This initiative is supported by **PacWastePlus**-a 72 month project funded by the European Union (**EU**) and implemented by the Secretariat of the Pacific Regional Environment Programme (**SPREP**) **to sustainably and cost effectively improve regional management of waste and pollution.**

Palau End-of-Life Tire Technical Booklet for Roadmaking

January 2025

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Our vision: A resilient Pacific environment sustaining our livelihoods and natural heritage in harmony with our cultures.

PacWaste Plus Programme

The Pacific – European Union (EU) Waste Management Programme, PacWaste Plus, is a 72-month programme funded by the EU and implemented by the Secretariat of the Pacific Regional Environment Programme (SPREP) to improve regional management of waste and pollution sustainably and cost-effectively.

About PacWaste Plus

The impact of waste and pollution is taking its toll on the health of communities, degrading natural ecosystems, threatening food security, impeding resilience to climate change, and adversely impacting social and economic development of countries in the region.

The PacWaste Plus programme is generating improved economic, social, health, and environmental benefits by enhancing existing activities and building capacity and sustainability into waste management practices for all participating countries.

Countries participating in the PacWaste Plus programme are: *Cook Islands, Democratic Republic of Timor-Leste, Federated States of Micronesia, Fiji, Kiribati, Nauru, Niue, Palau, Papua New Guinea, Republic of Marshall Islands, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu*.

Key Objectives

Outcomes & Key Result Areas

The overall objective of PacWastePlus is "*to generate improved economic, social, health and environmental benefits arising from stronger regional economic integration and the sustainable management of natural resources and the environment*".

The specific objective is "*to ensure the safe and sustainable management of waste with due regard for the conservation of biodiversity, health and wellbeing of Pacific Island communities and climate change mitigation and adaptation requirements*".

Key Result Areas

- **Improved** data collection, information sharing, and education awareness
- **Policy & Regulation** - Policies and regulatory frameworks developed and implemented.
- **Best Practices** - Enhanced private sector engagement and infrastructure development implemented
- **Human Capacity** - Enhanced human capacity

Learn more about the PacWaste Plus programme by visiting

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Table of contents

List of Figures

Glossary

Terminology	Definition
Crumbed rubber	A highly refined rubber product, typically less than 1mm in diameter, made from recycled tires.
De-beading	Removing the metal bead from the rim of the tire, required for some downstream processing of ELTs to reduce wear on shredder blades.
End-of-life tires (ELT)	A tire that is deemed no longer capable of performing the function for which it was originally made.
Granules (Granulated rubber)	A refined rubber product typically between 2-15mm in diameter, made from recycled tires.
Shredding	Process of cutting up waste tires using bladed shafts in an enclosed vessel, the size of product being determined by number and orientation of blades and/or number of passes (output screening)
SPREP	Secretariat of the Pacific Regional Environment Programme, the Client for this report.
Tire	A vulcanised rubber product designed to be fitted to a wheel for use on, or already fitted to, motorised vehicles and non-motorised trailers towed behind motorised vehicles.
Crumbed rubber	A highly refined rubber product, typically less than 1mm in diameter, made from recycled tires.

1. Introduction

This booklet is designed to provide practical, step-by-step guidance to Roadmaking Companies on reusing End-of-Life Tires (ELTs) in two specific applications:

- Road construction and,
- Revetment walls.

The purpose of this booklet is to outline the requirements for utilising ELTs in these applications, ensuring compliance with relevant engineering standards and industry best practices. The guidance includes:

- Pre-processing Requirements: Basic steps needed to select and prepare ELTs for use.
- Processing Requirements: Detailed instructions for processing pre-treated ELTs for specific applications.
- Engineering Standards: Relevant standards to ensure safety, durability, and environmental compliance.
- Cost Considerations: Estimated capital and operational costs.
- Monitoring Requirements: Guidelines for ongoing inspection and maintenance.

ELTs are a versatile material with significant potential for use in roadmaking projects. This booklet provides clear and concise guidance to help roadmaking teams implement these solutions effectively. Designed with hands-on professionals in mind, the information is presented in a straightforward manner, using simple language and practical examples to ensure accessibility and ease of on-site application.

2. Road Construction

2.1 Method of Utilisation

Crumbed rubber from ELTs can be combined with asphalt to form composite roads. In comparison to traditional roads, those constructed with the inclusion of crumbed rubber are more resistant to cracking, deformation and damage due to increased flexibility. These enhancements increase the cost-effectiveness of road construction by extending the lifespan and reducing the maintenance requirements of the road. The number of tires used is dependent on road length, width and base depth.

The asphalt-rubber method as outlined in Figure 1, uses crumbed particles of ELTs that can be sized anywhere between 2.36mm and 0.075mm depending on the binder design, however, typically between 0.6mm to 0.15mm is recommended. This requires a shredding, grinding and crumbing process which will be outlined in the following sections.

To incorporate ELT crumbed rubber into asphalt, crumbed rubber is blended with asphalt cement (typically in an 18-25 percent rubber ratio) before binder is combined with the aggregate. This method is the most commonly used and is known as the wet process. When the crumbed rubber is blended with the asphalt cement, it reacts by swelling and softening. The modified binder is then referred to as asphalt-rubber hot mix. This process can be conducted in an Asphalt Rubber Blending Unit at a typical Hot Plant Site and then transferred to a portable holding tank. Alternatively, the process can be performed on site with the use of a portable Asphalt Rubber Blending Unit.

> ***Note:*** *One average sized tire can produce approx. 6kgs of crumb rubber.*

> ***Note:*** *An average of 146 ELTs is used per lane kilometre of asphalt-rubber road construction.*

The asphalt-rubber hot mix is then used in a typical paving procedure.

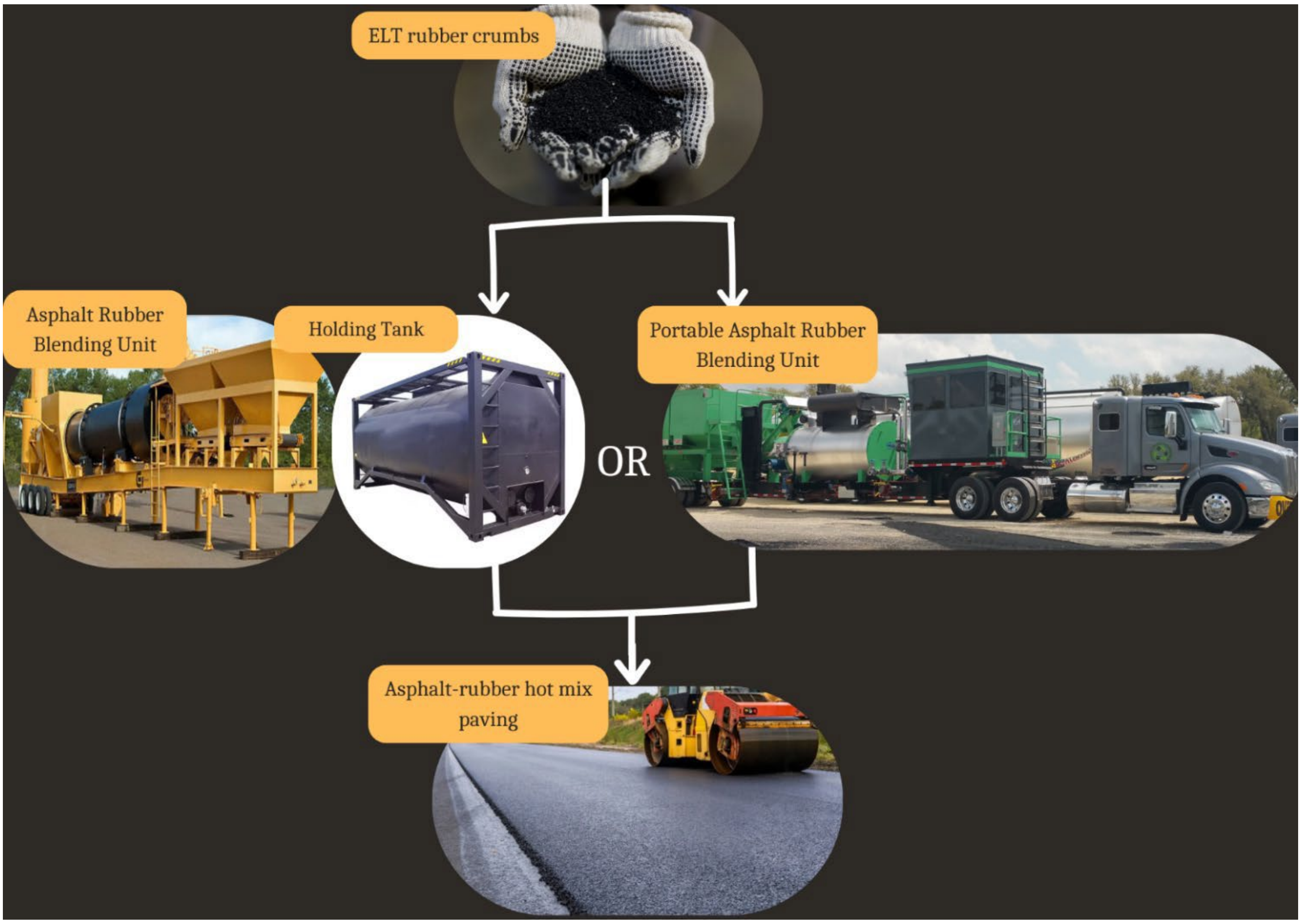

Figure 1: Asphalt-rubber hot mix production and paving process.

2.2 Processing Requirements

2.2.1 Pre-Processing

It is suggested that ELTs be treated according to the steps outlined in Figure 2 below before they can enter the processing stage.

ELTs used in road construction should meet all pre-processing requirements including:

- Not have been exposed to fire or extreme temperatures; ensure there are no visible signs or smells of smoke, burned rubber or deformation from heat.

ELTs that do not meet the above requirements should be rejected and disposed of at the ELT Recycling Facility located at the "M Dock".

Figure 2: Pre-processing Steps for ELT Crumbing

2.2.2 Processing

The following processing requirements for ELTs used in road construction are required.

- Tires are flammable. Tires should be stored in a stable condition in cool, dry, ventilated areas away from open flames and heat sources. It is recommended that firefighting equipment always be on hand when handling and processing tires.

***Note**: The current method of ELT processing in Palau includes shredding prior to debanding and debeading; the following steps have accounted for this method.*

Processing ELTs into shreds or crumbs involves a mechanical process as described below and in Figure 3.

1. **Cutting:** Cutting tires into smaller pieces may assist the shredding process. Cutting can be executed using a power saw, Dremel tool, strip cutter or block cutter, ensuring they have a metal-safe blade.
2. **Shredding:** A shredder, such as a rotary shear shredder, is first used to reduce the waste tires to smaller pieces generally less than 150mm in size.
    a. A wire drawing machine is an optional piece of equipment that may be used prior to shredding to draw the tire wires out of the tire to protect the blades of the shredder
3. **Debanding and Debeading:** Tires that are reinforced by steel bands or beads should have these removed prior to being shredded or crumbed. Removal is done using a debanding and debeading machine.
4. **Contamination removal:** steel, nylon and fibre contaminants are removed from the shredded tires via a drum magnet and air separation (blower).
    a. After passing through the shredder or a series of shredders and removal of the steel, the <150mm output can be further processed into rubber granules or crumb.
5. **Size reduction:** a secondary shredder, also known as a grater or rasping machine, may be used for further size reduction (10-44mm) to create “rubber mulch”.
6. **Granulation:** the shredded rubber is put through a granulator to form rubber granules (2-15mm).

Note: *Buffings* *are an output of the re-treading process as opposed to an output of the crumb/granule processing operations. Buffings are like granules however they are less than 2mm and are the pure tire rubber that is shaved off the tire casing before the new tread is applied, if applicable, buffing's may be integrated at this step.*

7. **Crumbing:** the rubber is further processed into a crumb less than 0.7mm in size via a grinding mill or "miller". This may first involve a dust removal system and further fibre removal via a zig-zag screen.

Note: *Recommended final output of crumbed rubber should be between 0.6 and 0.15mm in size.*

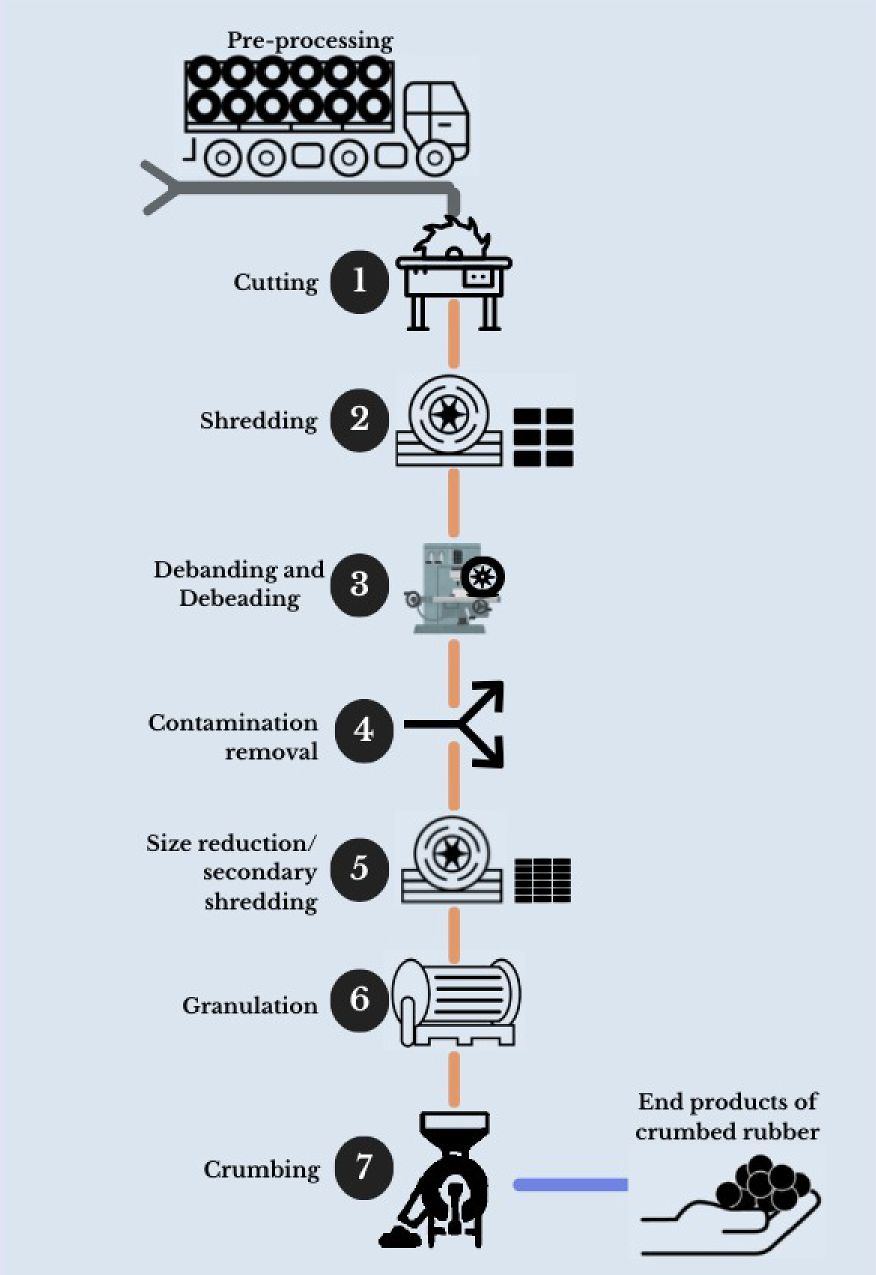

Figure 3: Tire shredding and crumbing process

2.3 Applicable Engineering Standards

The use of ELTs and the production of Asphalt-Rubber Binder for roads should be performed in accordance with specifications to ensure quality standards are achieved. The American Society for Testing and Materials (ASTM) develops and publishes technical standards which outline the necessary procedures for the classification and testing of materials.

Note: *All engineering standards mentioned can be purchased from: ASTM International - Standards Worldwide*

The relevant standard for roadmaking is:

- *ASTM D6114/D6114M-19 Standard Specification for Asphalt-Rubber Binder.*

To summarise, the relevant material specifications for ELT crumbed rubber before it is blended with asphalt cement include:

- Ground recycled tire rubber is to conform to requirements of:
  - *D1566-21a Standard Terminology Relating to Rubber:* This standard outlines technical terms used in the rubber industry, their definitions and expert recognition. The standard should be used if mathematical expressions are required for the time and temperature dependent physical properties of terms found within the *Standard Specification for Asphalt- Rubber Binder.*
  - *D6373 Standard Classification for Rubber Compounding Materials-Recycled Vulcanizate Rubber:* This standard classification outlines the compounding material of particulate rubber.
- Ground recycled tire rubber must contain less than 0.75% moisture by weight and shall be free flowing.
- Ferrous metal particles should be removed and no more than 0.01% ferrous metal particles (by weight) are allowed in the final product.
- Fiber content cannot exceed 0.5% (by weight) of ground recycled rubber.
- No rubber particles can be retained in the 2.36mm sieve (maximum particle size).

The relevant specifications for Asphalt-Rubber include:

- The asphalt-rubber must constitute only a blend of asphalt binder and ELT Crumbed rubber. Other additives such as other types of scrap rubber are not permitted.
- No foaming should occur when the asphalt rubber is heated.
- Testing of the asphalt-rubber blend must satisfy the *Physical Requirement for Asphalt-Rubber Binder (ASTM D6114/D6114M-19).*

To ensure these relevant testing and sampling procedures and material specifications are met, sufficient laboratory must be identified and employed to provide quality control.

2.4 Capital Cost

ELT pre-processing requires:

- **Tire washing facility** – (Hardstand area: approx. US$18-38 per m^2, Pressure washer: approx. US$150, Sump tank: approx. US$1,200)
- **DeBeader** – between US$2,000 for small-scale debeaders to US$39,000 for large-scale debeaders

ELT processing requires:

- **Shredder** – between US$20,000-US$50,000 for small-scale shredders to US$100,000 for advanced shredders with additional features
- **Secondary Shredder** – US$300,000 to $600,000.
- **Crumbing Rubber Plant** – Granulators US$420,000 to US$600,000.

Example: Australian ELT facility for size/cost comparison

A facility capable of processing **3500 tonnes p/a of tires** with an output of crumb rubber and rubber granules.

Facility cap cost: **AUS$4,000,000** for main facility + **AUS$1,500,000** for pre-processing facility.

This would be considered a large-scale ELT recycling plant.

Engineering standards:

- *ASTM D6114/D6114M-19 Standard Specification for Asphalt-Rubber Binder* – US$61
- *D1566-21a Standard Terminology Relating to Rubber* – US$76
- *D6373 Standard Classification for Rubber Compounding Materials-Recycled Vulcanizate Rubber* – US$69

2.5 Operational Cost

Total operational costs are comprised of the following demands.

- **Labour** – labour intensive process, minimum 10-15 Full-time equivalent dependant on scale of project: Palau minimum wage US$4.25 per hour
- **Administration** – visual monitoring 1-3 persons- skilled supervisor: Palau minimum wage US$4.25 per hour
- **Contractors** – Laboratory contracted professionals for testing; regular testing required as per engineering standards: cost varies contractor dependant.
- **Utilities** – water, electricity & compressed air: cost varies project dependant.
- **Consumables** – processing equipment consumables including grinding surfaces, greases, lubricants, belts, spares etc: approx. US$250/tonne of processed ELTs. Fire safety equipment & PPE: approx. US$180 per worker, per year.
- **By-Products Disposal** –Sump waste – oil, grease and grit must be disposed of to landfill: zero fees, nylon textile disposal to landfill: zero fees, excess water can be discharged.

2.6 Monitoring Requirements

The following monitoring requirements are recommended during the pre-treatment and processing stages of ELTs for road construction.

- Pre-treatment: minimal monitoring is required during the pre-treatment stages; however, regular quality control checks are to be conducted by a suitably experienced professional to ensure project standards are met. If deemed unfit tires should be rejected and disposed of at the ELT Recycling Facility at the “M Dock”.
- Processing: Regular lab testing is required as per applicable engineering standards for Asphalt-Rubber Binder specification. Periodic checks by a suitably experienced professional are recommended during the processing stage to verify quality and ensure efficacy of the final product.

3. Revetment Walls

3.1 Method of Utilisation

ELTs can be easily stacked and filled to form a protective barrier alongside roadways. Revetments are like retaining walls but have a more distinct slope and are typically used near water features (HR Wallingford 2005). ELTs as revetment walls are cost effective, allow for excellent drainage and offer great stability.

There are various methods of constructing a revetment wall using ELTs. The number of ELTs used is dependent on wall size. Two suggested processes are outlined below:

- **Gravity walls** (layers of tires laying down and fastened to each other)- these walls are used in engineering landscapes to create terraces, level grounds for construction, prevent erosion or provide support to structures such as roadways, bridges, trails etc (Figure 5). Gravity walls can be vertically constructed but are typically angled/slanted to increase its stability as they rely on solely their weight and mass to resist the presser exerted by the material they retain.
- **Anchored walls**- these walls are like gravity walls however they are designed with the addition of cables or rods that are anchored to the soil behind the wall (Figure 6). These walls are recommended for higher heights and landscapes where the wall is built to support/contain a natural terrain mass. For further stability, reinforce walls with concrete.

The steps required to achieve both gravity and anchored revetment walls are outlined below:

1. Remove ELTs sidewalls using a Tire Sidewall Cutter (machine) or a utility knife or retractable box cutter.
2. Ensure all selected tires are of similar size.
3. Prepare a level gravel bed for the wall foundation.
4. ELTs are laid side by side to desired length of wall and filled with a soil, rock and/or sand mixture with good compressive qualities. The mixture should be distributed and then pound using a sledgehammer to effectively compress the mixture into the sidewalls. Once the sides are adequately filled, the centre area of the tire should receive more mixture that is again compressed.
5. The next row of ELTs is then laid on top in a staggered/overlapping pattern (for angled/slanted walls, one half diameter staggering for each successive layer is a recommended maximum). An example of revetment wall angling is demonstrated in Figure 4. The fill and compression steps are repeated. Continue until wall reaches its full height (up to 25ft high has been successfully tested).
6. The indentations where tires meet is then packed using a filler such as mortared clay with rocks or straw to make the wall relatively flush.

***Note**: the following steps (7-8) are optional as per specific construction requirements:*

7. For further reinforcement of tire revetment walls, especially in instances where the wall is built to support/contain a natural terrain mass, wall anchoring is recommended. Wall anchoring can be achieved with plastic ties, ropes anchors, cables or rods can increase stability and retainment capacity as demonstrated in Figure 5 and Figure 6.
8. The finished wall can be insulated and waterproofed in several ways such as the application of waterproof sealant or membranes depending on the site location, requirements and codes.
9. ELT revetment walls can also be covered in concrete for increased stability or alternate cosmetic facings if desirable, an example of such is shown in Figure 7.

Figure 4: Tire retaining wall *(Tire Stewardship Australia, 2016).*

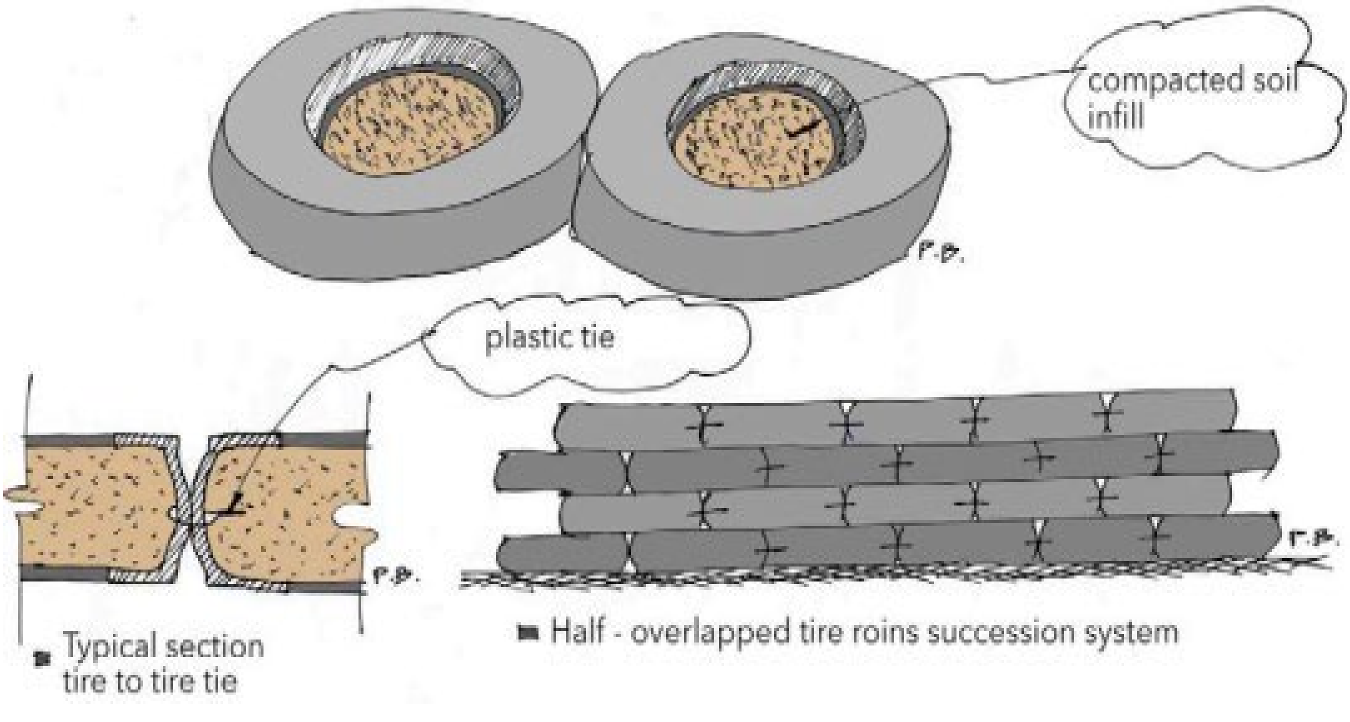

Figure 5: Diagram of tire stacking and reinforcement option using soil infill and plastic ties *(Barros et al. 2019).*

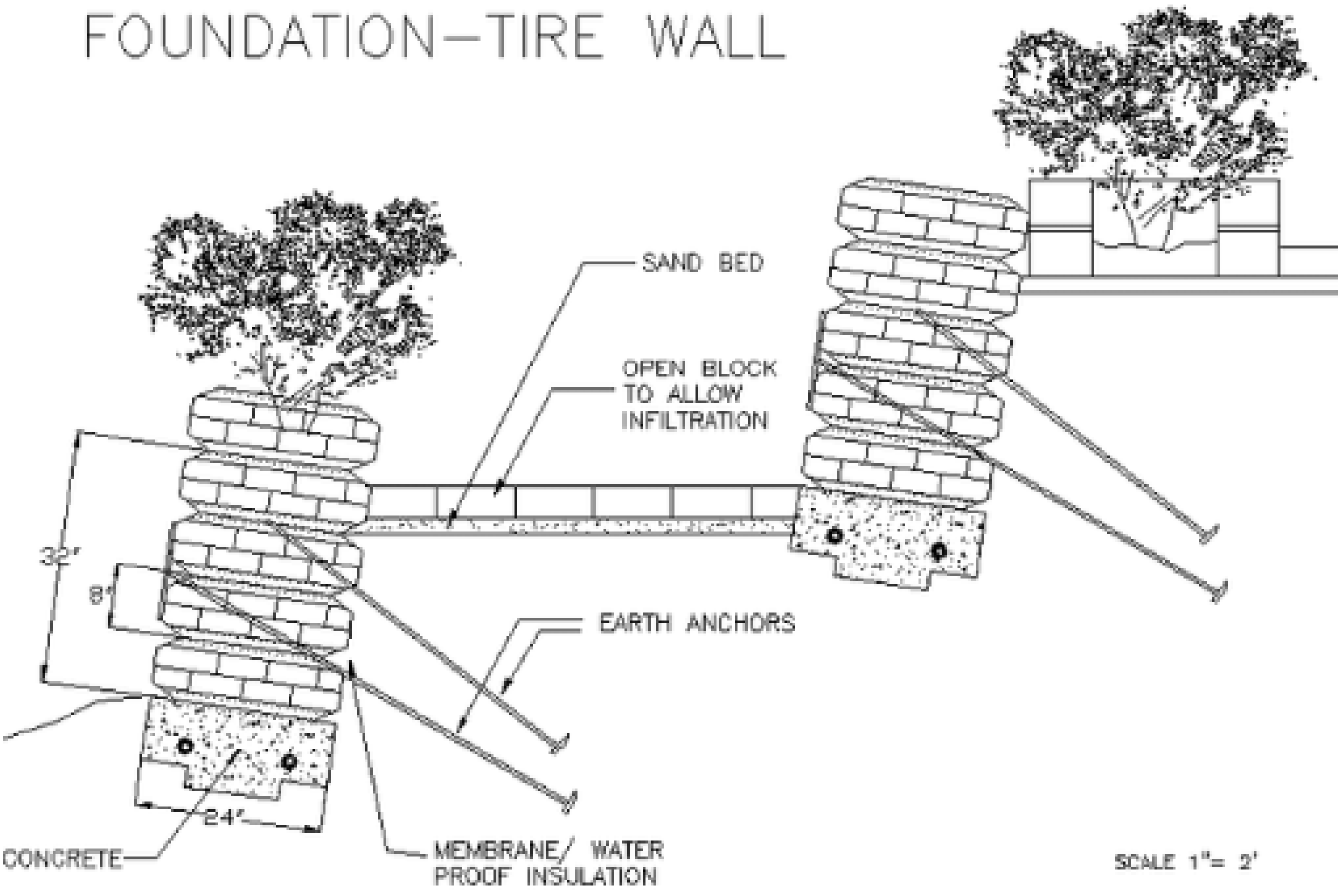

Figure 6: Diagram of tire stacking and reinforcement option using rope earth anchors and concrete *(Slack et al. 2018).*

Figure 7: Tire retaining wall covered in sprayed concrete *(Tire Stewardship Australia, 2016).*

3.2 Processing Requirements

3.2.1 Pre-Processing

It is suggested that ELTs be treated according to the steps outlined in Figure 8 and below before they can enter the processing stage and be used.

ELTs used in revetment walls should meet all pre-processing requirements including:

- Be whole, intact tires.
- Contain no potential hazards embedded in or amongst the ELT such as exposed steel wires etc.
- Not have been exposed to fire or extreme temperatures; ensure there are no visible signs or smells of smoke, burned rubber or deformation from heat.

ELTs that do not meet the above requirements should be rejected and disposed at the ELT Recycling Facility located at the “M Dock”.

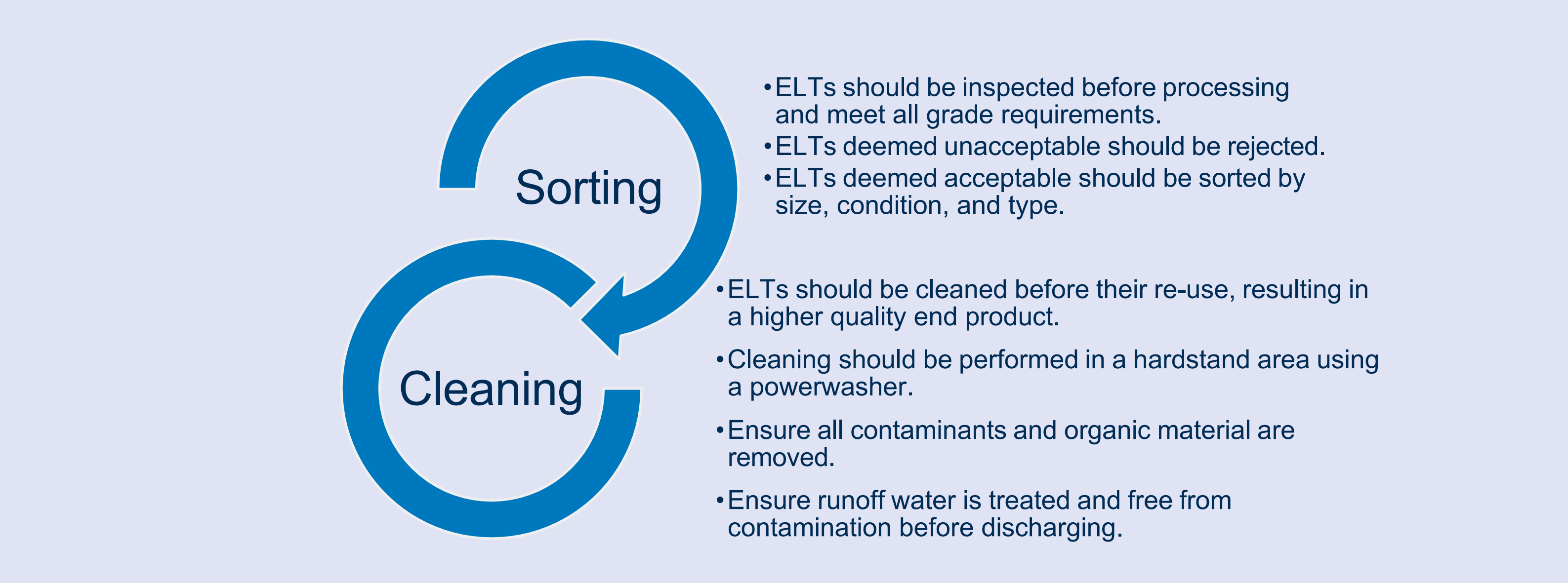

Figure 8: Pre-processing Steps for ELT whole tire use

3.2.2 Processing

The following processing requirements for ELTs as revetment walls are recommended.

- Removing ELT side walls: use a Tire Sidewall Cutter (machine) or manually using a utility knife or retractable box cutter. Ensuring cutter has metal safe blades.
- Ensure walls are reinforce anchoring and/or concrete facing if necessary.
- Tires are flammable. Tires should be stored in a stable condition in cool, dry, ventilated areas away from open flames and heat sources. It is recommended that firefighting equipment always be on hand when handling and processing tires.

3.3 Applicable Engineering Standards

There is no applicable engineering standards required for the use of whole ELTs for revetment walls.

It is essential to adhere to recognised general and safe handling methods throughout the process.

To ensure safety and quality:

- Follow common industry practices e.g. wash hands after handling ELTs
- Use appropriate tools and equipment e.g. as recommended by manufacturers
- Ensure proper protective equipment (PPE)

3.4 Capital Cost

ELT pre-treatment requires:

- **Tire washing facility** – (Hardstand area: approx. US$18-38 per m^2, Pressure washer: approx. US$150, Sump tank: approx. US$1,200)

ELT processing requires:

- **Miscellaneous** – Power drill, drill bits: approx. US$50-300 per drill (cost varies brand and quality dependant)
- **Tire sidewall cutter** (machine) – approx. US$1,000, or **utility knives** – approx. US$20 per knife.

3.5 Operation Cost

Labour – 3-5 persons- standard, unskilled workers: Palau minimum wage US$4.25 per hour

Administration – visual monitoring one person- skilled supervisor: Palau minimum wage US$4.25 per hour

Utilities – water & electricity: cost varies project dependant.

Consumables – fire safety equipment & PPE: approx. US$180 per worker, per year.

By-Products Disposal – nil: unused tires should be returned to the stockpile. Sump waste – oil, grease and grit must be disposed of to landfill: zero fees, excess water can be discharged.

3.6 Monitoring requirements

The following monitoring requirements are recommended during the pre-treatment and processing stages of ELTs for revetment walls.

- Pre-treatment: minimal monitoring is required during the pre-treatment stages; however, regular quality control checks are to be conducted by a suitably experienced professional to ensure project standards are met. If deemed unfit tires should be rejected and disposed at tire Recycling Facility at the M Dock.
- Processing: periodic checks by a professional are recommended during processing to verify quality and ensure efficacy of the final product.

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