental challenges.

Increased Availability of Inputs: Access to bamboo allows artisans and small enterprises to affordably and reliably source raw materials. This increases the production capacity and encourages entrepreneurship.

Building National Demand for Bamboo Products: Bamboo's eco-friendly characteristics make it a viable alternative to plastic, timber, and metal. Promoting bamboo as a sustainable material can appeal to environmentally conscious consumers and support India's circular economy goals.

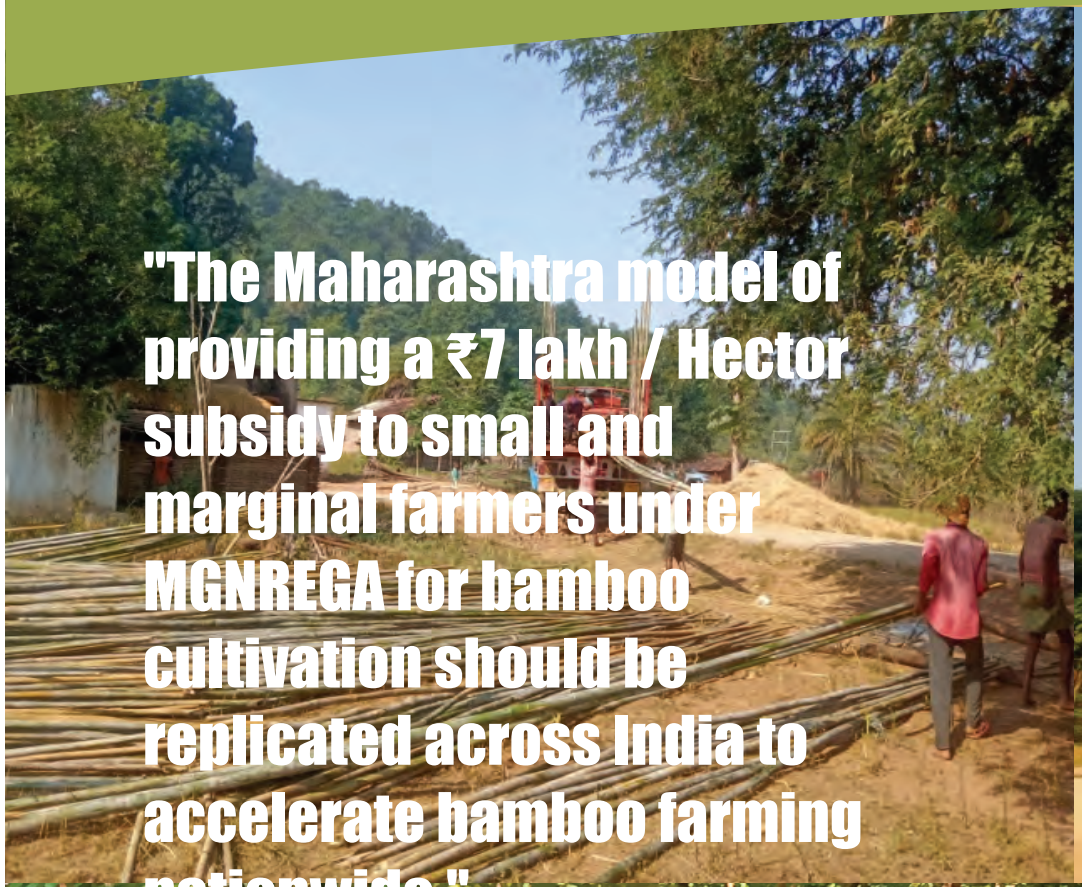
Facilitating Links to International Markets: With value addition and quality improvement, bamboo products, such as furniture, lifestyle goods, and eco-packaging, can reach global markets. Export-oriented support policies and certifications can enhance competitiveness.

The Nagaland Bamboo Development Agency (NBDA) has sought to promote bamboo charcoal production. The NBDA has set up almost 50 charcoals kilns. Additionally, Village Bamboo Development Committees have been established in six districts of the state. This project directly connects with approximately 200 people and provides support to approximately twice as many people through job creation. The NBDA has marketed charcoal briquettes under the name "Bam Grill" for barbequing and cooking purposes.

In Odisha, a recent study by the Council on Energy Environment and Water (CEEW) found that cultivation of bamboo across ~15,000 hectares (~3 percent) of cultivable wasteland and integrating it into bamboo-based industries such as furniture, housing, agarbatti, packaging, activated charcoal, and ethanol could generate approximately 29,000 jobs by 2030 (3,000 jobs are created through cultivation). The endeavor requires a cumulative investment of approximately USD 1,000 million, unlocking a market opportunity worth approximately USD 800 million annually.

"Unless there is a market, farmers will not grow bamboo. To boost bamboo as an industry and construction material, proven technology, economic viability, availability of raw materials."

Shri Nitin Gadkhari, Union Minister for Transport



"The Maharashtra model of providing a ₹7 lakh / Hector subsidy to small and marginal farmers under MGNREGA for bamboo cultivation should be replicated across India to accelerate bamboo farming nationwide."

- Mr. Pasha Patel, Chairman, Agricultural Price Commission, Government of Maharashtra

5.2 Policy and Legal support

The Forest Rights Act (FRA) of 2006 has played a transformative role in enabling forest-dwelling communities in India to sustainably harvest bamboo and use it for their livelihoods. Before the FRA, bamboo was classified as a forest product under the control of the Forest Department, and communities had limited access to it. The FRA changed this by legally recognizing the rights of tribal and traditional forest dwellers over forest land and its resources.

Under the FRA, communities can claim rights to manage and use forest resources, including bamboo, through CFR titles. This legal recognition empowered them to make decisions on resource use, conservation, and benefit sharing. The FRA treats bamboo as an MFP, giving rights-holding communities the authority to collect, transport, and sell bamboo without needing permits from the Forest Department. This has reduced bureaucratic hurdles and increased local income.

Communities managing bamboo under CFR titles often adopt sustainable harvesting practices, including rotational harvesting, selective cutting, and replanting, to ensure long-term resource availability. Under FRA, communities are empowered to prepare a Forest Management Plan, which can help communities sustainably manage bamboo resources in forests. In addition to the CFR, households with individual forest rights that are mostly in forest fringes could also benefit from bamboo cultivation.

Access to bamboo has opened up opportunities for value addition (e.g., furniture, handicrafts, and bioenergy), creating jobs, and improving rural livelihoods. In states such as Maharashtra and Odisha, bamboo-based enterprises are supported by local forest rights committees and NGOs.

In 2018, bamboo outside forest areas (ie farm bamboo) was freed from the transit pass (TP) regime and declared as a 'grass.' This was done to promote bamboo outside forest areas and to develop it on the lines of other farm commodities.

At the state level, some restrictions on felling permission and transit permit laws are imposed to ensure the sustainable harvesting of bamboo. In Assam and other northeastern states, there is no felling or transit permit required, except Tripura, where there is a transit permit required; in Sikkim and Nagaland, a royalty is to be paid for felling and transit.

Karnataka, Madhya Pradesh, Telangana and Maharashtra other important bamboo producing states have also exempted bamboo for felling and transit permission with no royalty to be paid. Odisha allowed for the exemption of 10 species of bamboo.

5.3 Policy support

The government of India launched the transformative initiative Agriculture Infrastructure Fund (AIF) to address critical infrastructure gaps and stimulate investments in agricultural development. This program, along with other key schemes, focuses on boosting production and ensuring better returns for farmers. The AIF scheme's expansion aims to strengthen the agricultural infrastructure nationwide and provide robust support to the farming community by broadening the scope of eligible projects, introducing additional supportive measures, and fostering a more comprehensive agrarian infrastructure ecosystem.

The scheme aims to attract investments for the development of agricultural infrastructure, with a total allocation of Rs 1 lakh crore distributed through banks and financial institutions until 2025-26. The beneficiaries receive a 3 % interest subvention on loans up to Rs 2 crore, with a maximum repayment period of seven years. In addition, the scheme covers the reimbursement of credit guarantee fees paid by banks. The list of eligible activities under the Agriculture Infrastructure Fund includes integrated primary and secondary processing projects. However, standalone secondary projects remain ineligible and will continue to be covered under Ministry of Food Processing Industries (MoFPI) schemes

The union government is implementing the Agricultural Marketing Infrastructure (AMI) scheme, a component of the Integrated Scheme for Agricultural Marketing (ISAM). The scheme provides assistance for the construction or renovation of godowns and warehouses in rural areas to boost the agricultural storage capacity. As of June 30, 2024, a total of 48,512 storage infrastructure projects, with a combined capacity of 940 lakh tons, have been sanctioned across 27 states. A subsidy of Rs. 4,734.73 crore has been disbursed for these projects.

One such market facilitation center has already been developed on a pilot basis by the Maharashtra Bamboo Promotion Foundation in eastern Maharashtra for the purchase and sale of farm bamboo. Who helped in forming the 'Vidarbh Bamboo Cluster' with more than 60 farmers who planted around 1.5 lakh plus Bamboo saplings in about 150 acres of their land and thus producing 750 metric tonnes of bamboo to sell.

Several national schemes and missions have been aligned to improve bamboo production in India. The Compensatory Afforestation Fund (CAF), National Rural Employment Guarantee Scheme (NREGS), Green India Mission and the National Bamboo Mission are few with high potential.

Under the Compensatory Afforestation Fund, several states have taken up the regeneration of bamboo in degraded land. Odisha restored approximately 70,950 hectare between 2010-2019 using funds. As of March 31, 2023, Rs. 55,292.40 crore was transferred to 34 states/UT under the CAF.

However, audit report by Comptroller and Auditor General has revealed that in many states, bamboo plantations under Compensatory Afforestation Fund were not fully successful due to encroachment of government forest land, lack of plantation and protectvvion initiatives by the forest department and plantation failures from forest fires and other pressure

In June 2023, a report by the Advisory Group on Bamboo Plantation under Mahatma Gandhi NREGS was published by the government of India. The report recommends promoting bamboo cultivation under MGNREGS to boost rural livelihoods, support environmental sustainability, and contribute to a nation's green economy. The report recommends using the NREGS scheme to undertake bamboo plantations on government and private land, including farmland and farm bunds, riverbanks, along railway lines and roads, and highways.

The key recommendations include a cluster-based approach for individual beneficiaries, especially in small landholders, where multiple beneficiaries work together on plantations and harvests, which makes logistics and transportation easier. Bamboo has a lateral root system, which makes it high in space and provides less scope for intercropping; however, a nominal space of 5X5 m for larger bamboos (160 bamboos per acre) and 3X4 m spacing for smaller bamboos (330 bamboos per acre) is recommended to improve the productivity of bamboo to a size of 8m in pole length and 7.5 cm in diameter. Priority should be given to bamboo species that best suit agroclimatic zones and soil conditions. Trimming culms beyond the required market pole length would also facilitate intercropping. Training and capacity building of Gram Panchayat are necessary for planting materials, irrigation, and market demand assessment, and the National Bamboo Mission could undertake the required training needs. The Green Skill Development Programme of the Government of India could also facilitate the required training.

Women Self Help Groups (SHG), FPOs and cooperatives must be sensitised on potential value addition in bamboo and processing such as Bamboo compressed biogas generation, Bamboo biomass waste to pellet.

Farmer Producer Organizations (FPOs), as collectives, have the potential to address the various input and output market constraints faced by cultivators in rural areas and have greater potential to harness market opportunities by increasing production and value addition. The government also promotes FPOs as a strategy to increase the income level of the farming community. Along with FPOs, self-help groups (SHGs) also play a major role in community-based institutions in improving rural livelihoods. The potential of bamboo and its products and collective strength of FPOs and SHGs as institutions can significantly contribute to improving rural livelihoods through entrepreneurship and skills. Identifying and building a proper value chain ecosystem based on bamboo products by bringing together FPOs, SHGs and other key stakeholders can contribute to improving the rural economy

The government of India has also introduced a draft National Policy on FPOs in June 2024, which aims to build a prosperous and sustainable ecosystem for the development of agriculture and allied sector/activities and to create an FPO ecosystem with a minimum of 7-8 active primary level FPOs in each block of the total 7256 blocks in the country. The policy would directly benefit 2.50 crore farmers (17 % operational holdings) out of a total of 14.64 crore farmers including 12.60 crore small and marginal ones (operational holdings as per the agriculture census, 2015-16) inhabiting 6,48,577 villages, with an average of 500 farm members per FPO.

5.4 Skill support

Under the Govt of India's Skill India Mission (SIM), the Ministry of Skill Development and Entrepreneurship (MSDE) delivers skill, skill, and skill training through an extensive network of skill development centers, colleges, and institutes under various schemes. Pradhan Mantri Kaushal Vikas Yojana (PMKVY), Jan Shikshan Sansthan (JSS), National Apprenticeship Promotion

Scheme (NAPS) and Craftsman Training Scheme (CTS) through Industrial Training Institutes (ITIs), to all the sections of the society across the country.

The SIM aims to enable the youth of India to acquire future-ready and industry-ready skills. Training is also provided through the National Institute for Entrepreneurship and Small Business Development (NIESBUD), the Indian Institute of Entrepreneurship (IIE), National Skill Training Institutes(NSTIs), and Training Centers registered on the Skill India Digital (SID) platform. A brief description of these schemes is provided below:

The Pradhan Mantri Kaushal Vikas Yojana (PMKVY) scheme is used to impart skill development training through Short-Term Training (STT), up-skilling, and re-skilling through the recognition of prior learning (RPL) to youth across the country, including in rural areas. The main target of the JSS is to impart vocational skills to the non-literates, neo-literates and the persons having rudimentary level of education and school dropouts upto 12th standard in the age group of 15-45 years, with due age relaxation in case of "Divyangjan" and other deserving cases. Priority is given to Women, SC, ST, OBC and Minorities in rural and urban low-income areas.

The National Apprenticeship Promotion Scheme (NAPS) aims to promote apprenticeship training and increase the engagement of apprentices by providing financial support to industrial establishments undertaking apprenticeship programs under the Apprentices Act, 1961. Training consists of basic and on-the-job training/ practical training at the workplace in the industry. In total, 42453 establishments were engaged in apprentices across the country.

Craftsmen Training Scheme (CTS) provides long-term training through Industrial Training Institutes (ITIs) across the country. ITIs offer a range of vocational/skill training courses covering a large number of economic sectors with the objective of providing a skilled workforce to the industry as well as self-employment of youth. The Skills Acquisition and Knowledge Awareness for Livelihood Promotion (SANKALP) scheme aims to improve the skills and knowledge of the workforce to provide better livelihood opportunities.

The National Skill Development Corporation (NSDC) is an industry-led, not-for-profit company that supports skill development initiatives by funding training programs and developing models for private-sector participation. The National Skill Development Fund (NSDF) provides financial resources to support skill-development programs, including those implemented by the NSDC.

The Ministry of Skill Development and Entrepreneurship is responsible for the coordination of all skill development efforts across the country, removal of the disconnect between demand and supply of skilled manpower, building the vocational and technical training framework, skill upgradation, building new skills, and innovative thinking not only for existing jobs but also for jobs that are to be created.

The Ministry aims to skill on a large scale with speed and high standards to achieve its vision of a 'Skilled India.' It is aided in these initiatives by its functional arms Directorate General of Training (DGT), National Council for Vocational Education and Training (NCVET), National Skill Development Corporation (NSDC), National Skill Development Fund (NSDF), 37 Sector Skill Councils (SSCs), 33 National Skill Training Institutes (NSTIs/NSTI(w)), about 15000 Industrial Training Institutes (ITIs) under DGT, and 187 training partners registered with NSDC. The Ministry also intends to work with the existing network of Skill Development centers, universities, and other alliances in the field. Further, collaborations with relevant Central Ministries, State governments, international organizations, industry, and NGOs have been initiated for multilevel engagement and more impactful implementation of Skill Development efforts.

Rural Self-Employment Training Institutes (RSETI), an initiative of the Ministry of Rural Development, Government of India, has dedicated infrastructure in each district to impart training and skill upgradation of rural youth geared towards entrepreneurship development. They are managed by banks with active cooperation from the central and state governments.

5.5 Research support

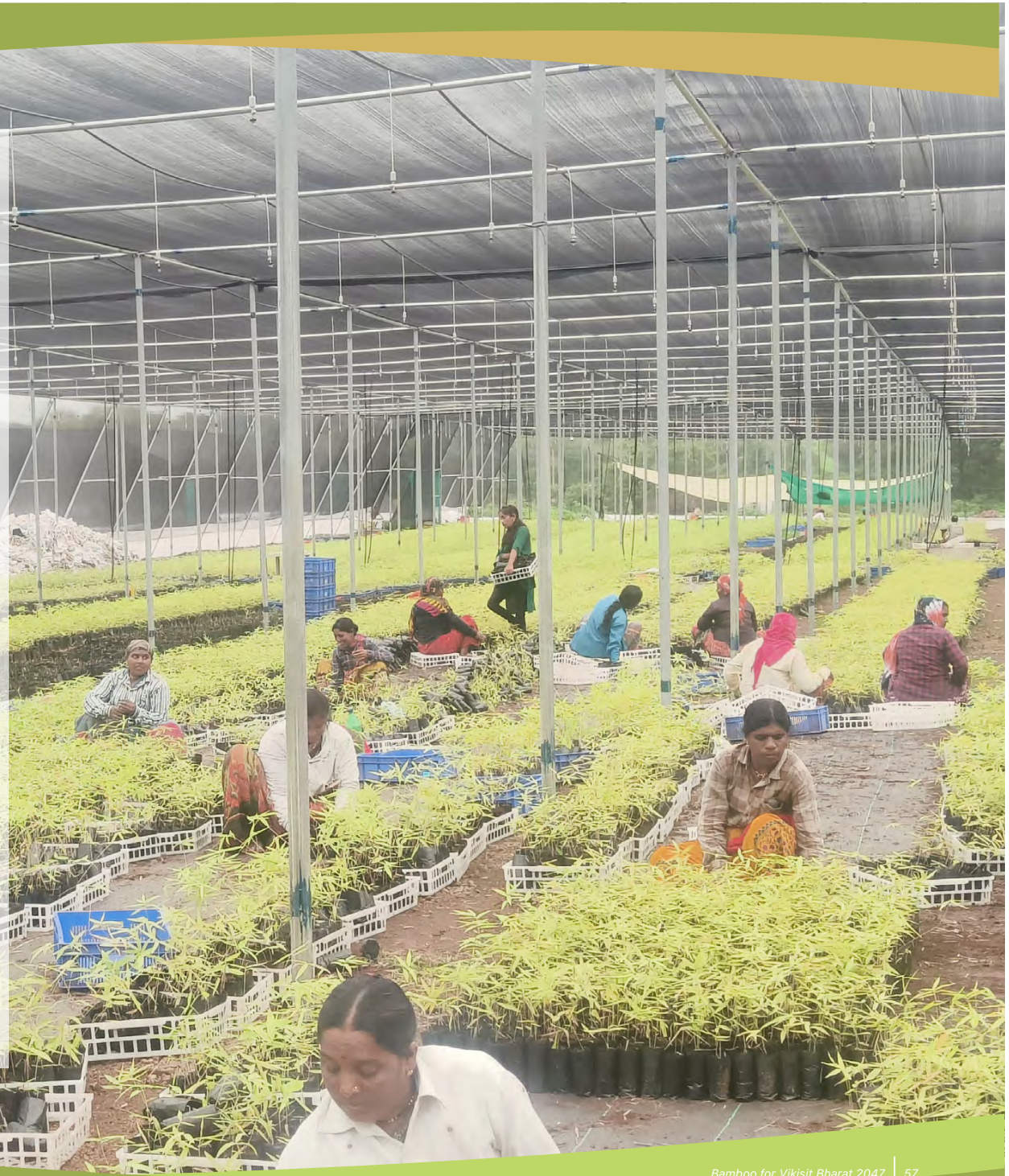
Bamboo research and training centre in Chandrapur, Maharashtra is an autonomous organization established by the Maharashtra Forest Department in December 2014. It was formed with a vision to become a premier institute in the Bamboo Sector through Research, Training, and Skill Development. The Bamboo Technical Support Group (BTSG) is hosted at the Kerala Forest Research Institute and is supported by the National Bamboo Mission of the Ministry of Agriculture and Farmers Welfare to provide technical support to the National Bamboo Cell. The center conducts around 12 training programs every year on bamboo construction, furniture, and other artisan works. So far over 2000 community members have been trained.

The National Institute of Design has set up a Center for Bamboo Initiatives (CFBI) at various campuses for activities related to bamboo-based research, design, technical development, and training. This is a platform for faculty members, students, and designers to innovate, experiment, and build new resources for the bamboo sector in India and abroad. CFBI also supports entrepreneurs with varied knowledge and connects various stakeholders to build bamboo-based ecosystems to popularize its applications. The center also participates in various events nationally and internationally to promote various new developments that took place at the NID for the advantage of the bamboo sector.

The Forest Research Centre for Bamboo and Rattan (FRC-BR) is one of the nine institutes and four centers under the aegis of the Indian Council of Forestry Research and Education (ICFRE), Dehradun, an autonomous body of the Ministry of Environment, Forests and Climate Change, Govt. of India. The FRC-BR was established in 2004 at Aizawl, Mizoram, as a unit of the Rain Forest Research Institute (RFRI) in Jorhat, Assam. The key objectives of the institute are to conserve the germplasm and have a germplasm bank for bamboo from the northeast region. In addition, nursery techniques and micropropagation of bamboo have been developed.

The Institute of Wood Science and Technology, under ICFRE, has been working on innovative wood products from bamboo. Bamboo is emerging as an important plant material alternative to wood required for panels and other sheet material, sawn wood including wood required for match splints, due to the growing shortage of industrial wood and also associated policy changes in recent years.

As a result of R&D efforts, a number of technologies have been developed that utilize bamboo as a principal raw material for the manufacture of bamboo mat boards and bamboo mat veneer composites as alternatives to plywood; bamboo mat-molded products such as trays are ideal substitutes for metals and plastics. Bamboo mat corrugated sheets is emerging as an alternate to corrugated sheets based on metals, asbestos-cement which are considered to be energy intensive as well as health hazardous. Bamboo splints for match sticks can replace wooden match sticks. However, sustained efforts are required for its adoption for commercial production, requiring technological backup, training activities, and creating awareness about the importance of these composites based on bamboo among various sections of people for its promotion, including marketing policies. State forest research institutes that are in many states can be developed into research and training centres for bamboo.



Tata Steel becomes the first Indian steel maker to introduce biochar to lower carbon emissions.

Source: Tata Steel, November 21, 2024

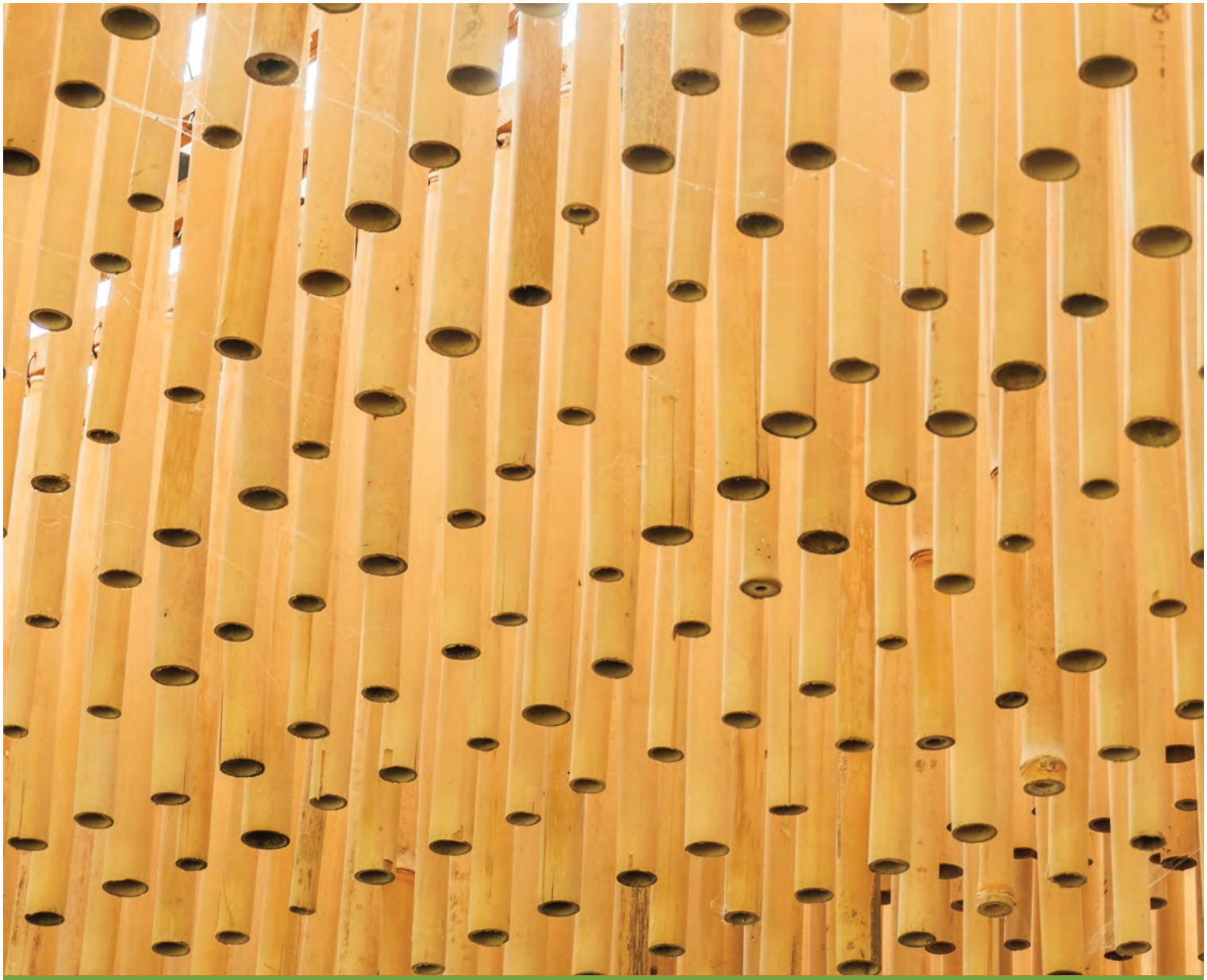
6 CONCLUSION

India's vast bamboo resources in over 23 million hectares of land and its potential for bamboo cultivation in another 4.4 million hectares of land means that there is a high opportunity for the bamboo economy within India to be a key exporter in the growing international bamboo trade. Recent government policies, such as blending 20 % ethanol in petrol, the coal and steel industries shifting towards biochar for co-firing, and technological advancements, making bamboo a useful resource in the construction, paper, pulp, and food industries, are likely to further spur domestic demand for bamboo in India.

Bamboo economy could also help India achieve multiple outcomes such as in the poverty alleviation of forest dependent communities and marginal farmers, carbon sequestration under the Paris agreement and forest restoration under the Bonn challenge etc. Over 13 million hectare of India's forests have bamboo, which could be sustainably harvested by state forest development corporations through Joint Forest Management and through Communities owning Community Forest Rights. Over 12 million hectare of bamboo grows outside of forestland.

To promote a bamboo economy, it is important to improve both domestic demand and supply. The government of India's current policies and schemes, such as the National Bamboo Mission, Agriculture Infrastructure Fund, Compensatory Afforestation Fund, and National Rural Employment Guarantee Scheme, all support the strengthening of the supply chain.

Frequently evaluating supply chain constraints and gaps in market linkages, policies, and schemes, and scaling up pioneering efforts such as co-firing bamboo in SAIL and ethanol production from bamboo in the Numaligarh refinery show promising signs of a strong future bamboo economy. Identifying and scaling up successful initiatives and business models could be a way forward.



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