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Reduction of UPOPs emissions by improving waste management practices at landfills

Management of Waste Tyres – Guidance Report

Resources & Waste Advisory Group[SCE]

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List of Acronyms

BAT	Best Available Techniques
BCRC-Caribbean	Basel Convention Regional Centre for Training and Technology Transfer for the Caribbean
BEP	Best Environmental Practices
BFR	Brominated Flame Retardant
BM	Brian McCarthy (Team Leader)
DG	Diana Gheorghiu (Deputy Team Leader)
GHG	Greenhouse Gases
PBDEs	Polybrominated diphenyl ethers
PCB	Polychlorinated Biphenyl
POPS	Persistent Organic Pollutants
RWA	Resources and Waste Advisory
SIDS	Small Island Developing States
SWM	Solid Waste Management
UPOPS	Unintentionally produced Persistent Organic Pollutants

Background

Each year, hundreds of thousands of waste tyres are created in eastern Caribbean countries. While these are generally well separated from other waste stream, there is either no or very limited treatment capacity in each country resulting in the stockpiling of waste tyres in large piles in the vicinity of island landfill sites. The chemical components making up the tyres, such as heavy metals, slowly release from these stockpiles into the environment, contaminating the soil and water sources. Due to the polymer content of the waste tyres they are highly flammable materials. The combustion of waste, and specifically tyres, release UPOPs into the atmosphere – amongst other Green House Gasses (GHGs) and the climate forcer black carbon - which could be avoided by implementing a sustainable recovery practice for waste tyres. The improvement of the management of waste tyres is therefore vital to protecting public health, people's livelihoods, and removing unnecessary strain on the local environment.

Several alternatives to stockpiling waste tyres exist, each of which require varying levels of investment. Tyre shredders are one of the more accessible options for Caribbean islands. Primary shredders enable waste tyres to be recovered into useable products such as landfill cover materials, gravel substitute, slope stabilisation material and Tyre Derived Fuel (TDF), which potentially have a number of local applications. More advanced post primary shredding machinery, such as steel liberator and granulators allow for further waste tyres products – such as Rubberized Asphalt Concrete (RAC) and others as detailed in the document – offer greater product diversity but require higher levels of investment.

Purpose of document

This document aims to describe some of the viable options for treating waste tyres as an alternative to stockpiling at landfill sites and in doing so reducing the risk of combustion and associated UPOPs emissions in the short-term, and their elimination in the long-term. It outlines different possibilities to divert tyres from stockpiles/landfills and move from waste disposal to resource recovery.

This report is not meant to be exhaustive or provide a single reference source for decision on a technology to be applied, as it is not based on actual quantities, compositions or content of waste tyres in any specific location. In addition, local conditions and enabling factors (or lack thereof) may affect the applicability of the presented solutions, thus further research and analysis are necessary.

Outline

This document is divided into 5 sections presenting the different options available for better tyre waste management. First, some background is given on tyre composition and the hazards of poor waste tyre management. Secondly, the challenges and options for better waste management are presented along with the tyre recycling process. Finally, the machinery and costs associated with the purchase of a shredder are given.

What are UPOPs

As they burn, waste tyres release greenhouse gases (particularly carbon monoxide and sulphur), heavy metals (lead, arsenic) and Unintentionally produced Persistent Organic Pollutants (UPOPs) (dioxins and furans). The latter are:

- **Persistent:** because they don't easily break down and remain in the environment for decades
- **Organic:** because they are made of organic components likely to stick to certain substances such as fatty acids in animals and therefore entering the food chain and human bodies. They are amongst the most carcinogenic chemicals known and can cause fertility problems and birth defects.

- **Pollutants:** because they contaminate the soil, air and water and are very difficult to clean up
- **Unintentionally produced:** because they are by-products of the combustion of waste and open burnings

UPOPs have no commercial or industrial use, so they cannot be reused/recycled further. Many other activities than open burning can result in the release of UPOPs, such as shredder plants for the treatment of end-of-life vehicles, fossil fuel-fired boilers and textile dyeing. They can travel thousands of miles and tend to accumulate in colder regions, where they become a problem for local populations. Therefore, their production cause harm globally, and not only at the local level where they are emitted.

In effect since 2004, the Stockholm Convention, is an international agreement between over 90 countries to remove POPs around the world and protect the environment and human health. 21 chemicals have been identified for reduction and elimination.

1. Aldrin
2. Chlordane
3. DDT
4. Dieldrin
5. Endrin
6. Heptachlor
7. Hexachlorobenzene
8. Mirex
9. Polychlorinated Biphenyls
10. Polychlorinated dibenzo- p- dioxins
11. Polychlorinated dibenzofurans
12. Toxaphene.
13. Alpha hexachlorocyclohexane
14. Beta hexachlorocyclo- hexane
15. Chlordecone
16. Commercial octabromodiphenyl ether (hexabromodiphenyl ether and heptabro- modiphenyl ether)
17. Commercial pentabromodiphenyl ether (tetrabromodiphenyl ether and pentabro- modiphenyl ether)
18. Hexabromobiphenyl
19. Lindane, Pentachlorobenzene
20. Perfluorooctane sulfonic acid (PFOS), its salts
21. perfluorooctane sulfonyl fluoride (PFOS-F).

The reduction and eventually the elimination of combustion is the first significant step to prevent further UPOPs emissions. Further information on POPs and UPOPs is available at https://www.stopthepops.com and good practice related to achieving this in the management of waste tyres is presented in the next sections of this document.

Factsheets on UPOPs from the Stockholm Convention:
http://chm.pops.int/Implementation/Publications/Factsheets/tabid/527/Default.aspx

1 Tyres - materials and construction

Tyres are composed of several parts, summarized in Table 1. Each type of vehicle have various tyres which can handle different weights, as shown in Table 2. Typically, tyres comprise:

- Natural rubber
- Synthetic polymers
- Antioxidants, antiozonants and curing systems
- Steel
- Fillers
- Textile

These materials exist in different proportion in passenger/light and truck tires, as shown in Figure 1. Figure 2 also shows how steel is intertwined with the rubber in the tyre structure. Each material has a defined purpose to strengthen the resistance and traction of the tyre, improve adhesion and permeability, and extend the usable life of the tyre. However, these components become threats to the environment and people if they are not disposed of safely. The tyres shape which results in large void spaces containing air in combination with the toxic components increases the risk of combustion and associated environmental and health impacts once exposed to potentially high temperatures or ignition sources during their end-of-life handling. As the number of tyres accumulate, the risk of fires becomes greater as does the potential for contaminants to rapidly enter the air, soil and water sources.

Figure 1: Construction of a typical tyre (https://www.lesschwab.com/article/tire-faq.html)

Table 1: Components of a typical tyre and their function.

Part	Function
Body Ply	Structure of the tire. Provides strength to contain inflation pressure. Also gives tire strength and flexibility
Bead	Assures an air-tight fit to the wheel
Belts	Provides stability and strength to the tread area of the tire
Inner liner	Rubber compound to retain the inflation pressure inside the tire.
Sidewall	Rubber compound to cover the body plies on the sides of the tires, providing protection from road and curb damage
Tread	Rubber compound and tread pattern provides grip and traction

Table 2: Examples of the range of weights for passenger car and truck tyres.

Type of vehicle	Weight (Kilograms)	Number of Tyres per ton
Passenger car	6.5 - 9	+100 - 154 per ton
Light utility vehicles	11	91 per ton
Heavy goods vehicles	50	20 per ton
Long-haul trucks	55-80	12-18 per ton
Agricultural tyres	100	10 per ton

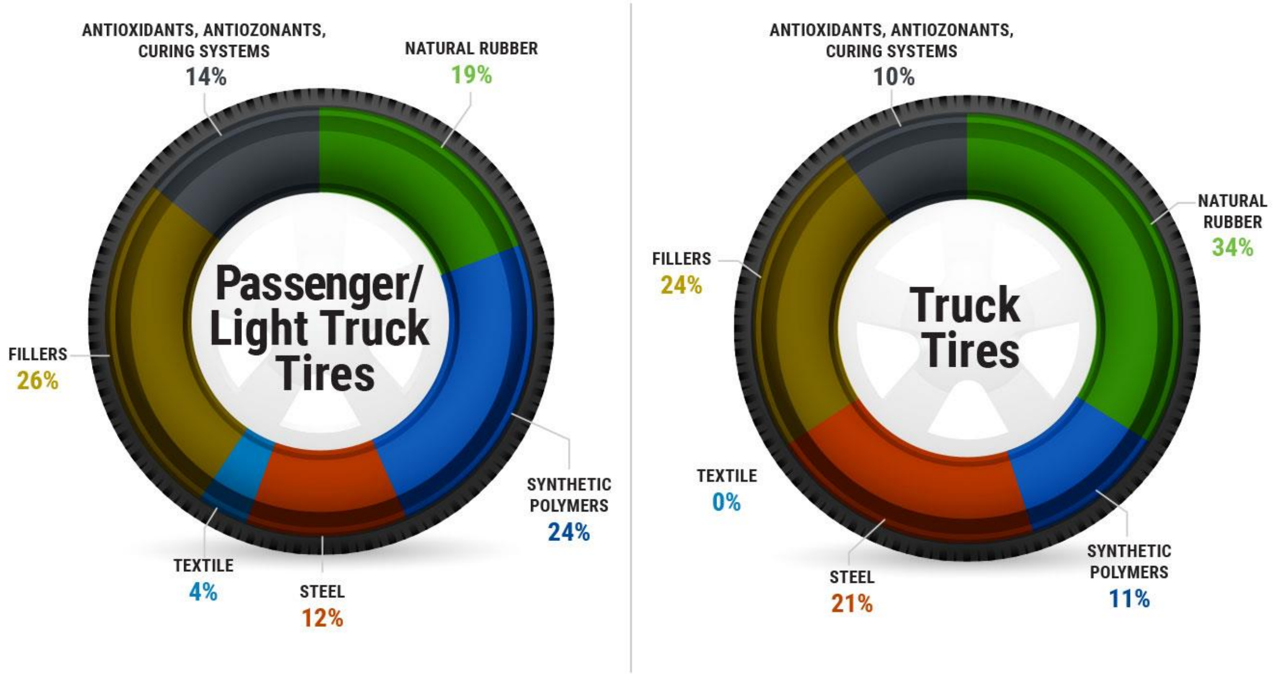

Figure 2: Typical composition of car and truck tyres (https://www.ustires.org/whats-tire-0)

Figure 3: Steel wire strands from the tyre belt visibly protruding from the rubber tread in a "blow-out" tyre (https://www.fastcompany.com/1788639/renewable-rubber-next-step-truly-oil-free-cars)

Table 3: Material components, their purpose and composition of typical car and truck tyres

Material	Type(s)	Purpose	Typical % composition (passenger car tyre)	Typical % composition of truck tyre
Natural rubber	Natural rubber	Reduce tear and improve fatigue crack resistance	19	34
Synthetic polymers	Butadiene rubber, styrene butadiene rubber	Improve overall tire performance with improved rolling resistance, wear and traction	24	11
	Halogenated polyisobutylene rubber (XIIR) (aka halobutyl rubber)	Makes inner-liner impermeable, which helps to keep the tire inflated		
Steel	Steel	Used in tire belts and beads, and the plies for truck tires. to stiffen the tire casing and improve wear performance and tire handling. The bead wire anchors the tire and locks it onto the wheel.	12	21
Textile	Polyester cord fabrics, rayon cord fabric, nylon cord fabric, and aramid cord fabric	Primary reinforcing material in the tire casing. Help the tire keep its shape in different road conditions which provide added endurance and performance characteristics. Also used to make the tire plies in passenger tires	4	0
Fillers	Carbon black, amorphous precipitated silica	Reinforce the rubber for better traction, rolling resistance and lower wear. Also improve tear, tensile strength and abrasion	26	24
Antioxidants	Antioxidants	Keep rubber from the breaking down due to the effect of temperature and oxygen exposure	14	10
Curing systems	Sulfur, zinc oxide	Shorten the vulcanization time (transformation of rubber into a solid article) or tire curing. Impacts the length and number of crosslinks in the rubber matrix that form during both processes		

2 Hazards of poor waste management

Figure 4: Hazards of poor management of waste tyres

2.1 Stockpiling / storing

Under certain specific climatic conditions, waste tyre dumps or stockpiles can become the breeding grounds for insects, such as mosquitoes, which are capable of transmitting diseases to humans. This is of particular concern in tropical or sub-tropical regions. In eastern Caribbean countries, mosquitoes are most active in the rainy season, between June and December, and can carry dengue fever. The country is also at risk of Chikungunya[1], transmitted by mosquitoes mostly during the early morning and late afternoons around dwellings. Hence, stockpiling and/or storing of waste tyres, if no other options are available, must be done in an isolated, protected space. It must also be a short transitional solution: once mosquitos have infested the stockpile, it becomes extremely hard to clean it up and plan for the reuse of tyres. In New Jersey, the 15 million tyres deposited in 24 sites were part of the surge in West Nile virus, which killed one person and sickened six in 2001.

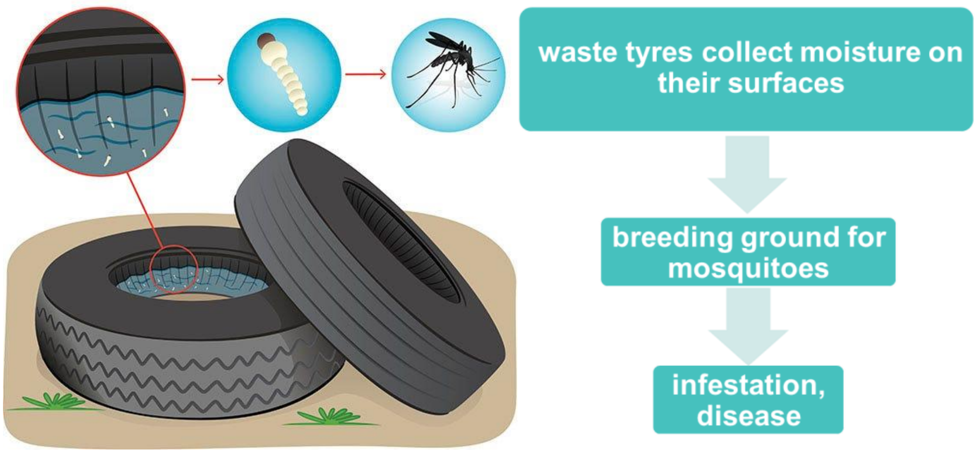

Figure 5: Mosquito life cycle and tyres (https://www.dynatrap.com/articles/mosquito-prevention-tips/)

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[1] https://www.iamat.org/country/barbados/risk/chikungunya

Tyres should not be stored in private properties or on farms, as the contaminants penetrate the soil quickly. The toxic chemicals can stop beneficial bacteria from developing, preventing local plants and animals from getting the nutrients they need. Besides, as the tyres are exposed to sunlight, methane is released as they age and represent a fire hazard[2].

2.2 Burning Tyres

Burning tyres can release potentially hazardous levels of carbon monoxide, mono – and polyaromatic hydrocarbon, particulate matter and especially dioxins and furans contained within the smoke plume (see figure 3). After open-air burning, organic compounds, like pyrolytic oils, rest in the soil (see figure 3) or washed into nearby environments by firefighting waters that can cause environmental damages to the flora and fauna[3].

Tyre fires are hard to control and stop. The emitted UPOPs persist in the environment, stick to other compounds like fatty acids in plants and animals, and travel thousands of miles. The easiest way to get rid of them is to eliminate their production – and therefore stop the open burnings - as once they are release into the environment, it is nearly impossible to capture them.

Most Caribbean countries have not identified stockpiles consisting of, or containing, chemicals listed in Annex A or B of the Convention, due to the following issues[4]:

- Lack of institutional or policy framework
- Lack of financial resources
- Limited human resources
- Insufficient technical capacity

Figure 6: Smoke and resultant soil pollution from uncontrolled open tyre fires. (RWA, 2019)

[2] https://tri-statedisposal.com/8-dangers-of-diy-tire-disposal-tri-state-disposal/

[3] http://archive.basel.int/meetings/sbc/workdoc/old%20docs/tech-usedtyres.pdf

[4] http://ers.basel.int/ERS-Extended/FeedbackServer/fsadmin.aspx?fscontrol=respondentReport&surveyid=73&voterid=49371&readonly=1&nomenu=1

2.3 Landfilling / burying tyres

The risks associated with landfilling tyres include those laid out for stockpiling; the accumulation of tyres, the heat and the airspaces make the ideal conditions for the tyres to catch fire, pollute the environment and harm the local community's health.

Buried tyres do not decompose. Their toxic components leak into the surrounding soil and water table, where they can travel farther from the source and ruin soils. If they are exposed to rain and wind, they develop as breeding ground for mosquitoes and other pests and become vectors of diseases transmissible to humans – as explained above. Animals and humans coming into contact with the infected water becomes at risk of cancer, gene mutation and other health problems.

Above all else, burial of whole tyres (individually or multiple as pictured in Figure 4) has the issue of tyres remaining full of air when covered and buried which can cause them to "float" up through the waste site and cause site instability, explosive gas pockets, and presents additional fire hazards and pathways within the site.

Figure 7: Deep burial of multiple whole tyres within a landfill should not be conducted (RWA 2019).

3 Challenges and options for better tyre waste management

Technical, environmental, economical and governance challenges must be solved to guarantee better tyre waste management. In Barbados, as an example, between January and June 2020, over 7,000 tyres were received monthly in Mangrove Pond Landfill alone. Similar situations exist in most eastern Caribbean counties and the volumes continue to grow as car ownership increases. Without intervention, the negative impact this has on people and the environment will continue to grow. Addressing the disposal fate of waste tyres will improve public health, reduce GHG emissions and soil contamination, and provide opportunities for resource recovery and investments. Local populations will become healthier and will benefit from increased investment, improving their well being on the long-term.

There are five things that can help establishing a long-term sustainable management planning for waste tyres and ensure they are diverted from landfills:

1. **Gain** endorsement and support from political leaders
2. **Identify** stakeholders to engage

3. **Establish** a working team
4. **Prepare** workflow and budget
5. **Obtain** the tools and equipment needed

All technical and governance procedures will get easier once these five criteria have been considered and prepared for. There's important pieces of data that will need to be obtained, such as:

- The number of waste tyres generated per year
- Number of landfills, their locations, capacity, composition and surface area

Obtaining this data will help tackle the challenges and corresponding options are presented in Table 4.

Table 4: Challenges and mitigation options associated with tyre management options

Challenges	Options
Environmental	
Tyre toxic components decompose and leach into soil, surface water, groundwater (zinc, chromium, lead, copper, cadmium and sulphur)	Landfill/soil covers with rubber from tyre recycling
Fire potential leading to air pollution (carbon monoxide, sulphur, lead, arsenic and UPOPs) and public health issues	Divert tyres from landfill by following tyre recycling system
Technical	
More expensive equipment for more refined products	Analyse which equipment has better value for money – i.e. potential outputs from considered investment
	Analyse local needs and how each equipment can contribute to them
Maintenance plan needed for equipment	Use manufacturer's documentation and services
	Train work force
	Refer to specific *Tyre Shredder Maintenance documents*
Need for skilled and knowledgeable workforce	Train existing and new workforce to new equipment
	Create training material
Lack of storage space	Ensure smooth coordination along tyre recycling system and stakeholders
	Analyse potential spaces for storage
Obsolescence of equipment	Buy equipment as new as possible from beginning
	Ensure smooth maintenance throughout equipment's life time
Malfunctioning of equipment	Have trained staff on site
	Plan for redundancy equipment
Determining location of recycling system	
Commercial & Economical	
Lack of secondary markets for tyre waste by-products	Stimulate market through public procurement rules requiring recovered tyre materials to be favoured, and / or developing EPR system to assist develop secondary markets
Price of needed equipment	Produce Business, Action and Budget Plans
	Ensure long-term return on investment and consider benefits on community
Costs of environmental clean-up caused by toxic leachates, fires and smoke plume	Calculate price of inaction vs price of action
	Reduce risk potentials by establishing clear tyre recycling system
Governance	
Lack of governance support (short and long-term)	Have analytical framework of ISWM and governance: guarantee inclusivity, promote pro-active policies, sound institutions and financial sustainability

	Engage with local stakeholders and country's officials

Several methodologies can be derived from the obtained data and desired level of investment. They will be presented in the following section.

4 Tyre Recycling Process

The typical tyre shredding and material recovery process is made up of 4 stages:

1. Shredding
2. Steel liberation
3. Granulation and fiber removal
4. Final milling and screening

Each additional steps provides more opportunities to transform tyre waste into useful materials for another application, but comes at an extra cost. The diagrams shown below highlight the different stages and the outputs they produce. The varioust potential applications for each output are summarized in Table 6.

The whole process is explained in a video by CM Shredders of the USA available to view at https://www.youtube.com/watch?v=gDRAosmLlUA.

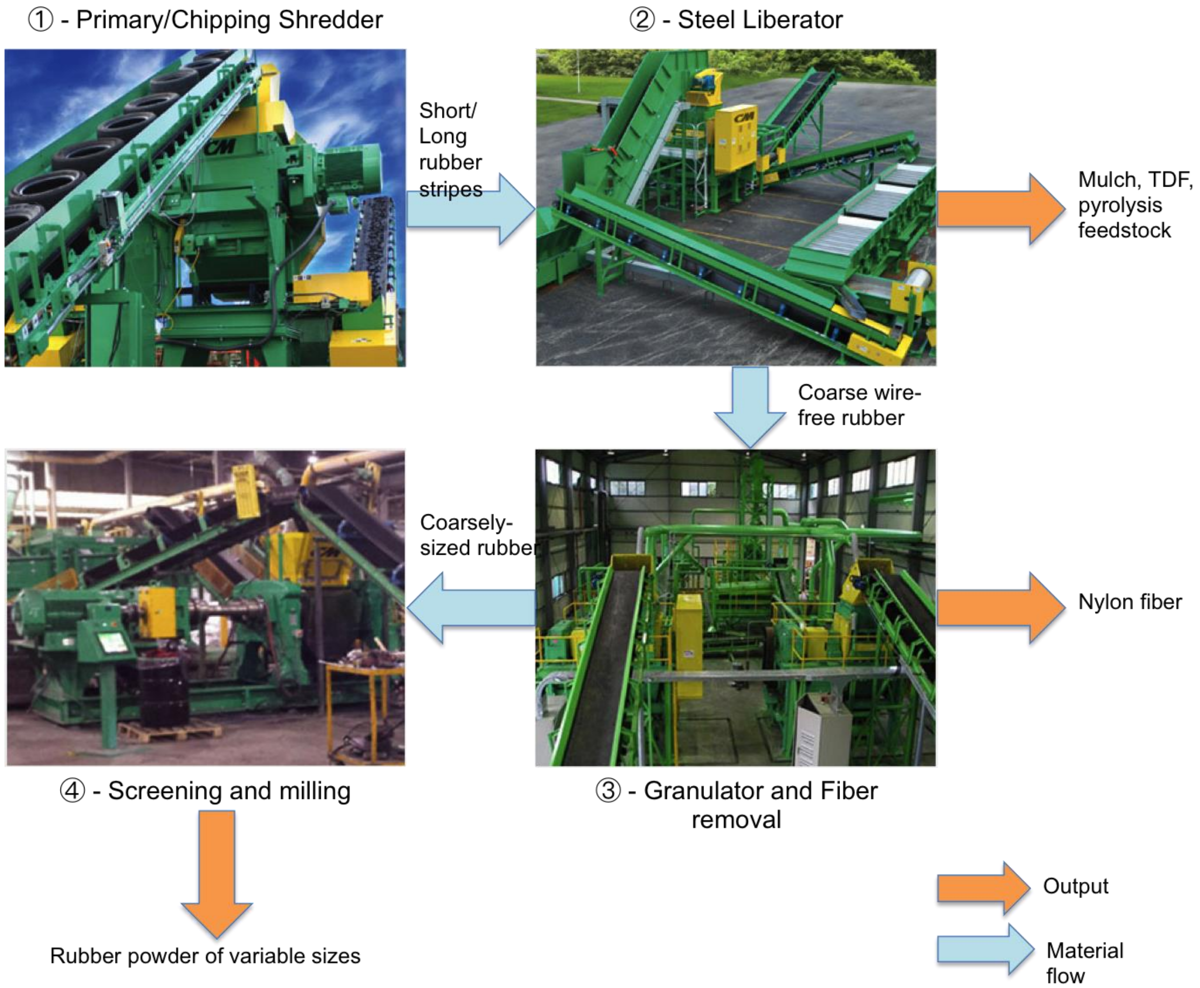
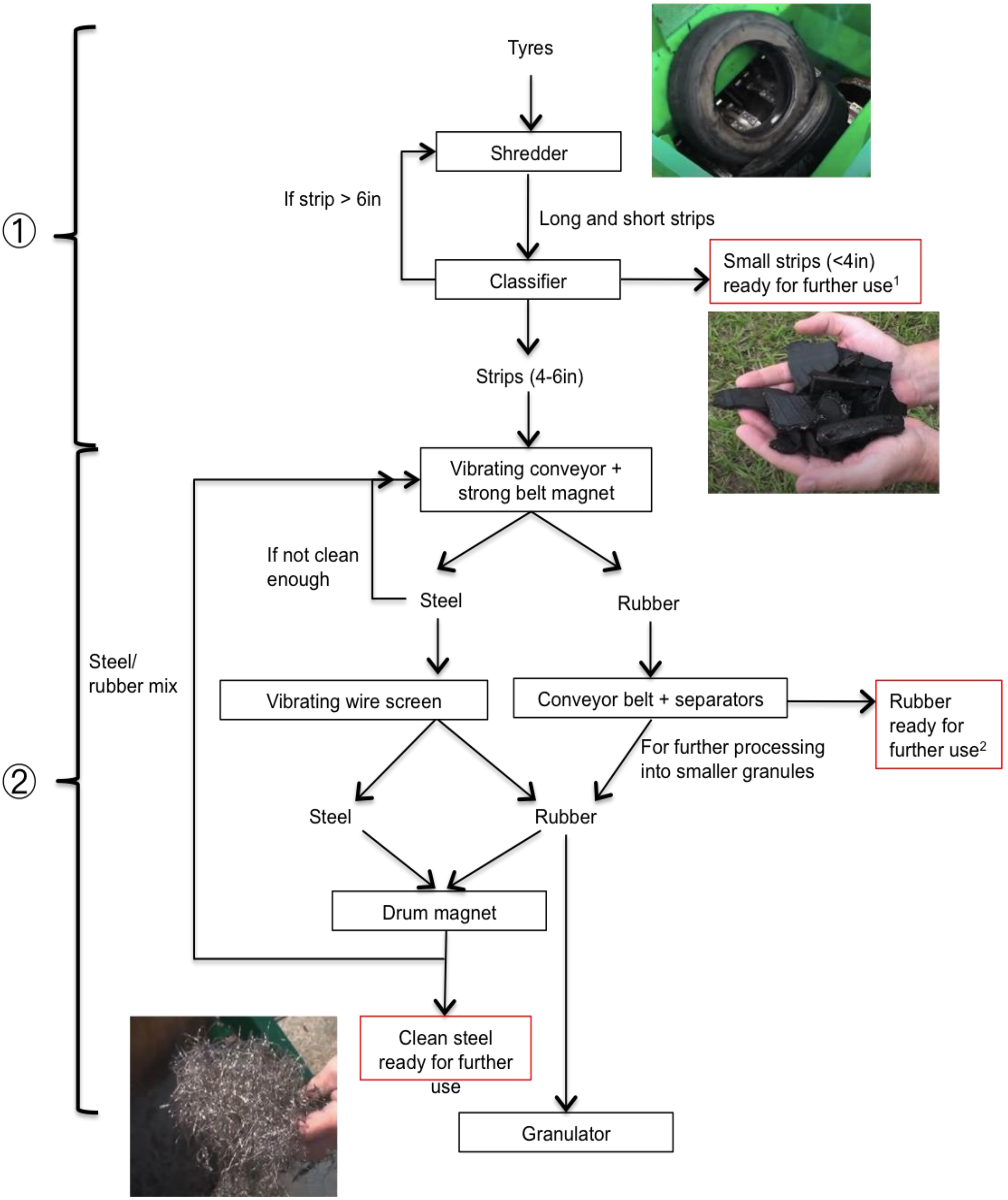
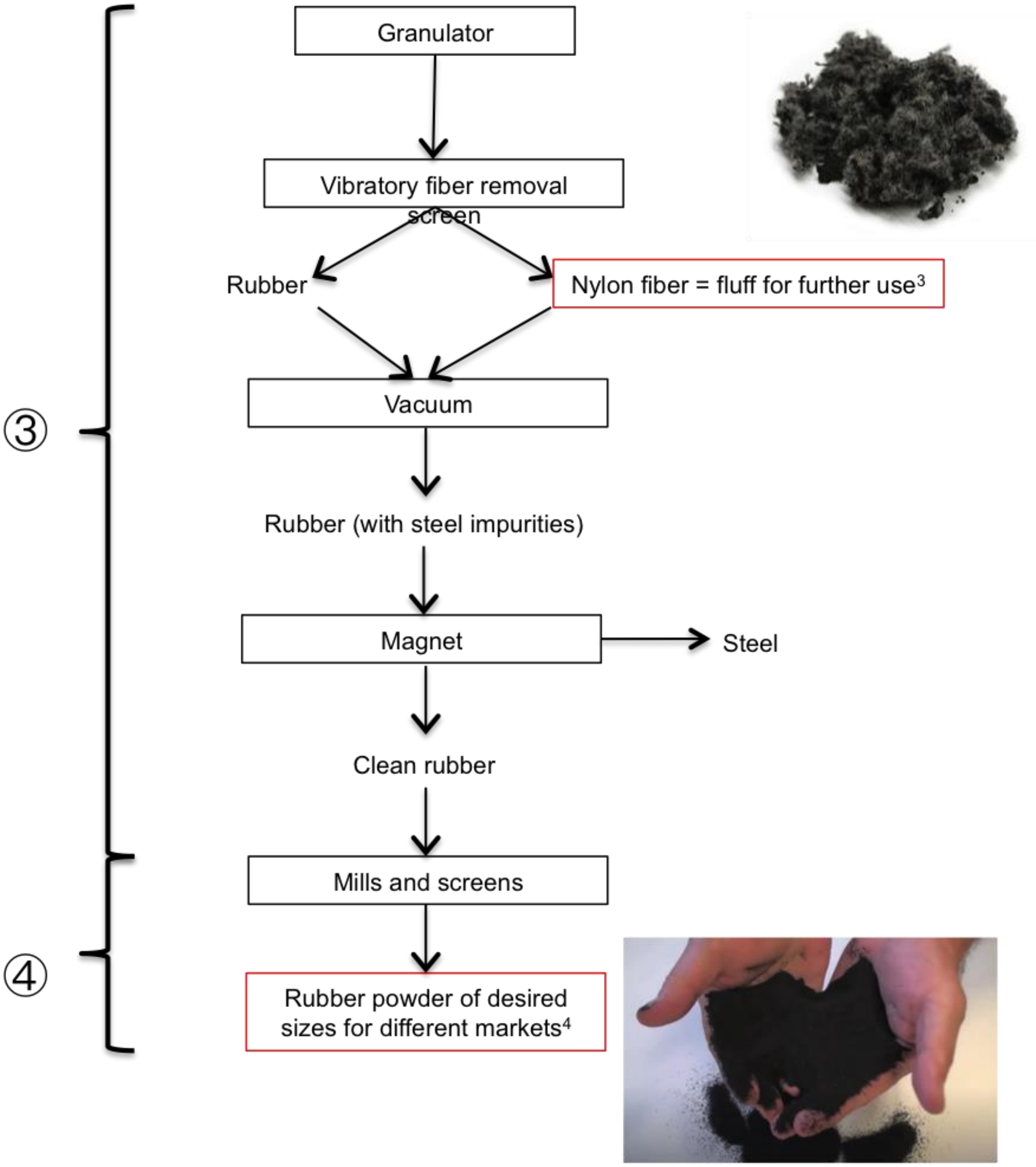


Figure 8: The four stage of a Tyre Recycling System and some outputs (images by CM Shredders USA, explanations by RWA, 2021)


①
②
Tyres
Shredder
If strip > 6in
Long and short strips
Classifier
Small strips (<4in) ready for further use[1]
Strips (4-6in)
Vibrating conveyor + strong belt magnet
If not clean enough
Steel
Rubber
Steel/ rubber mix
Vibrating wire screen
Conveyor belt + separators
Rubber ready for further use[2]
For further processing into smaller granules
Steel
Rubber
Drum magnet
Clean steel ready for further use
Granulator



[1]: Reusable as TDF (tire-derived fuel), cement kilns, paper and pulp mills and for energy generating facilities to be mixed with coal or other fuel for cost saving)

[2]: Reusable as mulch, playground cover, TDF for pulp and paper mills power plants, pyrolysis processes

[3]: Reusable as passenger car, light truck and SUV tyres

[4]: Reusable as rubberised asphalt, moulded products, automotive parts (for in-place surfacing, rubber mats, rubber lumber)

Figure 9: Flow Diagram of the Tyre Recycling System with outputs for each stage (RWA, 2021)

Table 5: Main steps in material recovery from shredding waste tyre

Step	Purpose of step	Output	Potential application for local use	Potential application for other uses
① - **Shredding**	Break down tyres into strips	1. Long strips needing further treatment 2. Short strips ready for other application	Landfill cover material, cement kilns, substrate site access	TDF (Tire-derived fuel), paper and pulp mills for energy generating facilities (to be mixed with coal or other fuel for cost saving)
② - **Steel liberation**	Separate rubber and steel	1. Clean steel ready for other application 2. Coarse granules rubber ready for resale 3. Rubber for further refinement	Playground cover, mulch	TDF, pyrolysis processes
③ - **Granulation and fiber removal**	Reduce the tyres crumb size and remove nylon fiber	1. Nylon fiber ready for resale (image from http://americantirerecycling.com/fiber.ph 2. Steel-free rubber		Passenger car, light truck and SUV tyres
④ - **Final milling and screening**	Mill crumbs and screen for size needed by specific market	Rubber powder of desired sizes for different markets	Rubbarised asphalt, automotive parts	Moulded products

Table 6: Potential outputs from each main step in material recovery from shredding waste tyre and related pros and cons.

Step - Output	Potential Reuse of output	Advantages	Disadvantages	Required equipment for production
Pre- ① - Whole tyre	Slope stabilization	• Lowest cost option for tyre reuse/recycling • Brings stability for embankment roads and slippery hills • Stiffens slope • Does not need shredder • Avoid problems linked to erosion (like departure of sandy soils) •	• Potential release of toxic components	Cleaning May require cutting out side wall
Pre- ① - Whole tyre	Crash barriers on highways	• Absorb energy from car crashes		Cleaning May require cutting out side wall
Pre- ① and ①	Landfill medium	• Whole tyres can be used for better site drainage • Excellent drainage properties for leachate collection • Can be mixed with soil (4:1 ratio) for landfill cover • Offers thermal insulation for primary and secondary landfills	• Leachate and variation in pH levels may affect the compressibility and hydraulic conductivity of the shredded tires	Cleaning + Shredder
① - Long and small strips	Gravel substitute	• Cheaper than gravel • Three times lighter than gravel so cost and time saving • Better permeability of subsurface if 6-12inch layer is added below road • Better drainage in clay soils and underground springs • Resistant against weed invasion	• Protective barrier between mulch and soil necessary to prevent infiltration of heavy metals and rubber leachates into soil (potentially onto groundwater sources) • Potential release of particulate matter, lead, zinc and organic compounds into the air at concentrations below air quality standards • Highly flammable	Cleaning + Shredder

Increasing capital and O&M costs

① - Long and small strips	Wastewater treatment filters	• Could replace organic compounds usually used as filters • Size of pores can be adapted to application	• No operating leachate treatment plant in Barbados	Cleaning + Shredder
① - Long and small strips	Tyre Derived Fuel (TDF) to power cement plants	• Reduction of fossil fuel use, i.e. of importation dependency • Reduction in operational cost to cement manufacturer • No production of by-products • No ash disposal • No residues • Reduction of NOx emissions • Lower sulfur percentage than coal • Calorific value from waste is extracted • Fixation of traces of heavy metals • Neutralization of acidic gases, sulfur oxides and hydrogen chloride by active lime in the kiln load	• Need for continupus supply, storage and transportation of tyres • Restrictions on importation of used tyres • Potential high costs for retrofitting the kiln • Incomplete combustion leading to production of dioxins and furans • Higher percentage of chlorine than most coals • Potential release of heavy metals • Potential increase in lead emissions	Cleaning + Shredder
② - Steel-free rubber strips	Garden mulch	• Appearance constant through time • Does not attract insects • Does not float away during rainstorms • Does not rot • Low maintenance • Requires 1.5 inch depth vs 3 inch for organic mulch	• More expensive than organic mulch • Does not decompose so it does not feed nutrients to the soil • Potential release of toxic components	Cleaning + Shredder + Steel liberator
② - Steel-free rubber strips	Playground cover	• Excellent shock absorber for children • Prevents slipping • Different designs/colours possible	• Specific chemical hazards are unknown, so caution must be taken such as avoiding mouth contact and limit playing times during hot days	Cleaning + Shredder + Steel liberator
③ - Nylon fluff	Car component (carpet, reinforcing additive for plastics)	• High absorption • Sound dampening	•	Cleaning + Shredder + Steel liberator + Granulator + Vacuum
④ - Crumbed rubber	Rubberized asphalt	• Used to pave road surface • Longer lasting than conventional asphalt • Resistance to cracking • Lower traffic noise	• Most expensive output • Requires extensive equipment and processing	Cleaning + Shredder + Steel liberator + Granulator + Vacuum + Mills + Screens

Higher investment

5 Shredding

Shredding whole tyres produces tyre strips of various sizes, which can have practical applications, has been introduced in the previous section. Without an initial shredding step it is not possible to progress the tyre recycling process to produce powder rubber for rubberized asphalt. It is therefore the first equipment to consider and is the minimum investment necessary to start domestically recovering material from waste tyres.

Various sizes, manufacturers and quality of shredders exist on the global market, it should be acknowledged however that a minimum of 750,000 USD is required for a good reliable primary shredder machine. This would be a primary (or coarse) shredder. Less than this amount would purchase a lower quality machine that would likely require significantly more operation and maintenance costs (as has proven to be the case in Grenada and was also experienced in Saint Lucia prior to purchasing the current equipment).

As explained in the previous section, rubber-granulating crumb needed for use in asphalt is generated only after the four stages of recycling, and therefore requires additional investment.

In order to ensure sustainable operation and maintenance of this type of equipment, outsourcing the operation to private operators who are free from potential constraints of public procurement rules and can therefore obtain spare parts and skilled maintenance staff can be beneficial. It is possible that local companies already have similar shredders or other equipment and therefore have the procurement systems, maintenance skills or contracts in place that would make sustainable operation and maintenance of the equipment more economically viable. There exists potential for the public sector to purchase the machine and having the private sector operate it, which has several benefits and is a potential solution that should be explored in your specific location.

Typical costing for a shredder is summarized in Table 7.

Table 7: Typical capital costs for tyre shredding equipment

Equipment	Company	Capital Cost (USD)	Comments/Advantages
Shredder + initial parts + Instructions on operations + Shipment	CM (https://cmshredders.com/portfolio/chipping-shredders/)	490,000 (x2 if add secondary shredder, magnetic separator and powder grinder to produce the granulate that can be directly added in asphalt production (with higher potential marketability rather than landfilling the shredded materials)	Primary (or coarse) shredder with the shredded material going to landfill or cement kiln as fuel
Building construction + shredder platform + its installation	Local artisan	150,000 to 400,000	Based on facility constructed in Saint Lucia
Mobile industrial shredder	Example: TANA Shark 440 (https://www.tana.fi/recycling-processes/success-stories/shredding-car-and-truck-tyres)	>915,000 USD	1. Similar to the shredder donated by the EU / UNDP to Antigua and Barbuda 2. Could handle mattresses and white goods 3. Be configured to do the work of the primary and secondary shredder and with a Cross Band Magnet on the final conveyor, could $remove the steel (doing multiple jobs with the one machine which would require a little more upfront capital investment (in region of USD 1,000,000).

Figure 10: CM Shredder (https://weibold.com)

Figure 11: TANA Shark 440 Mobile shredder (https://tana.fi/stories/tana-shredding-variety-of-materials/)

6 Alternative re-use: Geonet for road construction

"Mechanical Concrete™" is built with cylindrical tension bands created from used auto tyres from which both sidewalls have been removed. [5]

These tyre-derived cylinders are placed side-by-side on the ground covering the footprint of a road's foundation and nailed/stapled together into a grid. When appropriately sized stone aggregate is poured into the cylinders, the stones tightly lock together and behave as a solid, immovable mass. The use of this system minimizes the displacement of gravel by passing vehicles and therefore minimizes ruts and ponding in the roads.

This construction method uses less stone, requires no compaction or curing, and is instantly ready to support construction loads.

With the burying or landfilling tyres is with air or gas building up within the inner void space resulting in the tyre "floating up" through the waste and causing instability, this solution removes that hazard by removing the side wall. Both side walls are cut off the tyre using specialist side wall remover equipment, or reciprocating saw.

The road is then prepared with a level base, a geofabric / geotextile is laid on the road upon which the tyres, of equal tyre width, with side walls removed are then laid out in a grid as shown in Figure 12. The tyres are then connected with one another using a nail gun or screw.

Figure 12: Geogrid from tyres (RWA, 2020)

The tyre grid can then be filled with gravel or similar aggregate to create the road as seen in Figure 13.

This system is perfect for constructing landfill access roads on and off the waste mass as well as stabilizing the landfill side slope benches when placing final cover on the landfill. A similar approach can be used to construct vertical walls, using rammed earth / soil instead of gravel and inserting rebar stakes periodically between each vertical row.

[5] http://www.mechanicalconcrete.com/green-road-construction-invention-deployed-in-five-states/

Figure 13: Gravel fill of tyre cylinder geogrid once in place http://www.mechanicalconcrete.com/county-takes-green-approach-to-roadbuilding/.

Figure 14: Gravel Road construction http://www.mechanicalconcrete.com/county-takes-green-approach-to-roadbuilding/

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