WORM

Waste in humanitarian Operations:
Reduction and Minimisation

D1.5. Technical and economic viability assessment of bio-based alternatives

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LIST OF ACRONYMS

ACRONYM	FULL NAME
Bio-PP	Bio-polypropylene
Bio-PU	Bio-polyurethane
EC	European Commission
HO	Humanitarian Organisation
PHA	Polyhydroxyalkanoates
PLA	Polylactic Acid
PPE	Personal protective equipment
rPET	Recycled Polyethylene
TPS	Thermoplastic Starch
VFF	Vietnam Fatherland Front
VNRC	Vietnam Red Cross
WPs	Work Packages

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BACKGROUND ABOUT WORM

WORM aims to design guidelines and support actions for circular economy in the humanitarian sector. It integrates bio-based technological solutions, leverages procurement for waste reduction, improves waste management methods and prioritises the sustainable livelihoods of waste pickers. WORM focuses on two selected settings: field hospital deployments and humanitarian livelihood programmes with a waste picking component. Following a collaborative and multi-actor approach, WORM brings together medical and humanitarian organisations (HOs), procurement service providers, logistics providers, waste management services and academic partners.

EXECUTIVE SUMMARY

This document is a deliverable of the WORM Project, funded under the European Union's Horizon Europe research and innovation programme under the grant agreement No 101135392.

The aim of this document is to:

- Assess the technical and economic viability of bio-based solutions for the indicated priority medical products.
- Attention to be paid to medical requirements, local livelihoods, and technical viabilities.

The document highlights global trends in relation bio-based and biodegradable alternatives to our five priority products. The discussions are further delineated along our two focal countries of Vietnam and Kenya where we breakdown material developments across both nations detailing key manufacturers. This highlights the availability and subsequent accessibility of such bio-based and biodegradable alternatives for deploying humanitarian organisations. A significant challenge with a viability analysis is understanding how such alternative materials progress through a humanitarian waste management value chain. Summarily, whilst there is substantial interest from humanitarian organisations, there is little evidence of implementation borne from increased cost of such bio-based alternatives and the inability of manufacturers to scale production due to limited local infrastructure. Downstream, there is no clear tracking of such bio-based alternatives within the subsequent waste management value chain thus presenting immense gaps (and opportunity) in discerning the underlying socio-ecological impacts of such materials within humanitarian operations.

NON-TECHNICAL SUMMARY

The selection and inclusion of bio-based and biodegradable materials is about maintaining a balance between functionality and sustainability for humanitarian operations. Within our focal countries of Vietnam and Kenya, we highlight the accessibility of such bio-based alternatives of our priority products. In both contexts, there is increasing developments in the production of bio-based materials, however, such developments are still limited by production capabilities and a dependence on international manufacturing and technology. This results in increased costs reducing the underlying viability such bio-based alternatives, which in turn limit their implementation across humanitarian operations across both focal nations.

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INTRODUCTION

As indicated prior, the selection between conventional synthetic or bio-based and biodegradable materials is crucial in maintaining balance between sustainability and functionality especially within humanitarian field hospital settings. The inclusion of such materials/items within humanitarian activities can significantly reduce the inherent waste in the ecological setting as such materials breakdown more quickly via natural processes. Moreover, bio-based materials are derived from biological sources further offering the advantage of reducing overall carbon footprints. Invariably, such waste attributes are desirable given that our field hospital settings are often characterised by poor waste management infrastructure, for example, a warzone, or refugee camp clinic.

However, there is essential need in considering the availability and performance of such materials within our localised settings. Availability is an upstream humanitarian supply chain procurement argument, and it is necessary to ensure that there is a readily available source of such alternatives for our priority products. Likewise, the bio-based alternatives should also meet the required performance and safety standards suitable for medical use within our field hospital settings. The following technical and viability case reports will put forth considerations for the implementation of bio-based alternatives of our priority products within our context settings of Vietnam and Kenya.

The remainder of the report is organised as followed. In Section 1, we highlight the available bio-based alternatives to our priority products along with the relevant technologies. Sections 2 and 3, will illustrate our case-briefs for Vietnam and Kenya with specific focus on the development of bio-based alternatives of our priority products. These sections will also indicate local availability of bio-based materials and the prevalence of waste management practices to support in the processing of said materials. Section 4 summarizes the main conclusions.

Bio-based alternatives of priority products

Globally the market for bio-based medical products is expanding rapidly, driven in part by evolving environmental regulations, material innovation for biodegradables, and, more importantly for WORM, increased healthcare demand. Such demand also generates a greater focus on the environmental impact of subsequent medical waste management generation and a desire to reduce institutional ecological footprints without any diminishment of safety and performance (Joseph et al., 2023). As part of the WORM project, we have identified five priority product groups within our field hospital setting – personal protective equipment (PPE), syringes and needles, sharps containers, body bags, and temporary water/sludge bladders.

Whilst there have been material innovations across these five priority products there is increased evidence of enhanced traction within the market for medical disposables such as PPE, surgical mesh, and sutures. This is also the case for syringes and needles where innovation in biodegradable materials polylactic acid (PLA), and bio-polypropylene have fostered growth, whilst circular business models have mitigated high production costs making such alternatives more economically viable (Joseph et al., 2023).

However, the adoption of such bio-based alternatives is still plagued by many issues, including scalability of technology and supply chain limitations. These are further exacerbated within challenging settings such as emerging markets where there can be technological gaps and a lack of knowledge on such materials (Hatvani et al., 2022). Moreover, whilst costs are falling with continual developments in technology and innovative business models, cost-effectiveness remains a persistent obstacle as HOs contend with the challenges of balancing performance and affordability (Burelo et al., 2023).

Building from D1.1. the scoping exercise and the identification of our five priority products within a medical setting, we delineate commonly used bio-based material alternatives for PPE, syringes and needles, sharps containers, body bags, and temporary water or sludge bladders in Table 1.

Table 1 Bio-based material alternatives for the identified five priority products

PRIORITY PRODUCT	BIO-BASED MATERIAL ALTERNATIVE
PPE	**Natural rubber latex** • Sourced from rubber trees • Appropriate elasticity and adequate protection • Some risk associated to allergic reaction from use
	Polylactic acid • Derived from fermented sugars such as corn and sugarcane • Compostable polymer used in the manufacture of face masks and gown linings • Lower durability under stress compared to conventional materials.
	Cellulose-based fibres • Fabrics from cellulose derivatives • Use in the manufacture of surgical gowns and mask • Enhanced breathability and biodegradability

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Syringes and needles	**Polyhydroxyalkanoates (PHA)** • Microbial polymers utilised in the experimental manufacture of syringe components • Enhanced biodegradability • Production costs limit scalability at this stage
	Polylactic acid (PLA) blends • A combination of PLA with other (conventional) materials used in the production of disposable syringes • Yet to consistently meet the technical and mechanical requirements
Sharps containers	**Bio-polypropylene (Bio-PP)** • Derived from renewable sources such as sugarcane and coffee ground • Offers enhanced durability and biodegradability
	Polylactic acid (PLA) with additives • PLA with reinforcing agents such as a nanocellulose • Reinforcing agents provide the strength required for a sharps container • Durability in extreme conditions is questionable
Body bags	**Starch-based bioplastics** • Extracted from carbohydrate-rich plants such as corn, and potatoes • Offers enhanced compostability and biodegradability • Mainly for short-term applications
	Polyhydroxyalkanoates (PHA)-based films • PHA-based films offer better durability than starch-based bioplastics • More resilient as a material
Temporary water or sludge bladders	**Thermoplastic starch (TPS)** • TPS films derived from starch • Suitable for temporary water storage • Continued concern about durability in extreme conditions
	Bio-polyurethane (Bio-PU) • Widely derived from plant oils • Currently being tested for used as sludge bladders due to their material flexibility and water resistance • Promising alternative to conventional synthetic materials

Case brief - Vietnam

Vietnam has emerged as a promising market for bio-based and biodegradable materials, especially within healthcare use cases. Such growth is fostered by supportive public and private policies, such as active promotion of sustainability through central government decrees, increased green manufacturing initiatives encouraging private sector infrastructure investment, and in-bound knowledge capability building via numerous international collaborations. This has led to Vietnam's traditional materials sectors, such as rubber and plastics, exploring bio-based and biodegradable alternatives to comply with evolving environmental regulations (Rinn et al., 2024). Moreover, there is also increased motivation from international stakeholders to further sector capabilities with these materials given Vietnam's export-oriented economy and growing demand from foreign clientele for sustainable provisions.

Locally, the implementation of new and enforcement of existing sustainability regulations in medical practice has also driven the demand for bio-based and biodegradable materials within the Vietnamese healthcare sector. This has led to increased adoption of bio-based PPE and more robust waste segregation at source to minimise plastic waste and meet global environmental standards. This increased demand from the healthcare sector has also spurred regional private-sector investment, with companies such as Hyosung TNC setting up production facilities within the country with the hopes of capturing early market share (Van, 2024). These larger companies within the bio-based material sector are joined by a buoyant and innovative start-up environment that understands the local Vietnamese agricultural ecosystem and the subsequent by-products that can be exploited for the development of bio-based and biodegradable materials (Rinn et al., 2024).

As a sector, bio-based and biodegradable materials for healthcare present substantial opportunities for growth. Currently, the sector sits within a research and development (R&D) phase, with numerous groups exploring the ecological benefits of new materials as well as innovative use cases. For example, there are existing projects exploring the manufacture of face masks utilising banana fibres via non-standard thermal pressing methodologies (Natural Resources and Environment, 2024). Other notable developments within the Vietnamese bio-based material sector are with polylactic acid and chitosan – materials extracted from plant- and crustacean-based sources respectively. Moreover, Vietnam's largely agriculturally focused economy, also provides numerous material sources for the development of bio-based healthcare supplies.

The outcomes of such material experiments highlight the stark improvements in environmental credentials and benefits with higher and quicker biodegradability – the aforementioned banana fibres decompose 94% of their mass within nine weeks and are fully degraded at thirteen weeks, vastly better than the average 50 years for conventional synthetic face masks (Natural Resources and Environment, 2024). Such materials have also demonstrated their technical capabilities with antibacterial properties highlighting themselves as viable alternatives to their conventional PPE counterparts. However, whilst such experiments are indicative of improved environmental performance, such innovations are largely small-scale with limited commercialization. These limitations are driven by challenges with scaling production capabilities and the funding ecosystem for the sector remains highly competitive.

We provider further case specific dynamics below, especially in relation humanitarian operation landscape, i.e., key entities involved, if there is evidence of use of bio-based materials, and if there is brief indication of such bio-based materials being progressed via the local humanitarian waste management value chains:

- **Key HO:** Vietnam Fatherland Front (VFF) and Vietnam Red Cross (VNRC)
    - Humanitarian operations are governed and coordinated by two central entities – Vietnam Fatherland Front (VFF), and Vietnam Red Cross (VNRC). The former addresses the strategic directions of humanitarian coordination, whilst the latter is tasked with on-the-ground implementation. Additionally, the majority, if not all, international support

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is channelled via both these entities, however, there are exceptions whereby humanitarian activities fall outside VFF and VNRC purview. Such exceptions are addressed on a case-by-case basis.

- **Indication of use of bio-based materials within humanitarian operations**: No
  - Humanitarian operational crews, e.g., first responders, specialist search and rescue, humanitarian logistics, have indicated no clear use of bio-based alternatives in relation to medical based supplies, especially within a field hospital setting.
  - Centrally, VNRC have indicated an interest in implementing such bio-based alternatives for medical supplies but yet there is little to no evidence of operational usage.
- **Waste management landscape for bio-based materials:** Waste management at municipal level.
  - Given the limited use, there is little indication of cognate bio-waste recovery or treatment within the waste streams.
  - The most common means of medical waste treatment is incineration followed by landfilling. It is likely, that if there is bio-based alternative implementation that the subsequent waste generate is treated in one of the two aforementioned methodologies.
  - If bio-based alternatives are landfilled, there is no information in relation to validity of biodegradable claims of decomposition. The need for parameter measures such as ground and air moisture present challenges towards ascertaining this dimension. Such data is not readily collected and presents an avenue for further analysis.

Key material developments within the Vietnamese bio-based health supplies sector

In Section 2.1, Table 2, we highlight the key bio-based material developments locally in Vietnam. Such material developments can indicate the overall viability and accessibility of such materials to be utilised by HOs within a field hospital setting with a Vietnamese context. We also highlight, where available, the technical quality standards of the bio-based alternatives of our priority products.

Table 2 Local bio-based material manufacturers/distributors - Vietnam

MEDICAL ITEM	MANUFACTURER/ DISTRIBUTOR	BIO-BASED MATERIAL	DETAILS
Fabrics	• Thanh Cong	Bio-degradable corn	Cellulose-based fibres with increased biodegradability (68.8% decomposition after 180 days) No indication of certification for medical use
		Bio-degradable polyester	Contains additives in polyester that accelerates the rate of decomposition (near complete decomposition between 2–4 years)

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			No indication of certification for medical use
		Bio-polyester	Ethylene glycol that is needed in the polymerization process is derived from molasses and behaves like conventional polyester in terms of recyclability No indication of certification for medical use
Gloves	• S&S Gloves	Nitrile (biodegradable)	Nitrile glove production adopts a low carbon production process and environmental benefit arise from increased biodegradability and quicker decomposition once again minimising carbon release. Technical specifications align with medical use cases with appropriate certifications including: • EN455 • EN374 • ASTM D6319 • ASTM D5511 • CE PPE CAT III TYPE B
	• Kamereo • Aneco	Biodegradable polymer blend	Materials derived from polymer blends and environmental benefit is increased bio-degradability (estimated complete decomposition within 6 – 12 months) No medical quality standard certification
	• VRG Khan Hoan • HTC Gloves	Natural latex	Gloves made from natural latex without inclusion of synthetic materials Technical specifications align with medical use cases with appropriate certifications including: VRG Khan Hoan Gloves • ASTM D3577 • ISO 13485:2016 • FDA 510K HTC Gloves • EN455-1, EN455-2, EN455-3, EN455-4

Needles	• Cesti	Self-destructing metal alloy with biodegradable coating	Vietnamese manufacturing capabilities of WHO recognised K1 syringe and environmental benefits are biodegradable needles designed to prevent misuse Technical specifications align with medical use cases with appropriate certifications including: • ISO 9001, 13485 • ISO 7886-1, ISO 7886-3 • ISO 7864
Body bags	• Suit Protector Garment Bag (distributor)	Polyethylene vinyl acetate (PEVA)	Increased biodegradability No indication of medical quality standard certification
Containers	• Buyoplastics • Biopolymer • NTV Envi	Bio-polypropylene	Mix of bio-based and synthetic materials with a common mix ratio or 60:40 bio-based to synthetic virgin plastics (coffee grounds are a commonly used bio-based material) FCM food certification but no evidence of medical certification

Case brief – Kenya

Similarly, the bio-based medical supplies sector in Kenya is gradually evolving, once again, driven by increasing regulatory and institutional emphasis on sustainable practices. As the Kenyan healthcare sector has moved towards universal health coverage, the momentum has also brought an increased demand for advanced medical implements, including eco-friendly solutions (Netherlands Enterprise Agency, 2021b). Centrally, Kenya's transition towards bioeconomy positions and aligns the nation broadly with East-African regional policies promoting circularity and environmental conservation. Like many, these policies advocate for the use of biodegradable materials and recycling schemes, especially in healthcare applications, as part of a broader circular economy framework. Much of the developments in bio-based alternatives for healthcare supplies aligns with this national and regional agenda in providing viable solutions to the move away from fossil-based plastics (Netherlands Enterprise Agency, 2021b). Some notable national achievements include the development of international partnerships to foster bio-based material innovation with the goal of reducing medical waste and harmonising the sector with global environmental standards (Ecuru et al., 2016; Virgin et al., 2022).

However, the nation and the sector has had to endure numerous challenges, the chief of which is the dependence on material and capability imports. This, combined with the lack of local manufacturing capabilities and infrastructure, greatly inflates the cost of such bio-based and biodegradable material use in healthcare supplies, resulting in reduced accessibility. Such issues have slowed the adoption of these bio-based alternatives in the healthcare sector (Netherlands Enterprise Agency, 2021b). To address such obstacles in the local bio-based and biodegradable materials sector, there have been centralised efforts to encourage participation, especially from the private sector. Kenya's proactive policy environment and the promotion of regional bio-economy initiatives offer significant opportunities for companies who are

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interested and specialise in sustainable medical supplies. These policy initiatives are also complemented with increasing interest from private sector investors who have shifted some focus towards green investment opportunities (Netherlands Enterprise Agency, 2021a).

In conclusion, Kenya's bio-based medical sector is poised for growth, although it requires strategic efforts to reduce import dependencies and build local manufacturing capacity. Partnerships between the public and private sectors, along with international investments, will be crucial for overcoming existing challenges and ensuring the long-term sustainability of the sector. This is largely the scene for the East-African region as well. Numerous entities are conducting early experiments into such technologies, fostered by a somewhat accommodative policy environment but challenged with underdeveloped infrastructure and a reliance of expensive foreign capabilities.

Like Vietnam, we also provide further case specific dimensions for Kenya, once again with a focus on the humanitarian landscape, an indication of use of bio-based alternatives within deployments, and if there is enhanced information of such bio-based materials progressing throughout the humanitarian waste management value chain:

- **Key HO:** International Federation of Red Cross (IFRC), Medecins Sans Frontieres (Doctors Without Borders), Oxfam International, Save the Children
    - The landscape for humanitarian operations for Kenya is diverse with a mix of international organisations with regional and/or local chapters operating alongside local institutions. We are aware that the list above is not exhaustive but rather focuses on HOs who have provisions along medical aid.
- **Indication of use of bio-based materials within humanitarian operations:** No
    - There is indication that there is increased interest for the implementation of bio-based alternatives for medical supplies within deployments and operations.
    - There is little evidence of actual implementation of bio-based alternatives for medical supplies with many HOs citing costs, accessibility, and technical specifications as obstacles.
- **Waste management landscape for bio-based materials:** Addressed by humanitarian organisation or external contractor
    - Key methods of medical waste treatment are incineration or landfilling.
    - There is little indication of awareness by waste management service providers of the presence of bio-based materials, if any, within the waste value chain.
    - Likelihood that such bio-based materials are either incinerated or landfilled. If landfilled, it is likely that polymers such as plastics maybe recovered for recycling.
    - Given the lack of available data, it is difficult to verify the biodegradability claims of various bio-based materials if landfilled.

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Key material developments within the Kenyan bio-based health supplies sector

Within Section 3.1., Tables 3 and 4 we highlight the bio-based material developments in Kenya and the wider (East-) African region. As before, these material developments indicate the availability and accessibility of bio-based alternatives to our priority products that deploying HOs can leverage.

Table 3 Local bio-based material manufacturers/distributors - Kenya

MEDICAL ITEM	MANUFACTURER/ DISTRIBUTOR	BIO-BASED MATERIAL	DETAILS
Fabrics	• Rethread Africa	Polyhydroxyalkanoates (PHA)	PHA derived from post-harvest agro-waste – usually sugarcane. Textiles are recyclable up to 6 time. Blended fabrics can be up to 20% stronger, with increased biodegradability. Blended fabrics are also flexible and characteristics such as breathability and water resistance can adjusted to match use requirements. No indication of certification for medical use
		Cellulosic superabsorbent polymer	Bio-organic treatment for cotton fabrics. Treatment improves water absorbency of cotton fabrics to up to 30 times its weight in water. No indication of certification for medical use
		Recycled polyester (rPET)	Polyester recovered from consumer supply chains and is processed via hydrothermal process. Not bio-based but contributes to reduction in carbon footprint. No indication of certification for medical use

Packaging	• BioInnovate Phase III Project	Biodegradable polymer blend	Materials derived from polymer blends. Key environmental benefit is increased biodegradability. Project utilised starch from cassava waste. Estimated complete decomposition within 3 - 6 months. • No medical quality standard certification. Current focus is on packaging but can be extended to food safe gloves.

We are aware that the development of bio-based and biodegradable materials within the Kenyan context is growing and advanced manufacturers and providers are limited at this stage. As such we extend our consideration for bio-based and biodegradable material developments beyond just the Kenyan context into the (East-)African sub-region.

Table 4 Local bio-based material manufacturers/distributors – East-African Region

MEDICAL ITEM	MANUFACTURER/ DISTRIBUTOR	BIO-BASED MATERIAL	DETAILS
UGANDA			
Fabrics	• TexFad	Banana pseudo stem fibres	Using material weaving techniques to create fabrics. Fabrics have increased biodegradability. No indication of certification for medical use
Packaging	• ORIBAGS	Biodegradable polymer blend	Eco-friendly materials derived from waste management recycling. Key environmental benefit is increased biodegradability. Additional social benefits for welfare and job provisions to local communities No medical quality standard certification. Current focus is on paper based packaging.
TANZANIA			
Fabrics	• Katani Limited • SFI Tanzania Ltd.	Sisal fibres	Using material weaving techniques to create fabrics. Fabrics have increased biodegradability. No indication of certification for medical use.

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Containers	• EcoAct Tanzania	Eco plastic lumber	Mix of bio-based and synthetic materials. Synthetic materials derived from recycled plastics. No evidence of medical certification.
RWANDA			
Packaging	• Arth Biobag Ltd.	Biodegradable polymer blend	Compostable bioplastics derived from starches. Increased biodegradability with complete breakdown between 60 to 180 days. No medical quality standard certification but possesses organic material manufacturing standards: • IS 17088
	• Umuti Paper	Biodegradable polymer blend	Eco-friendly materials derived from waste management recycling. Key environmental benefit is increased biodegradability. No medical quality standard certification. Current focus is on paper based packaging.
SOUTH AFRICA			
Containers	• Fortis X	Bio-polyester	Mix of bio-based and synthetic materials. Use of sugarcane as bio-based foundation. Increased biodegradability. REACH compliant certification but no evidence of medical certification

Summary and conclusion

There is immense growth and development within the bio-based and biodegradable materials sector globally, especially in relation to healthcare implementations. This growth is driven both centrally via policy focus on continued greening of medical provisions and a steady appetite from the private sector investors for green investments. This is also the case for humanitarian operations as HOs seek to green their activities. This has resulted in a buoyant ecosystem of for research and development for alternative bio-based materials for healthcare. This evident within both our focal nations of Vietnam and Kenya where there are numerous local manufacturers (and distributors) for bio-based alternatives for our priority products. However, it should be noted, that the sector for bio-based materials within both countries is still in its infancy, and very small when compared to the conventional marketspace for synthetic healthcare supplies.

Moreover, whilst there is increasing evidence from HOs for such bio-based alternatives for healthcare supplies, there is little evidence of implementation of such alternatives across deployments within field hospital settings. It is likely that there remain questions about viability of such materials in relation to local and regional availability, manufacturing capabilities, and inherent comparative costs to conventional synthetics that limits the overall accessibility of bio-based alternatives.

The lack of implementation also poses further challenges with verification of the ecological efficacy of said bio-based alternatives given that lack of readily available data from waste treatment methodologies to confirm biodegradable claims.

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