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PacWastePlus
PACIFIC WASTE MANAGEMENT

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.**

End of Life Tyre Management:

THERMAL PROCESSING OPTIONS

February 2022

This Management Option Booklet explores possible reuse options for ELTs without processing. Several end-use markets exist to manage ELT such as Energy generation whereby ELT are used either whole or shredded straight into the kiln. shredded and used as fuel (TDF).

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

Acronyms

Abbreviation	Description
BaP	Benzo(a)Pyrene
ELT	End of Life Tyres
EU	European Union
TDF	Tyre Derived Fuel
CO	Carbon Monoxide
CO2	Carbon Dioxide
LCA	Life Cycle Analysis
NO2	Nitrogen Dioxide
NOx	Nitrogen
PAHs	Polynuclear Aromatic Hydrocarbons
PICs	Pacific Island Countries
PM	Particulate Matter
SO2	Sulfur Dioxide
SOx	Sulfur Oxides
SPREP	Secretariat of the Pacific Regional Environment Programme
TDF	Tyre Derived Fuel
OTR	Off The Road Tyres
VOCs	Volatile Organic Compounds
ZnO	Zinc Dioxide

Contents

About the PacWastePlus Regional Bulky Waste Management Project

PacWastePlus is assisting Pacific Island Countries to improve the management of End-Of-Life vehicles and End-of-Life Tyres by providing guidelines and technical notes on safe handling and dismantling and options for in-country management of these items. This regional project will complement the bulky waste management initiative under the ISLANDS Pacific Project and develop:

- Guiding document and a Decision Support Too l to guide participating countries on how to design and implement a national ELV management programme.
- Develop Drafting/Guiding Notes on how to draft national legislation for the management of identified bulky waste
- Establish safe Dismantling Training Manual to be implemented by national governments to ensure both safeties of workers and prevent discharges into the environment.
- Publications and awareness materials

End-of-Life Tyre Management Publication Series

Technical Booklets: End-of-Life Tyre Management Options

Non-Processing Reuse Options
Non- Processing Method for Utilising ELT: End of Life tyres are utilised "as is" with no processing requirement. Detailed information on repurposing ELT without mechanical or Thermal is provided in the PacWastePlus End of Life Tyre Management – Guideline for Non- Processing Booklet.

Mechanical Processing Options
Mechanical Processing where ELTs are mechanically processed using specialised equipment to create outputs of steel, nylon, and various rubber forms. Detailed information on this type of ELT processing is provided in the PacWastePlus End of Life Tyre Management – Guideline for Mechanical Processing Booklet.

This publication

Thermal Processing Options
Where ELTs are substituted in place of new raw materials reduces associated environmental and economic costs. Detailed information on this type of ELT processing is provided in the PacWastePlus End of Lite Tyre Management – Guideline for Thermal Processing Booklet.

Research Report

Assessment of End-of-Life Tyres in the Pacific

Factsheets: End-of-Life Tyre Management

Community

Retailers/Suppliers

The PacWastePlus Programme

The Pacific – European Union (EU) Waste Management Programme, PacWastePlus, 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 PacWastePlus

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 PacWastePlus programme will generate 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 PacWastePlus 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 PacWastePlus programme by visiting

https://pacwasteplus.org/

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PacWastePlus PACIFIC WASTE MANAGEMENT

Introduction

An estimated one billion tyres worldwide (about 17 million tonnes) reach the end of their useful lives every year. This number has been growing steadily and this trend is expected to continue.

While there are efforts by governmental authorities, the tyre industry, and individual manufacturers to manage end-of-life tyres (ELTs), there is still much to be done. This Management Option Booklet explores possible reuse options for ELTs without processing. Several end-use markets exist to manage ELT such as Energy generation whereby ELT are used either whole or shredded straight into the kiln. shredded and used as fuel (TDF).

ELT are also recycled in the Infrastructure Sector whereby ELT are used whole, shredded, or ground and used as embarkment, asphalt, or synthetic field turf. ELTs that do not enter an end-use market are usually landfilled, burnt, or illegally stockpiled posing several environmental and social risks.

Some of these risks includes:

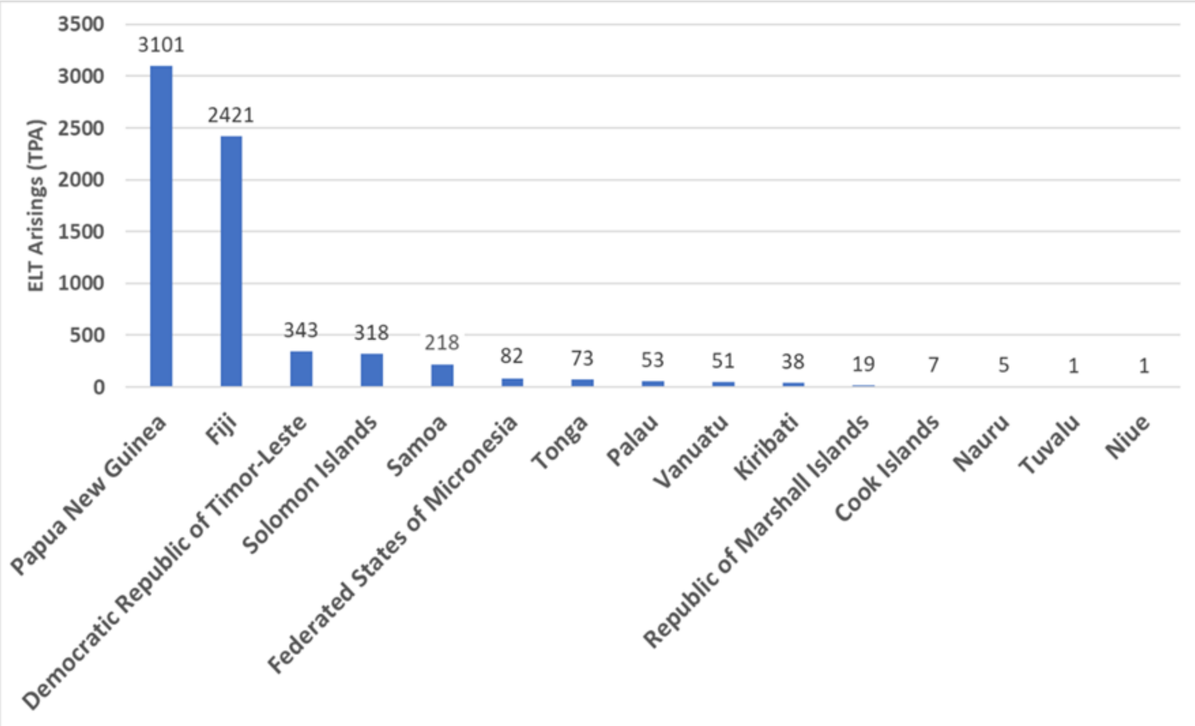
- Incubation of mosquito larvae due to the ability of whole tyres to hold water. This presents a biosecurity risk of the spread of mosquitos as non-native species, and the associated risk for disease such as malaria and dengue fever. In drier regions, dust settles within tyres with the associated risk of transfer of seeds, insects, and other vermin associated with export of baled tyres.
- Emission of several types of classified pollutants, such as particulates, carbon monoxide (CO), sulfur oxides (SOx), oxides of nitrogen (NOx), volatile organic compounds (VOCs), polynuclear aromatic hydrocarbons (PAHs), dioxins, furans, hydrogen chloride, benzene, polychlorinated biphenyls (PCBs); and metals such as arsenic, cadmium, nickel, zinc, mercury, chromium, and vanadium.
- Tyre fires, apart from intense heat, give off black carbon with CO gas emission. Research has reported that the emission levels of CO from different type of tyres were 21–49 g/kg, SO2 emission was found to be 102–820 g/kg, while NO2 emission was 3–9 g/kg. Among metals, ZnO and CO have been found to be 21 and 92 times higher than an area far from the open fire[1].
- Emissions from an open tyre fire can represent significant acute (short-term) and chronic (long-term) health hazards to firefighters and nearby residents. Depending on the exposure time and concentration, these health effects could include irritation of the skin, eyes, and mucous membranes, respiratory effects, central nervous system depression, and cancer. There are 16 PAH types known to be emitted from tyre fires, including several compounds known to be carcinogenic including benzo(a)pyrene (BaP).
- Illegally dumped ELTs will degrade overtime due to exposure. ELTs are sensitive to UV light (the sun) and temperature, and over time, will leach toxins such as zinc and manganese into the surrounding environment.

[1] Ferronato & Torretta - Waste Mismanagement in Developing Countries, March 2019

Most Pacific Island countries and territories generate seemingly large amounts of ELTs due to having little legislative influence over the quality of tyre imports, often resulting in the importation of second-hand tyres (re-treads) which have a limited life once installed on vehicles.

It is estimated that some 6,700 tonnes, or approximately 670,600 tyres, reach end of life annually across all PICs (**Figure 1**)[2].

Figure 1 Estimated generation of ELT in PIC per year



***Source**: Hyder, Stocks & fate of end-of-life tyres, 2015*[3]

Due to lack of international demand for ELTs as a commodity, shipping tyres to safe recycling or disposal in other remote countries is a costly exercise with limited opportunity for resale (currently). In the absence of options for in-country ELT reprocessing, many ELTs are dumped or landfilled consuming critical landfill space, exacerbating an already critical issue for atolls and small islands with limited land availability.

This booklet will explore several the potential use of ELT through thermal processing. Several of the references supplied in this report provide multiple options for further analysis, as PIC ELT systems develop and mature.

The options presented here provide preliminary information designed to assist countries to understand immediately available opportunities and does not reduce the need for more detailed assessment prior to implementation.

[2] An estimated one billion tyres worldwide (about 17 million tonnes) reach the end of their useful lives every year.

[3] This estimate is based on estimated tyre import and stockpile volumes and assume a lifespan of 3.4 years for a passenger car tyre, 1.5 years for a truck tyre and 1 year for an OTR tyre.

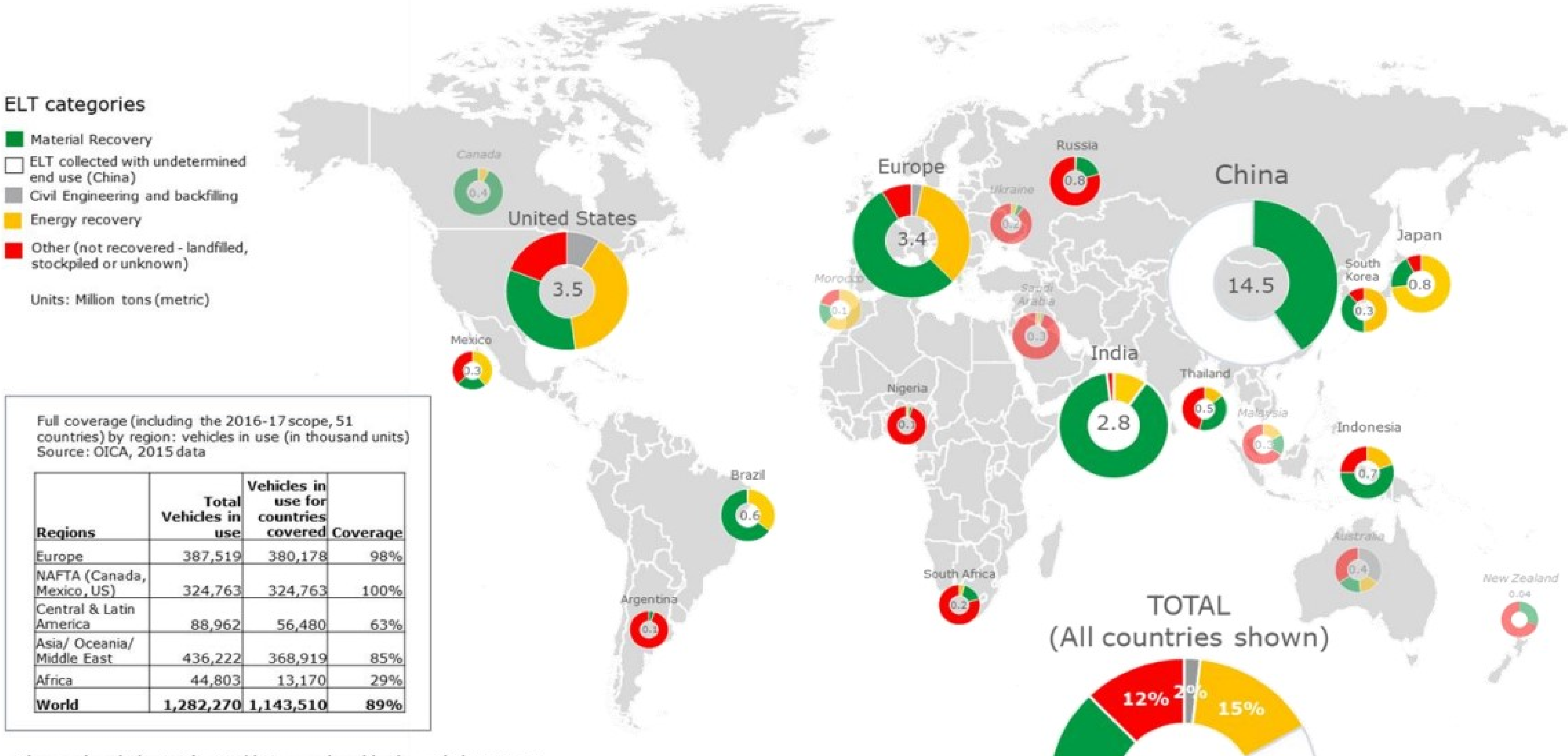
ELT Recovery Around the World

Countries with successful ELT recycling programs often include regulatory instruments, along with voluntary system management from the tyre industry.

According to World Business Council for Sustainable Development (WBCSD) data drawn from more than 13 countries, 89% of 29 million tonnes of ELT generated is recovered. Globally, China, the United States of America, and Europe recover the most ELTs.

A snapshot of ELT management behaviour from around the world is below:

- Due to the limited landfills space, and strict European Union Directives (including a ban on tyres to landfill) sees European countries recovering the greatest number of ELTs globally.
- India and Brazil also report high ELT recovery rates (although India's is a high proportion of informal/undocumented recovery).
- North America provides subsidies for the use of rubber granulate in high value applications, promoting recovery and material recycling.
- Africa, the Middle East, and Russia show high numbers of landfilled or non-recovered ELT.



Regions	Total Vehicles in use	Vehicles in use for countries covered	Coverage
Europe	387,519	380,178	98%
NAFTA (Canada, Mexico, US)	324,763	324,763	100%
Central & Latin America	88,962	56,480	63%
Asia/ Oceania/ Middle East	436,222	368,919	85%
Africa	44,803	13,170	29%
World	**1,282,270**	**1,143,510**	**89%**

Changes in relation to the World Map produced in the period 2016-17:

- To avoid underestimating ELT management collection rates, the blank portions of the charts for China and Total data identify ELT collected with undetermined end use. It is understood that all ELT is collected in China, however complete data on end use is not available. The ELT volume generated in China increased significantly between the two TIP ELT studies consistent with extrapolations of an increasing number of vehicles in use.
- For the 2016-17 study, which had a larger scope than that of 2018-19 (6 countries), coverage of most recent data available was 89% of vehicles in use (OICA): The countries in italics and a lighter shade were not studied in detail for the 2018-19 State of Knowledge and therefore may not be the most recent reliable data. However the past data available from the 2016-17 study has been added to this map to provide the broadest picture possible. Out of the total for all countries shown this group of countries represents 1.7 million tons or 5%.
- The color coding has been altered to align with those used commonly to illustrate the waste hierarchy.
- The data shown is considered the best available data at the time of the respective studies (2016-17 and 2018-19).

Figure 2: ELT Recovery in 13 countries and the European Union[4]

[4] Source: WBCSD Global ELT Management – A global state of knowledge on regulation, management systems, impacts of recovery and technologies, December 2019

ELT Recovery Methods in Key Countries

Once diverted from landfill and available as a commodity, ELTs are typically managed via some type of processing (wall removal, steel removal, shredding, grinding, etc.). The different processing methods enable different use applications.

Energy recovery is usually the final option following retreading, shredding, and granulation and often in countrieswhere disposal has been banned such as the case in the European Union through EU legislation. ELT are either used whole or shredded to size suitable for the intended use as Tyre Derived Fuel (TDF). TDF may be mixed with coal or other fuels, such as wood or chemical wastes, to be burned in concrete kilns, power plants, or paper mills.

Table 1 presents data sourced from the WBCSD Global State of Knowledge and the predominant processes and uses of ELTs around the world.

Table 1 Main ELT recovery methods in key countries around the world[5]

Country	Annual ELT Recovery (t)	Method of Recovery
China	14,545,000	Reclaim rubber and granulation Low emission pyrolysis methods are under research and development
Europe	3,425,000	Rubber granules and powder (43%), cement kiln burning (38%) Use of ELT in asphalt and low noise surfaces and in plastics Research into pyrolysis
United States	3,700,000	Energy recovery (39%), material recovery (33%) of which most is granulated, and 9% civil/infrastructure use of ELT. Significant focus on environment and health related impacts of ELT recycling.
India	2,750,000	Material recovery process with a large part going to crumb rubber Research for ELT use in is steel production and rubber-modified concrete
Indonesia	684,000	Pyrolysis is the main recovery route, obtaining oil as TDF for industrial purposes ELT are also used in brick manufacture 15% goes to material recovery, mostly granulation
Japan	849,000	Mostly energy recovery (73%), with exemption of reporting and reduction objectives for energy from waste Material recovery of ELT is 19% Civil infrastructure use is 0.1%
Nigeria	113,000	Use as TDF for cooking (currently studies recommending against this practice) Civil/infrastructure applications (carpark barriers and marine jetties) Research into rubber granules absorbing oil spills
Thailand	515,000	Pyrolysis and cement kilns process around 54% of all ELT, creating issues around pyrolysis pollution Recent study by the government on a regulatory system for ELT Similar issues to PIC with little or no ELT collection infrastructure outside major cities

Overall, 97% of ELT are recovered either for civil infrastructure or energy recovery.

[5] Source: WBCSD Global ELT Management – A global state of knowledge on regulation, management systems, impacts of recovery and technologies, December 2019

[Waste to energy](#) is considered as a preferable method of ELT recovery in terms of environmental impact assessment and resource efficiency.

However, thermal treatment of ELTs requires more initial investment, research and development efforts, and joint agreements with industry.

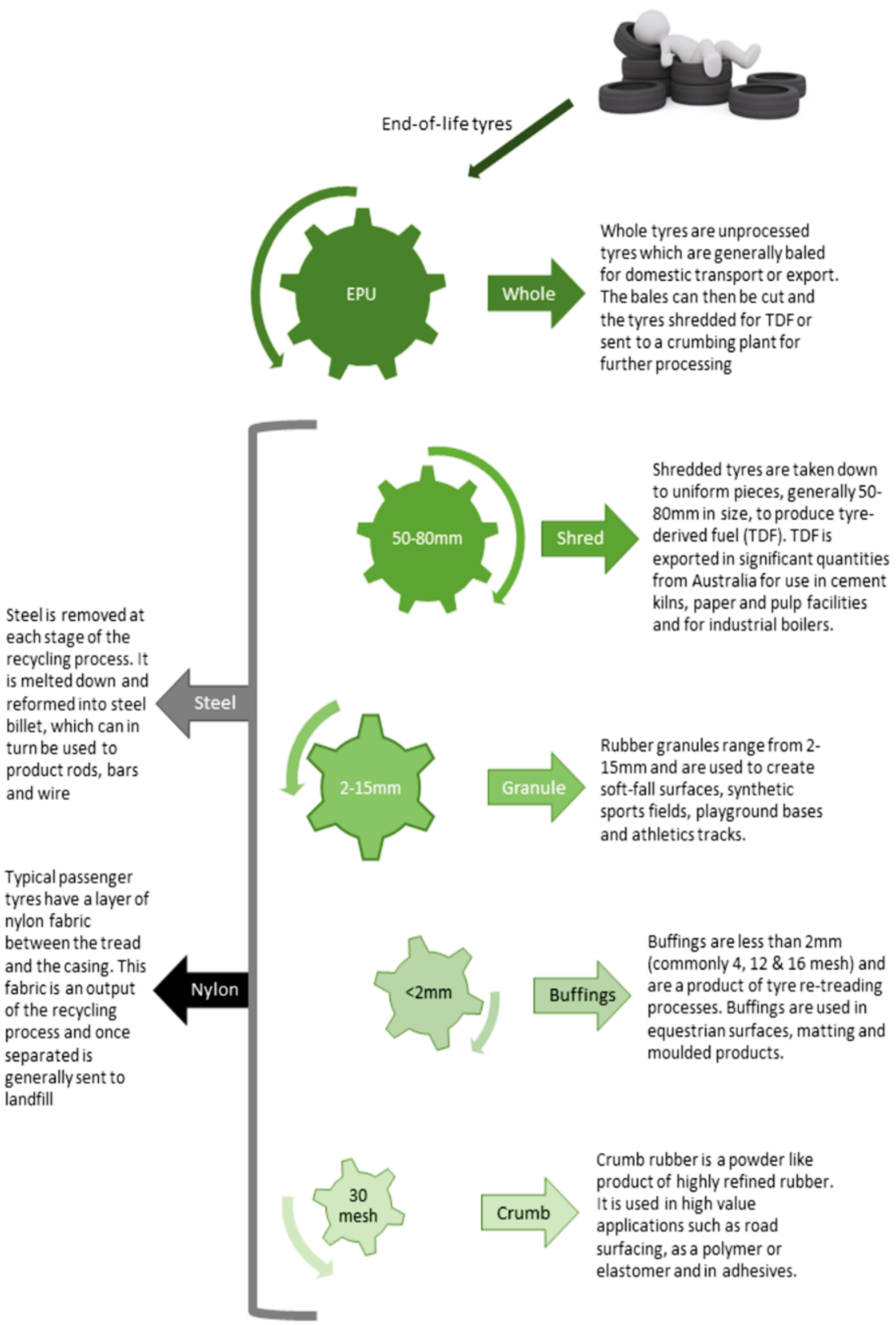


Figure 3: Common types of Tyres Derived Products generated from ELT and common application

Benefits of Recovering End-of-Life Tyres

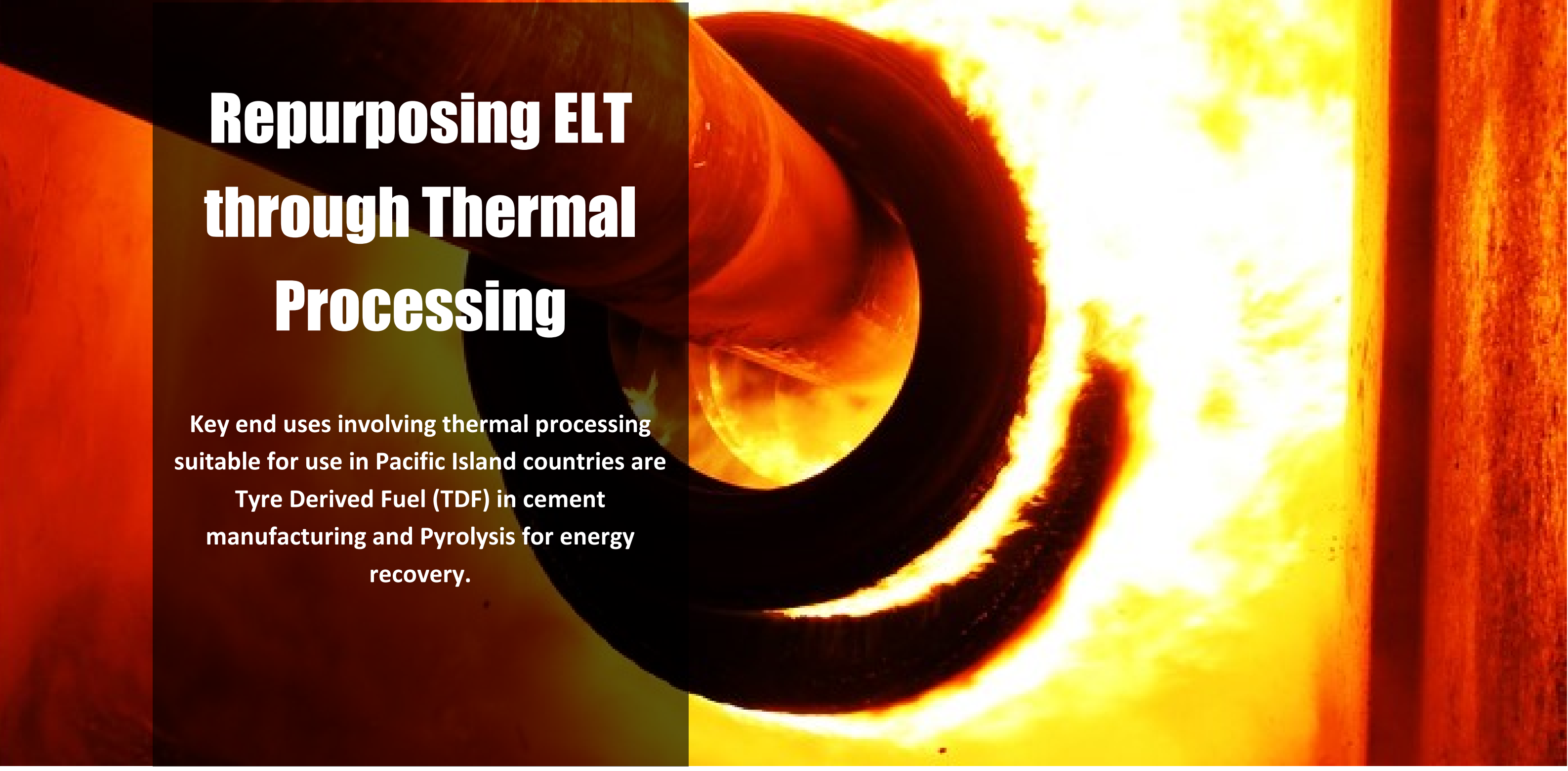
There are many benefits of recovering End- Of- Life Tyres.

Recovering End-of-Life tyres means that these items are no longer dumped in landfills or illegally dumped in the environment. Tyres takes up significant space in landfills due to its bulky nature and shape and would take hundreds of years for the rubber to decompose. Diverting ELT from landfills can preserve critical landfill airspace, leaving more space in landfills for things that cannot be easily recycled.

Recovering ELT contributes to protecting health of local communities. When illegally dumped in the environment, ELT serve as home to rodents and insects that can carry disease that can be passed on to humans. Rodent urine can cause leptospirosis which can bring about life threatening symptoms such as meningitis, kidney failure, and liver damage. Mosquitoes, can also breed in discarded tyre, spreading dengue fever, Zika, and Malaria to local communities.

More than 40% of tyres consists of rubber and tend to have high calorific value making it a potential replacement for coal.

The establishment of tyre recycling industry will generate employment opportunities for local citizens. Employment opportunities will be created to facilitate collection, processing, recycling, and sales.



Repurposing ELT through Thermal Processing

Key end uses involving thermal processing suitable for use in Pacific Island countries are Tyre Derived Fuel (TDF) in cement manufacturing and Pyrolysis for energy recovery.

Tyre Derived Fuel (TDF)

ELTs are an energy source that can replace fossil fuels and help conserve natural resources. Life cycle analysis (LCA) has shown the calorific value of ELTs is viable as an alternative fuel.

Tyre-Derived Fuel (TDF) are commonly used in cement kilns as a fuel substitute for coal. Industrial facilities across the world, including cement kilns, pulp and paper mills, and electric utilities, use TDF as a supplemental fuel to increase boiler efficiency, decrease air emissions, and lower costs.

Pyrolysis

ELTS are heated through thermal decomposition that heat the tyre rubber in the absence of oxygen, and break it into its constituent parts, e.g., pyrolysis oil (or bio oil), synthetic gas (syngas) and char.

Typical energy recovery processes around the world from ELT include:

- The USA uses ELTs in cement kils (and pulp and paper industry) as a fuel. This use accounts for half of the ELT market in the USA[6] Pyrolysis is only slowly developing in the USA with some pilot plants. Overall, this recovery method has had some difficulty commercializing products and has been facing operational risk including safety hazards and air polluting emissions.
- South Korea shas set a limit that up-to 70% of the recovered ELTs can be used in energy generation[7]
- Europe, where material recovery is prioritized over energy recovery still sees some 40% of recovered ELTs used in energy recovery/generation processes.[8]Japan actively promotes the use of TDF through the country's energy policy (exemptions from reduction objectives) and ELT mainly becomes TDF for paper manufacturing boilers. Repurposing ELT through pyrolysis and gasification are also significant in Japan and other Asian countroes like Indonesia and Thailand.

[6] https://archive.epa.gov/epawaste/conserve/materials/tires/web/pdf/brochure5-08.pdf
[7] South Korea shas set a limit that up-to 70% of the recovered ELTs can be used in energy generation
[8] South Korea shas set a limit that up-to 70% of the recovered ELTs can be used in energy generation

TDF in Cement Manufacturing

Cement manufacturing is a complex process that begins with mining and then grinding raw materials that include limestone and clay, to a fine powder, called raw meal, which is then heated as high as 1450 °C in a kiln. A report[9] by the United States Environmental Protection Agency (USEPA) highlighted that TDF contains about the same amount of energy as oil and 25% more energy than coal.

This means that each ton of TDF fed through a Cement kiln has the potential to replace 1.25 tons of coal. ELTs are either use either whole or shredded before being fed straight into the kiln. High calorific value of tyres assists in heat generation, while iron and zinc content are useful additives to the process.

Processes

Figure 4: Injection of ELT into Kiln

ELT can either be used whole or shredded and fed TDF are fed into the cement kiln via modified conveyor systems, depending on the size of the ELT used.

TDF is a compact fuel, with very low moisture and some iron and zinc content, which are desirable properties in the raw material mix for cement manufacturing.

The materials handling operations already in place at many cement plants require only minimal modification to accommodate TDF feed.

Advantages of TDF in Cement Plants

Benefits of using TDF in Cement Kilns include:

- High Calorific value and have potential to replace coal.
- Significantly save fuel cost as traditional fuels can be replaced with cheaper tyre shred that has almost equal heat value to oil and is even 25% more effective than coal.
- Burning process of tyre derived fuel (TDF) is easier to manage compared to the typically used refuse-derived fuel (RDF) or solid recovered fuel (SRF).
- Large and regular feedstock source.
- Emissions of particulate matter from burning ELT in controlled environment such as Cement kiln are lower. Emission tests indicate that kilns firing TDF had emissions approximately one-third of those kilns firing conventional fuels. Emissions of particulate matter (PM) from TDF-firing kilns were 35% less and nitrogen oxides, most metals, and sulphur dioxide emissions from TDF-firing kilns also exhibited lower levels than those from conventional fuel kilns. The emission values for carbon monoxide and total hydrocarbons were slightly higher in TDF versus non-TDF firing kilns.[10]
- Reduction of nitrogen oxide emissions of nitrogen oxides from Cement plants and costs since less urea is needed. [11].

[9] https://archive.epa.gov/epawaste/conserve/materials/tires/web/pdf/brochure5-08.pdf
[10] https://archive.epa.gov/epawaste/conserve/materials/tires/web/pdf/brochure5-08.pdf
[11] https://tana.fi/stories/end-of-life-tyres-tdf-in-cement-kilns/

Pyrolysis

Pyrolysis is rapid thermal decomposition of material in the absence of oxygen. It is operated at elevated temperatures and pressures. Feedstock are requred to be dried and crushed to small particle sizes before entering the reactor. Numerous pyrolysis reactor types have been designed to convert materials into three classes of products: liquid, solid, and gas. The yields of individual products depend on the reactor configuration and operational conditions. The composition of each fraction of the three main products obtained from ELT pyrolysis, i.e. gas, liquid (oil) and solid (char, steel and ash), depends not only on the given pyrolysis conditions, but also on the type of reactor used. The diagram below higlight the different reactor type for pyrolysis of ELT.[12]

Process Description

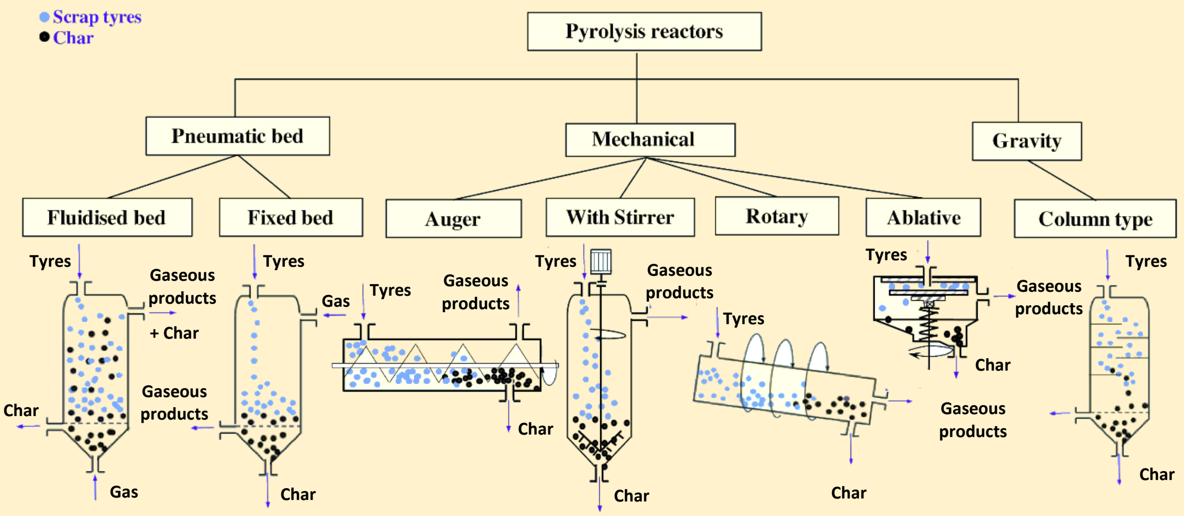


Figure 5: Reactor Type for Pyrolysis of ELT

ELT can be used for pyrolysis whereby a two-phase treatment is involved. The pyrolysis method for ELT recycling involves heating whole or shredded tyres in a reactor without oxygen and a heat source. In the reactor, the rubber softens and the polymers disintegrate into smaller molecules which vaporize and exit from the reactor. These vapours are either (i) burned to produce power or (ii) condensed into an oil type liquid, called pyrolysis oil or bio-oil. The pyrolysis oil has high calorific value, low ash, low residual carbon and low sulphur content. The pyrolysis oil is used as a fuel alternative by numerous industries. The solid residue, called char, contains carbon black, and inorganic matter is typically used as reinforcement in the rubber industry, as activated carbon or as smokeless fuel.

Consideration of Type of ELT Input in Pyrolysis

- The quality of ELT feedstock is critical in determining the success of pyrolysis operations. Effective pyrolysis requires shredding of ELT to achieve the optimal size required to ensure efficient feeding into the reactor. Poor selection of feedstock can stall operations, resulting in poor thermal perfomance and the production of large volme of ash that would need to be landfilled.
- Stockpiling ELT near a pyrolysis plant can result in contamination of feedstock from Char generated from the pyrolysis process. Prior to installation of pysolysis plants, a Cost and Benefit analysis on long term benefit must be undertaken as temporary plants often bring temporary solution.

The mechanical and thermal properties of whole or shredded tyres differ significantly from the typical waste biomass from forestry or agriculture.

[12] https://www.sciencedirect.com/science/article/pii/S0165237019300208

Financial Considerations

Costs of pyrolysis Costs of procuring a complete vacuum pyrolysis plant processing 100kg/h of tyres (approx. 10 tyres per hour) can be relatively low, for a. Ongoing operating and maintenance costs is an additional cost that will need to added.

Environmental Considerations

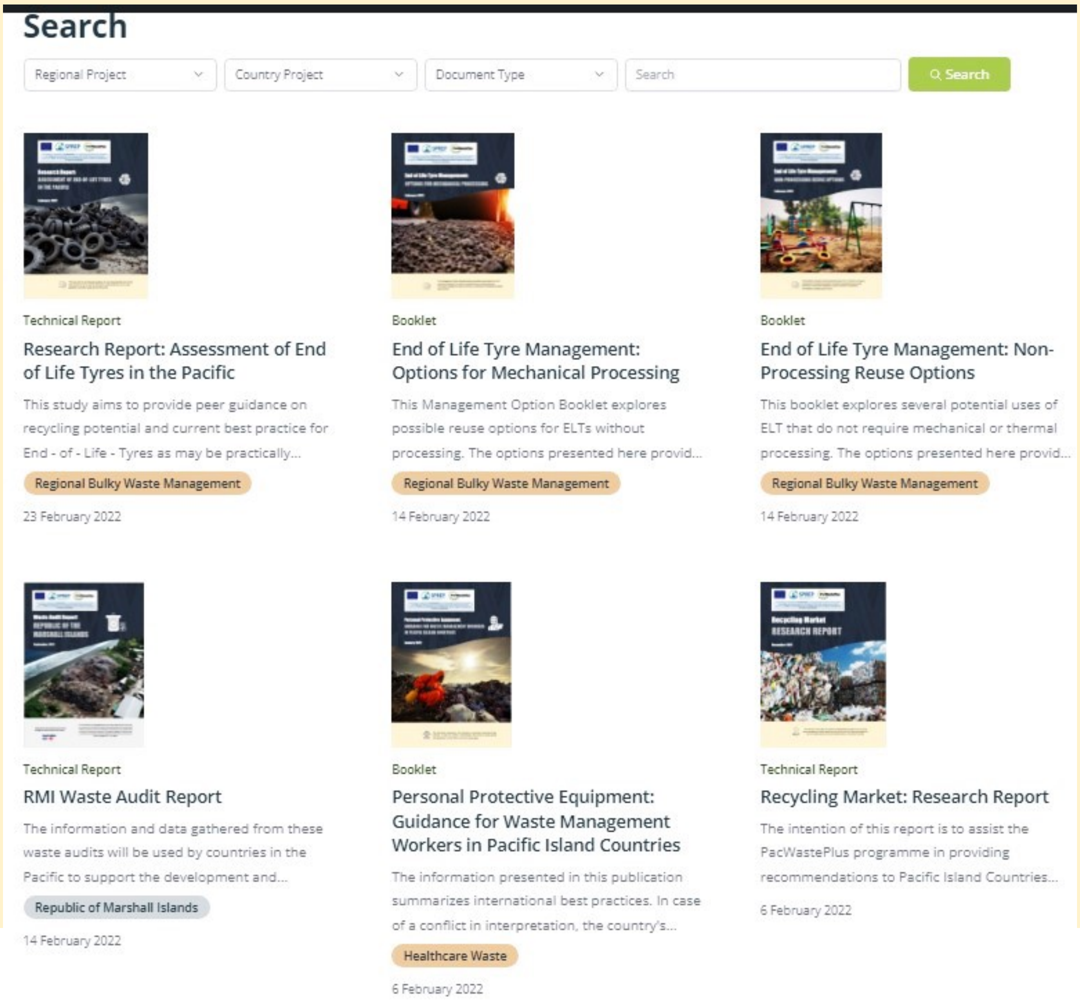
Pyrolysis is promoted as a clean method to derive carbon black, diesel oil and other products from ELT; yield of pyrolysis process has been demonstrated as 41% pyrolytic oil, 38% carbon black, 12% gas and 8.9% steel scrap, with a calorific value of 36 MJ/kg of ELTs. The carbon black is 90% carbon, a higher quality than required as a raw material by steel and ink industries. Pyrolytic oil contains 66% gasoline and 33% other oils, sufficient quality to be used as an additive for fuels, or as fuel for engines and furnaces.

Pyrolysis	
Advantages	**Disadvantages**
• Reduces waste whilst providing a useful energy output at the same time. Economic advantage with regarding operating costs when using waste as feedstock.	• Unwanted by-products produced. Inert bottom ash is produced which requires contained disposal such as landfill.
• Low air pollution. The oxygen starved environment means no dioxins nor ultrafine particulate matter is produced (or at least very minimal amounts).	• Most pyrolysis types require some form of pre-treatment of feedstock. This includes crushing and drying the MSW before entering the pyrolysis reactor.
• Range of products. The different types of pyrolysis and operating conditions allow different products to be produced with different applications, whether that be solid biochar, liquid bio-oil, or syngas.	• Elevated temperatures. The required elevated operating temperatures are a disadvantage from both a safety and an operating cost perspective.
• Controlled emissions. All emissions are easily captured within the syngas, providing easy removal through syngas cleaning, allowing better containment of contaminants.	• Potentially difficult to gain required consent and other specific legal requirements and sign off due to nature of technology – it has a negative reputation as it is seen as “burning rubbish”.
• Efficient. Pyrolysis is a very efficient process with high conversion of feedstock to products (e.g., high bio-oil yield). Although, if electricity is the desired product, pyrolysis efficiency is lower, like that of combustion technologies.	• Significant financial capital expenditure, especially compared to combustion technology, however, this was not viewed as a fatal flaw given the potential for externally funding (providing it meets donor or lender criteria).
• Easy to operate and transport due to modular units available. Additionally, this makes them easy to scale up or down by simply adding more units.	• Elevated operating pressures (above atmospheric pressure) pose an additional safety risk, especially in conjunction with the elevated operating temperatures.
• Liquid products have a similar heating value compared to fossil fuels.	
• Can be used to convert a wide range of waste streams.	

Emerging Pyrolysis Operations

Despite the quality and environmental issues described above, the value of the by-products from pyrolysis is forcing further research and development, with operational experience partially driving the momentum towards a future use for this method of ELT processing.

Tyre Stewardship Australia (https://www.tyrestewardship.org.au/guidelines/pyrolysis-guide/) **has produced a comprehensive guide to ELT thermal processing that is essential reading for any project proponent .**



The PacWastePlus programme team is committed to producing meaningful and valuable publications and resources that provides guidance for improving waste management in the Pacific.

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