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# From Agricultural Residue to Building Material: A Review of Bioplastic Applications in Construction

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## Abstract
*Construction is the second-largest consumer of plastic in the world after packaging, and almost all of that plastic is petroleum-based, non-degradable, and produced for buildings that will outlast it. This review paper synthesises current research on the use of bioplastic within the construction industry, drawing on published studies of waste-derived polymers and their behaviour in building applications. The review compiles findings on bioplastics produced from organic waste streams — potato skin, fruit residues, rice straw, and jute fibre — and evaluates their reported performance against the requirements of seven construction application areas: erosion-control geotextiles, thermal insulation, composite panel boards, fibre reinforcement for cement and concrete, moisture barriers and films, drainage piping under no pressure load, and short-term site materials. For each category, the review draws together evidence from the recent literature comparing candidate bioplastics with the petroleum plastic they would substitute, using four selection criteria that drive real-world specification: mechanical behaviour, durability under exposure, cradle-to-gate carbon impact, and price. The collected evidence supports a nuanced rather than uniform verdict. Reviewed studies indicate that for applications involving short service life or contact with soil geotextiles being the clearest example, alongside temporary site barriers bioplastic already makes good engineering sense. Insulation panels and partition boards show strong potential pending further work, while structural roles and pressurised pipework sit outside what current bio-based materials can handle. The paper concludes by consolidating the research gaps identified across the reviewed literature, pointing to the questions that must be addressed before wider industrial adoption becomes feasible.*

***Keywords:*** *Bioplastic; Biodegradable building materials; Cellulose nanocrystals; Embodied carbon; Geotextile; Natural fibre composite; Sustainable construction.*

## 1. Introduction
There's a plastic problem in the construction sector that doesn't get the same attention as packaging. About one-fourth of all plastic manufactured is used in buildings pipes, insulation foams, window frames, vapour barriers, electrical conduits, flooring, and sealants. It is inexpensive, long-lasting, and simple to install. It is also fossil-derived, and once in the building it is likely to remain there for decades, until it goes to landfill when the building is demolished. An earlier review by the same authors focused on the

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use of organic wastes, such as potato peel, banana and jackfruit peels, mangosteen rinds, rice straw, jute fibre, and other agri-residues, to produce bioplastic. That work was in the field of production chemistry. This paper continues the discussion and asks the more practical question: can any of those bioplastics be applied in the field of construction, and if so, where? The answer is not "everywhere." There are physical constraints to bioplastics based on organic waste. Fruit peels produce films which are too weak to be used structurally. Starch-based materials do not withstand moisture and cannot be used outdoors for long periods. PLA melts at temperatures any south-facing facade will attain during summer. The honest answer is that bioplastic should be used in construction where it would replace conventional plastics that are already discarded, sacrificial, or in protected in-building locations. That is still a substantial fraction of plastic used in construction, and it is important that it be replaced [1, 2].

### 1.1. Objectives

This paper has three aims. The first is to present the current and potential future use of bioplastics in the construction industry in relation to the previously mentioned feedstocks. The second is to compare the bioplastic candidates with the conventional plastics they would replace, using the metrics that are most relevant for selecting materials on a building site: mechanical performance, durability under exposure, embodied carbon, and cost. The third is to pinpoint the missing pieces — the applications in which bioplastic is not yet ready, and what research is required to make it ready.

## 2. The Plastic Problem in Construction

In total, the construction industry uses around 70 million tonnes of plastic per year, and approximately 28% of this amount is PVC [19]. Most of this plastic will not see sunlight after it is installed it is either buried in a wall, embedded in a floor, or laid below grade but it must still be manufactured, transported, installed, and disposed of. The worst part is at the end of life: end-of-life waste streams from construction are generally difficult to recycle, leading to landfill or incineration. The uses of conventional plastic in buildings are summarised in Figure 1. Leading the list is PVC pipes and conduits, followed by insulation foams (EPS, XPS, polyurethane) and uPVC window frames.

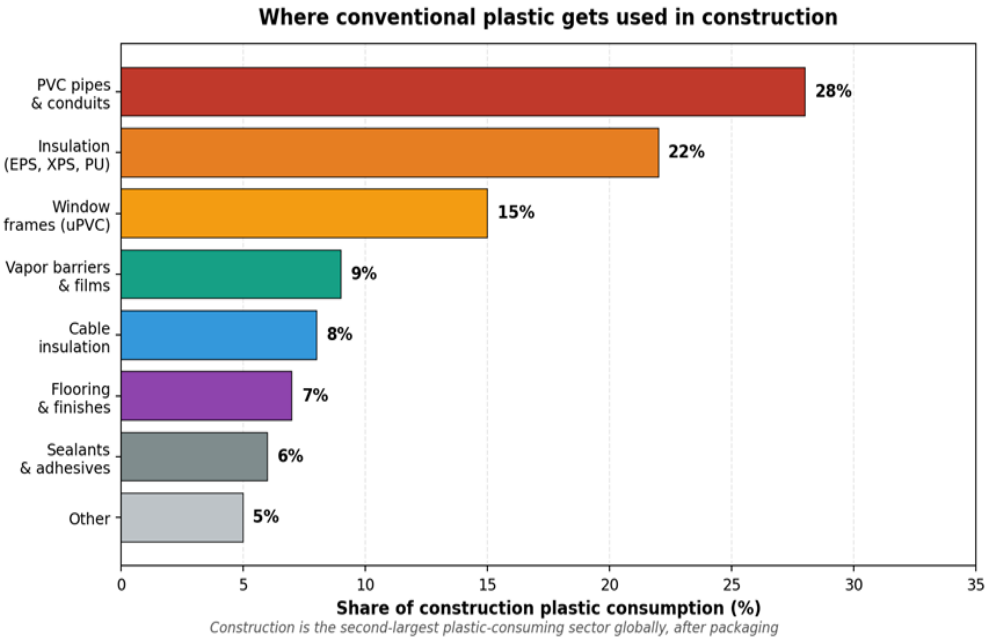


**Figure 1 Breakdown of Conventional Plastic Consumption in the Construction Sector by Application**

These three categories account for approximately two-thirds of construction plastic. The remaining

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one-third is distributed between vapour barriers and cable insulation, flooring, sealants, and a long tail of smaller applications. Two patterns are important for what follows. The first is that a substantial portion of plastic in the construction industry takes on short-life or sacrificial functions — such as vapour barriers for slab construction, temporary site fencing, plastic release film for forming, and slope-stability geotextile. These are cases where the plastic is required to perform its function for a period of months or years and then move out of the way. The second is that even applications with long potential service lives (pipes, insulation, panels) are typically located in protected positions inside the building, away from direct UV exposure, high mechanical stress, or immersion in water. For bioplastics, that is good news: their weaknesses lie precisely in those three areas.

## 3. Bioplastic Feedstocks: A Quick Recap

It is worthwhile to provide a brief review of the feedstocks considered in the previous review, since each one has a particular niche in construction applications. Potato peel starch films are flexible but very weak in mechanical strength and sensitive to water [4, 6]. Banana peel pectin films are similar, with high elongation and low strength, and biodegrade in two weeks when in contact with soil [3]. Pineapple and jackfruit cellulose extracts provide better mechanical performance, with jackfruit nanocellulose offering improved thermal stability for higher-temperature applications [3, 9]. The highest tensile strength is provided by mangosteen-CNC composites, which is in turn accompanied by the poorest elongation [10]. Rice straw and jute directly provide cellulose fibres that can be used in composites jute fibres are particularly close to the tensile strength of glass fibre on a weight-for-weight basis [11, 17]. Of the available bio-based plastics, PLA (a corn or sugarcane-based fermentation product) is the only one with a proven track record in construction-related applications such as 3D printing of disposable products. These feedstocks are plotted in Figure 2 against the construction applications that are the focus of this paper. A good fit is shown in green and a poor fit in red. After studying the patterns, the rules become apparent: lignocellulosic fibres (rice straw, jute) are applicable for nearly all uses except pressure piping; soft starch films (potato, banana) are confined to indoor or short-life applications; and PLA can do almost anything at a cost.

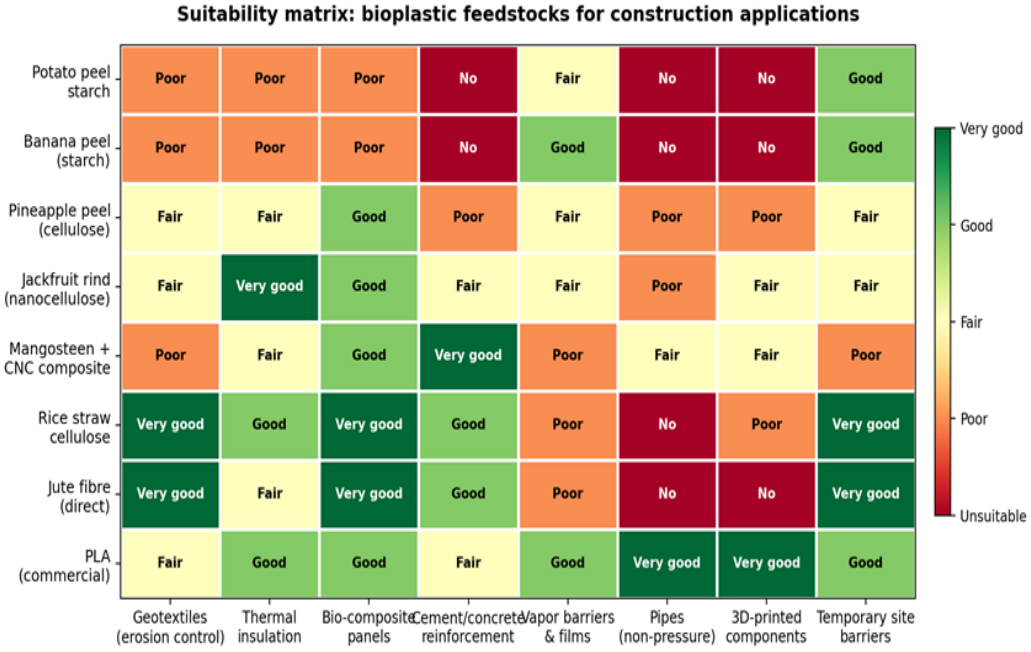


**Figure 2 Suitability Matrix Mapping Eight Bioplastic Feedstocks Against Eight Construction Applications**

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## 4. Application Categories

### 4.1. Geotextiles and Erosion Control

The first and longest-standing use of bioplastics in the building industry is for geotextiles. Many situations require a fabric that retains soil to protect slope stability, reinforces banks, and provides protection against erosion until vegetation is established, and that ideally does not interfere with that vegetation. Synthetic polypropylene geotextiles excel at the first job (long-term durability in the ground) but persist as microplastic for decades after the slope no longer requires them. The first choice here is obvious: jute and rice straw geotextiles. Both are constructed from natural cellulosic fibres, and both biodegrade in soil 12 to 24 months after construction a time frame that aligns well with re-assumption of the load by vegetation. Jute geotextiles are already commercially available in India and Bangladesh and have been successfully employed on highway slopes, riverbank slope protection, and construction sites. Rice straw mats, cheaper and more readily available, suffer from a lack of standardisation but are adequate for most applications in rice-growing regions. The slope-stabilisation requirement over time is plotted in Figure 3 alongside the degradation curves of various geotextile materials. The synthetic polypropylene curve is essentially flat (the material outlives its purpose by orders of magnitude). The plain jute curve loses strength too rapidly for some applications (significant loss in months 3 to 8). The closest match to the demand profile is the PLA-coated jute curve, which provides strength during the critical period for vegetation establishment and breaks down thereafter.

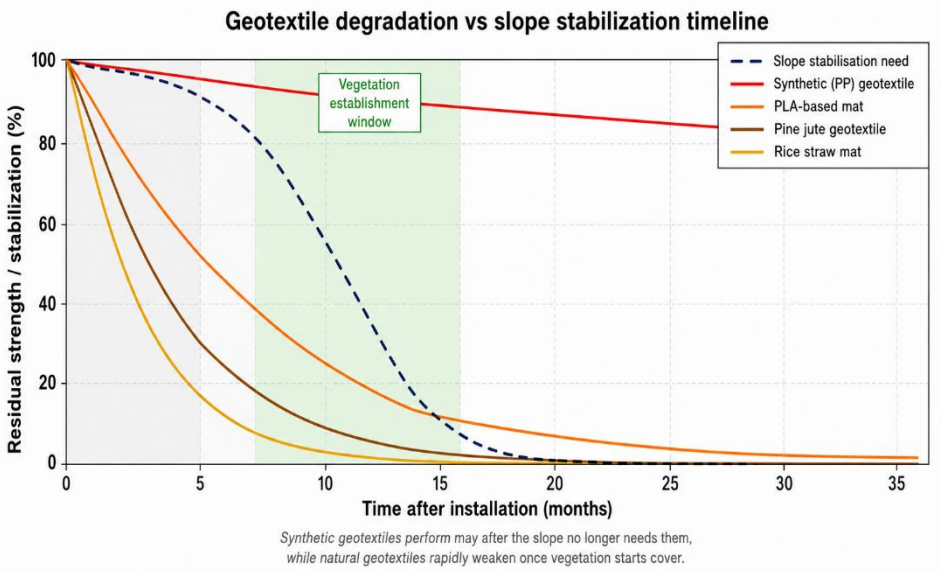


**Figure 3 Geotextile Retained Strength Over Time Vs Slope-Stabilisation Demand.**

There is no doubt about the verdict for this category. Bioplastic geotextiles are not only viable; they are the right material for the job. Persistence of synthetic polypropylene is a true environmental liability, and the material is over-engineered for the application.

### 4.2. Thermal and Acoustic Insulation

Insulation is the second-largest sector of building plastic [19]. The dominant materials are expanded polystyrene (EPS), extruded polystyrene (XPS), and polyurethane foam, the most competitive on price as well as thermal performance. They have known issues too high embodied carbon, end-of-life difficulty, and significant fire-performance concerns following incidents such as the Grenfell Tower fire of 2017. A small but growing market exists for insulation based on biological materials. Rice straw bales have been used in straw-bale construction for more than a century, with thermal conductivity in the range of 0.045–0.060 W/mK comparable to EPS [15]. The constraint is moisture: straw walls must be very carefully detailed to remain dry, and insurers remain wary. Compressed rice straw boards combined with

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a bio-resin (potato starch or PLA) are a more buildable alternative, with thermal conductivity around 0.060 W/m·K and mechanical strength suitable for partition walls. An emerging research field involves nanocellulose foams derived from jackfruit (Artocarpus heterophyllus) stems. Jackfruit-derived nanocellulose has been shown to be thermally stable [3, 9] and could be considered for foamed insulation, but it has yet to reach industrial production. The same is true for pineapple-derived bacterial cellulose foams. As shown in Figure 4, the processing of a bio-composite panel using rice straw fibre and starch-based bio-resin produces a panel suitable for use as a partition wall or non-load-bearing insulation panel.

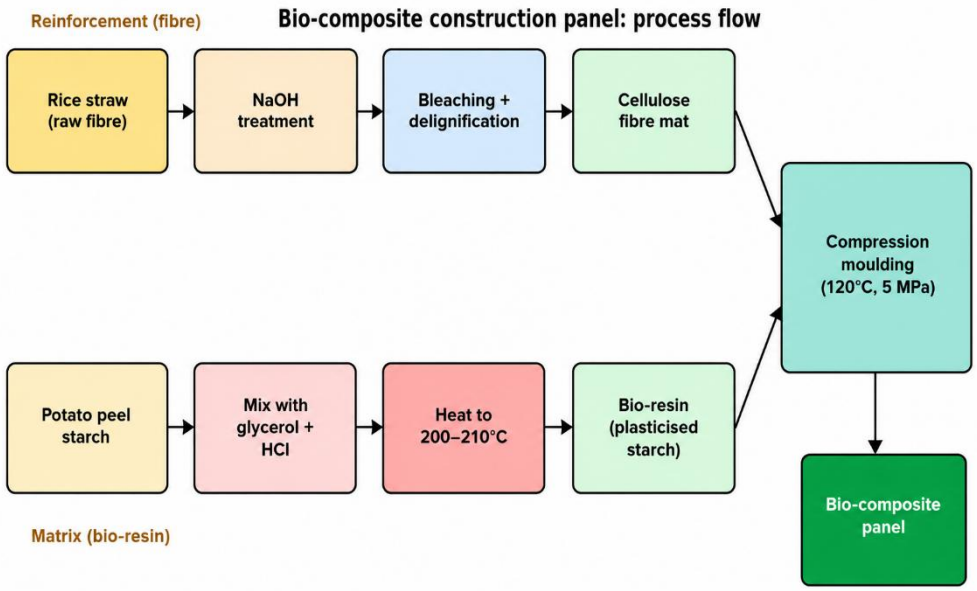


**Figure 4 Process Flow For A Bio-Composite Construction Panel Using Rice Straw Fibre As Reinforcement And Potato-Peel Starch As Bio-Resin Matrix**

### 4.3. Bio-composite Panels and Boards

The most widely used partition and sheathing materials in construction are particle board, MDF, and plywood. Most of these use formaldehyde-based resins that continue to off-gas for many years after installation and are a recognised indoor air quality (IAQ) issue. By replacing the petroleum-derived resin with a bio-resin and the wood fibre with an agricultural-residue fibre, a fully bio-based panel becomes possible. The most common approach in the literature is to use rice straw or jute fibre as reinforcement, bound by a starch-based or PLA bio-resin, then compression-moulded at moderate temperature. Reported tensile strengths range from 30 to 75 MPa, comparable to MDF and around 60–80% of typical plywood [12, 17, 20]. The bond between the cellulose fibre and the starch matrix is the limiting factor; the cellulosic surface is generally treated with alkali (NaOH) or silane coupling agents to enhance the bond and increase tensile strength. Mechanical performance of bio-based and conventional construction plastics is compared in Figure 5. There are two takeaways. First, jute-fibre and rice-straw composites compare well to PVC on a tensile-strength basis and even outperform HDPE. Second, they are still well below the high-performance conventional plastics such as glass-fibre-reinforced polymer but so are the requirements for partition walls and non-structural panels, where the design loads are well within the bio-composite's capabilities.

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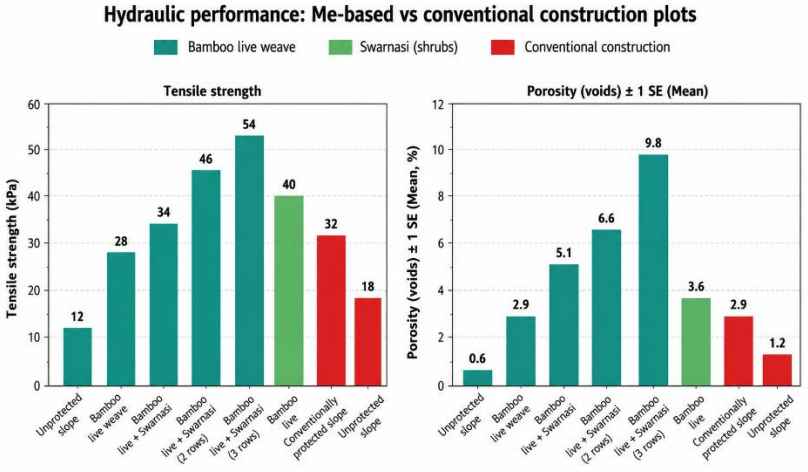


**Figure 5 Tensile Strength and Young's Modulus Comparison for Bio-Based Vs Conventional Construction Plastics**

### 4.4. Cement and Concrete Reinforcement

It is here that things start to take a turn for both better and worse. The addition of natural fibres to cement and mortar to improve crack resistance is not new; several fibres have been tried over the decades, including coconut coir, sisal, jute, and rice straw [13, 20]. Results are inconsistent. The toughness improvement that occurs at early age is often lost after several years, as the natural fibres degrade in the alkaline pore solution of cement. The newer and more promising option is cellulose nanocrystals (CNCs). CNCs produced from rice straw, jackfruit rind, or mangosteen peel can be incorporated in cement paste at 0.1–0.5 wt %. At those loadings, published studies report flexural-strength improvements of 20–30% and significantly improved hydration kinetics at early ages [16]. Two effects appear to drive this behaviour: a nucleation effect, in which the CNCs accelerate cement hydration, and bridging of early micro-cracks. The limitations are dispersion and cost. CNCs tend to clump together when incorporated in a cement formulation, so surfactants or specialised mixing procedures are required. CNC prices remain quite high, typically several hundred USD per kg in 2024, but can be significantly reduced when the source is agricultural waste rather than purified cellulose. As things stand, CNC-reinforced cement remains a research material rather than a product in field use.

### 4.5. Vapour Barriers and Films

Under slabs, behind drywall, or in attic floors, vapour barriers are short-life applications where the film does not face UV or significant mechanical load. The standard is 6-mil polyethylene film: it is inexpensive, gets installed in the wall, and remains there for the life of the building. In principle, banana pectin films and jackfruit nanocellulose films can perform the same function. Banana pectin films have shown satisfactory water-vapour transmission rates in laboratory tests and biodegrade in soil within two weeks [3] a desirable end-of-life characteristic, but undesirable if the film comes into contact with water during its useful life. Jackfruit nanocellulose films exhibit better water resistance and are more promising candidates. However, bio-based vapour barriers are not yet economical. The polyethylene films they would replace cost less than half a US dollar per square metre. Bio-based alternatives currently cost three to five times as much at present production scales. The barrier here is not technical — it is cost parity.

### 4.6. Pipes, Conduits, and 3D-printed Fittings

There is at present no pressure piping made from bioplastics. PLA melts at around 60°C, well below any hot-water or process-line temperature. Starch-based plastics swell and weaken in the presence of water. For pressure applications, PVC and HDPE will continue to be the obvious choice. Non-pressure drainage and ventilation conduits, however, are a different matter. PLA conduits with adequate wall thickness are suitable for use as gravity drainage, dust extraction, or electrical conduit under low load. The market is small but expanding, and 3D printing of

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bespoke fittings connectors, junction boxes, and terminal mounts is a particularly good fit for PLA. The combination of low-volume custom geometry plays directly to PLA's strengths, as does the indoor-only service environment.

### 4.7. Temporary Site Materials

Construction sites consume vast quantities of short-life plastics: site fencing, hoarding, safety nets, formwork release films, dust barriers, and packaging for materials arriving at site. Most of this plastic is used for weeks or months and then disposed of. Substitution here is technically simple and offers a high environmental benefit per kilogram, since the plastic was being thrown out anyway. Rice straw mats and jute fabric are suitable substitutes for site fencing and dust barriers. Banana pectin films can replace polyethylene wrap for short-term material protection. Potato-peel-derived starch films can be used for indoor formwork-release applications. All of these are realistic technically feasible, and since volumes are small, the price difference relative to standard plastics is not extreme.

## 5. Application Summary

The application analysis is summarised at a glance in Table 1. For each category of use, the table gives the best-suited bioplastic feedstock, the displaced conventional plastic, and a one-line assessment of bioplastic readiness.

**Table 1 Bioplastic Applications in Construction Best-Fit Feedstock, Displaced Plastic, and Readiness**

| Application | Best-fit bioplastic | Displaces | Readiness |
|---|---|---|---|
| Geotextiles, erosion control | Jute, rice straw, PLA-coated jute | Polypropylene geotextile | Commercial; deployed at scale in some regions |
| Thermal insulation | Rice straw composite, jackfruit nanocellulose foam | EPS, XPS, polyurethane foam | Near-commercial; moisture detailing is the constraint |
| Bio-composite panels, boards | Rice straw + bio-resin, jute fibre + PLA | MDF, particle board with formaldehyde resin | Pilot scale; cost is the gating issue |
| Cement, concrete reinforcement | CNC from rice straw or jackfruit | Polypropylene fibre, polymer admixtures | Research stage; dispersion and durability uncertain |
| Vapour barriers, films | Banana pectin, jackfruit nanocellulose film | Polyethylene film | Research stage; cost gap is large |
| Pipes (non-pressure) | PLA | PVC, HDPE drainage pipe | Niche; suitable for indoor drainage and ventilation only |
| 3D-printed fittings | PLA | Injection-moulded ABS, PVC fittings | Commercial for small parts; useful for custom and prototype work |
| Temporary site materials | Rice straw, jute, banana pectin film | PE wrap, PP fencing, PVC dust barriers | Commercial; easy substitution, cost premium is small |

## 6. Where Bioplastic Fits in a Building

It helps to visualise this. A typical residential building is shown in Figure 6 with the locations of potential bioplastic use indicated. Geotextile is used under the foundation (below grade). Insulation panels fit within the wall cavities. A bio-vapour barrier is installed beneath the roof tiles. The exterior is finished with cement plaster reinforced with CNCs. Bio-PLA fittings are used for electrical conduit and in-house drainage. Temporary site barriers serve their purpose

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during construction and are then composted.

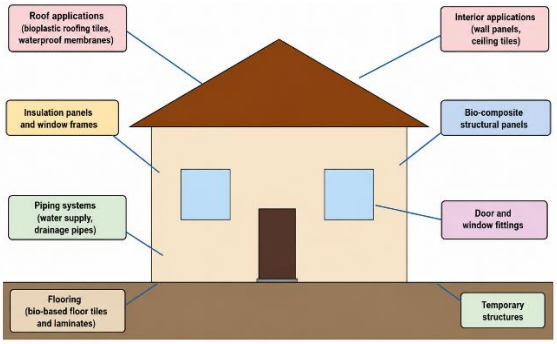


**Figure 6 Bioplastic Deployment Zones in a Typical Residential Building**

Worth highlighting in this picture is the extent to which plastic material used in different parts of a building can be substituted by a bio-based alternative. Structural elements remain conventional concrete, steel, masonry. Conventional plastic is retained for high-stress applications such as pressure piping. All of the other application areas, on a per-application basis, have a bio-based research or commercial candidate.

## 7. Lifecycle and Economic Considerations

Mechanical performance is only one side of the material-selection question. The other two are embodied carbon and cost — and these often determine which materials are ultimately specified. Cradle-to-gate embodied carbon for the materials discussed in this paper is plotted in Figure 7. The pattern is clear. Waste-derived bioplastics fall below 1 kg $CO_2e$ per kg of material: rice straw composite, jute board, banana pectin film. Crop-derived bioplastic (PLA from corn) carries an additional cost from agricultural inputs but remains below conventional plastics. Within the 2–3.3 kg $CO_2e$/kg range, the conventional plastics PVC, polypropylene fibre, HDPE, and EPS are clustered together. EPS is the worst performer. Wood, included for reference, is the lowest-impact option. The harder issue is cost. Processing of waste streams into bioplastics is, in principle, a low-cost process the raw material is cheap or free but production is not yet at scale. The cost per kg of waste-derived bioplastic in 2024 is typically two to four times that of the conventional equivalent. PLA is closer to parity, around 1.5 to 2 times. Once production scales up, this gap closes; until then, it remains the classic Catch-22 of any new construction material. Two policy levers would shift the economics. The first is internalising the end-of-life cost of conventional plastic: landfill fees, microplastic clean-up, ocean-plastic remediation. The second is preferences in public construction procurement for low-carbon materials, which already exist in some EU countries.

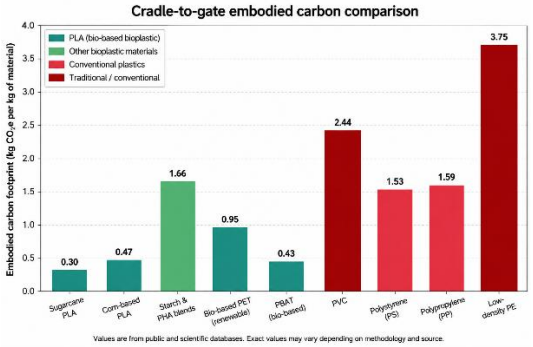


**Figure 7 Cradle-To-Gate Embodied Carbon for Bio-Based and Conventional Construction Material**

The harder issue is cost. Processing of waste streams into bioplastics is, in principle, a low-cost process the raw material is cheap or free but production is not yet at scale. The cost per kg of waste-derived bioplastic in 2024 is typically two to four times that of the conventional equivalent. PLA is closer to parity, around 1.5 to 2 times. Once production scales up, this gap closes; until then, it remains the classic Catch-22 of any new construction material. Two policy levers would shift the economics. The first is internalising the end-of-life cost of conventional plastic: landfill fees, microplastic clean-up, ocean-plastic remediation. The second is preferences in public construction procurement for low-carbon materials, which already exist in some EU countries.

## 8. Limitations and Open Challenges

Several open technical questions remain. The first is the durability of bio-composite panels under prolonged moisture exposure. Laboratory tests show acceptable performance over several months; field tests over years are sparse. The second is fire performance. Cellulose-based products are combustible, and the use of fire retardants will

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increase both cost and embodied carbon. The third is in-service degradation by fungi and microorganisms, which is a property that should ideally be expressed only at end of life: degradation after disposal is good; degradation while in the wall is bad. Supply-side restrictions are different. Rice straw is readily available in rice-growing areas and is mostly treated as waste (often burned, with the resulting air pollution during the rice-growing season). The opportunity to build a rice-straw supply chain feeding composite-panel production is real but will require investment in collection and processing equipment. Jute is a commercialised fibre. The most difficult feedstock is fruit waste it is geographically diffuse, seasonal, and variable in composition. Building codes are another restriction. Most national codes specify materials in terms of performance fire rating, structural capacity, moisture transmission but the materials currently listed as code-approved are predominantly conventional plastics. Getting bioplastics onto approved-material lists is a slow and expensive process. This barrier is worth highlighting because it is institutional rather than technical, and it slows adoption even where the technical case is sound.

## 9. Future Research Directions

Five research questions stand out. First, long-term measurement data on bio-composite panels and films exposed under realistic conditions, not only in accelerated laboratory weathering chambers. Second, dispersion and durability of CNC reinforcement in cement, with focus on the alkaline-pore-solution problem that has historically undermined natural-fibre cement composites. Third, fire performance of rice straw and jute composites, including the trade-off between fire retardants and embodied carbon. Fourth, supply-chain economics of agricultural-residue collection for construction-grade bioplastics, with case studies from rice-growing and jute-growing regions. Fifth, comparative life-cycle assessment that includes end-of-life rigorously cradle-to-grave rather than only cradle-to-gate with realistic disposal scenarios for both bio-based and conventional construction plastics.

## Conclusion

Bioplastic in construction is not a single substitution question. It is a series of application-specific questions, each with a different answer. For geotextiles and temporary site materials, the answer is already yes bioplastics are technically and increasingly economically viable. For insulation and bio-composite panels, the answer is yes if cost can be reduced and moisture issues addressed. For cement reinforcement and vapour barriers, the answer is at the research stage but promising. For pressure piping and structural members, conventional plastics will remain. The honest framing is this: bioplastics from organic waste have a future and are beginning to enter use in the construction sector, but they will not displace petroleum plastic across the board. What they can do is replace some of the short-life, protected-environment plastics that currently account for a significant share of construction-sector plastic use, while feedstocks and production techniques mature for other uses. It is a useful contribution that aligns well with the broader push toward circular-economy thinking in the building industry.

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