Sustainable Communities and Waste

National Environmental Science Program

Indian Ocean Territory: Case Study

IP2.02.02 Finding Fit for Purpose Technological Recycling Solutions for Regional and Remote Communities

Demonstration of case study 2 - Remote Community Project Progress Report

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The Sustainable Communities and Waste Hub acknowledges all Aboriginal and Torres Strait Islander Traditional Custodians of Country and recognises their continuing connection to land, sea, culture, and community. We pay our respects to Elders past, present, and emerging. We support Aboriginal and Torres Strait Islander peoples and their aspirations to maintain, protect and manage their culture, language, land and sea Country and heritage.

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Executive Summary

Overview

This project aims to investigate the characteristics and analysis of plastics, metals and nonmetals waste from marine waste and electronic waste (e-waste) destined for landfill, stockpiling or polluting the land and ocean in the Indian Ocean Territories of Australia. This valuable investigation will help to suggest future recycling, resource recovery and waste management strategies for these remote territories so that waste can be utilised as a valuable resource in a supply chain for remanufacturing. Specifically, the project identified key problems in the waste streams to leverage advanced physical and chemical characterisation of highly contaminated mixed plastic wastes from marine waste and e-waste in the future. Addressing these problems will create a unique opportunity for researchers, industries, government, and the community to collaborate with the common goal of creating value from the mixed plastic wastes of the Indian Ocean Territories (IOT) for remanufacturing.

At the initial stage, the project identified waste challenges that the community is facing, the types of waste and their current status.

The Challenges

Indian Ocean Territories, comprising Christmas Island (CI) and the Cocos (Keeling) Islands (CKI), are remote island groups. As a result, all goods that cannot be produced locally must be shipped via sea or air, incurring significant costs. CI is a high island (the highest point on CI is 300 meters above sea level) and landfill is the most common method of waste management. CKI is a low-lying island (the highest point is only 5 meters above sea level) and landfill is not an option. Any waste that can be incinerated is burned, while the remainder is shipped off the islands at considerable financial and resource costs.

There have been several reports on waste volumes—particularly marine waste—on CI and CKI, conducted by organizations such as Tangaroa Blue, Sea Shepherd, the University of Tasmania, and the University of Western Australia's Oceans Institute (Taylor Simpkins, 2021a). However, as far as we are aware, there is no detailed breakdown of specific plastic types, their properties, other materials' co-existence, etc.

The main types of waste on CI and CKI (noting that a breakdown by plastic type is lacking) are as follows:

Marine waste: This is the most abundant form of waste and has been the subject of several reports. Common types include polyurethane shoes and single-use plastics, such as PET drink bottles and polystyrene containers.

E-waste: This is the costliest type of waste to manage per item and contains both plastics and potentially recyclable metals. Due to the Western Australia ban on e-waste in landfills, items need to be shipped to the mainland at the expense of the local government.
It is worth noting that the CKI community and Shire are likely highly motivated to implement waste management solutions, given the limited options: incinerating waste, which negatively impacts air quality, or shipping it off the island, which incurs high costs.

Prior research provided preliminary information on types of waste in CI and CKI, which indicates that both the territories experience similar environmental conditions. Given the many opportunities for collaboration between the two islands, this project will particularly be interested in research that looks at both CI and CKI.

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Waste materials from the IOT are complex, due to their heterogeneous nature, which means that conventional sorting and recycling is usually not economically feasible. The IOT present a unique case study in the significant distance from the islands to mainland Australia. Due to the high cost of shipping (estimated by the CKIs Shire to cost $15,000/container) plus biosecurity regulations for items arriving at Fremantle port (WA), the value of exported products must outweigh the extreme shipping costs if plastics are exported.

The major policy question that needs to be addressed is: How can elements of the plastic waste of the IOT be integrated into their respective circular economies? The detailed information on the types of plastics present and how they could best be incorporated in the supply chain is missing. This project will help identify that valuable information.

Future research direction

This project aims to deliver new knowledge necessary to understand and precisely identify the types of plastics waste, their chemical and physical properties, various transformations and impacts phenomena through in situ and ex situ advanced characterisations. This will help to further suggest the strategies for isolating different valuable resources from the mixture of waste plastics for creating value-added materials and resources for remanufacturing. These waste plastics include PET plastic drink bottles, expanded polystyrene/polypropylene containers, personal care/ pharmaceuticals, ropes, fishing nets and gears, food packaging, straws and lighters and other contaminations, such as woods, textiles, seashells, metals, etc..

In this research project, we will collaborate with industry partners to transform complex waste streams into cost-effective manufacturing processes used in the production of building materials, thereby creating value from waste.

Specifically, the future research needs to:

- Characterise the waste products to identify the properties (physical and chemical) and decomposition behaviour
- Identify the mechanisms through which different structures of materials within the plastics waste is influenced by chemical and environmental contaminations
- Conduct fundamental and applied studies on the waste plastics and other materials to identify recycling strategies.

The lack of available test and characterisations on the waste materials links to several critical challenges associated with their design and production. First, plastic waste found in the marine environment vary widely in their properties, including size, shape, polymer type, additive content, and extent of ageing, etc. Numerous combinations of these variables are possible which have impact on the properties and recyclability of the plastics. An advanced characterisation of these mixed plastics contents that can feasibly account for all dimensions of this variability does not yet exist.

These various materials characteristics, all have the potential to influence the fate and impact of microplastics in the environment. For example, plastics from e-waste have different characteristics compared to those from synthetic clothing fibres or microbeads in cosmetics. In depth characterisation helps to identify plastic pollution sources and solutions for circularity.

Advanced analytical techniques for these waste streams, such as advanced microscopy, spectroscopy, and advanced mechanical, chemical and thermal techniques will be used to identify and quantify the plastics and their properties. The physical and chemical characteristics of materials must be understood to address the challenges faced from heterogeneous composition and the presence of metals. This will help to further identify the best recycling or remanufacturing strategies and to guide further research on remanufacturing and policy development.

Contents

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1. Background

The most recent comprehensive assessment of plastic accumulation on the CKI estimated a minimum of 238 tonnes of plastic debris washing ashore in the island group and accumulating over time (Lavers et al., 2019). A similar condition is present in CI. Due to the high cost of shipping to mainland Australia and the inability to bury waste due to the risk of penetrating the freshwater lenses (the main drinking supply for the island), controlled incineration was historically the best option for plastic waste processing. Currently, a conservative estimate of 16,000kg of high-density polyethylene (HDPE) and 12,000kg of polyethylene terephthalate (PET) are municipally collected from Home Island and West Island and incinerated (Taylor Simpkins, 2021a). The Shire is now looking for an alternate approach to incineration of plastic waste, for which it is very important to know the characteristics of the contaminated plastics waste to identify the suitable option for responsible recycling strategies. Microplastics are part of the plastic problem on the beaches of Cocos. Although difficult to remove or recycle, these particles are dangerous to organisms in the environment, and their identification should be prioritised to provide direction for mitigation and policy development.

Hybrid materials made from blended waste plastics, incorporating other sources such as waste wood and textiles, can form a multiphase solid material. These materials are typically composed of two major components: the matrix and the reinforcement. The matrix acts as a binder, while the reinforcement imparts various properties, including dimensional stability (Saba and Jawaid, 2017). One of the key features of these materials is their reduced weight, along with other performance characteristics (e.g. mechanical properties, thermal resistance, UV resistance, shock absorption nature, acoustic properties, etc), making them suitable for applications ranging from household items to aerospace industries (Shanti and Satyadevi, 2021). Plastic, being mouldable, serves as an excellent binder (or flexible matrix) in the creation of these hybrid materials and offers additional beneficial properties, such as hydrophobicity (Petchwattana and Covavisaruch, 2013). Studies conducted globally have explored the use of plastic as a matrix in various applications, with polymers like PE, PP, PS, PVC, PET, PA, and ABS being the most commonly used due to their favorable properties (Yue et al., 2022). In the context of this proposed project, the focus is on mixed waste plastics from marine debris and e-waste, which present significant challenges.

The IOT are eligible to participate in a new internationally recognised plastic credit system through the 3R Initiative, which could help offset some of the costs associated with landfilling and transporting plastics to the mainland. This system allows companies to mitigate the impact of plastic waste beyond their control by funding the collection and recycling of plastics in communities like the IOT, which are inundated with offshore marine plastics (Guidelines for Corporate Plastic Stewardship, 2021). By integrating recycling, remanufacturing, plastic credits, community education programs, and sustainability practices, the Shire of the Cocos (Keeling) Islands (CKI) and Christmas Island (CI) can leverage the value of ocean plastics to create new products for their local market and generate local jobs.

2. Impact on environment and human

2.1 Environmental Risks

There is evidence of plastic waste in the Indian Ocean Territories (IOT) affecting terrestrial, marine, and intertidal ecosystems, endangering the species that inhabit these environments. Iconic IOT species at risk of plastic entanglement or ingestion include fish, seabirds, invertebrates, sea turtles, and marine mammals species (Kühn and Van Franeker, 2020).

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2.2 Human Health Implications

Plastics containing phthalates and bisphenol-A have been linked to health issues in humans, particularly in children and pregnant women. Although incineration can be an effective waste management technique, it is known to release carcinogenic chemicals and substances that can affect the endocrine system, behaviour, and brain function in both animals and human. Further research is needed to understand the impact of plastic use, disposal, and incineration on the ecosystem and human health, particularly concerning Christmas Island and the Cocos (Keeling) Islands.

3. Marine Debris Inspection

In February 2021, a quick inspection of beached marine debris was conducted at Home and Direction Islands, with additional surveys done in parts of South and West Islands. The survey involved walking along the beach, stopping every 50–100 meters to obtain GPS coordinates, and counting and identifying any trash within a 1-meter transect through the lower, middle, and upper beach zones. Plastic abundance was categorized using density scales: Very High (>50), High (30-50), Medium (15-35), Low (5-15), and Very Low (<5). The highest plastic debris densities were found on the east-facing outer edge of the atoll, while hotspots were also identified on West and South Islands. Although a larger portion of South Island was not surveyed, residents of the Cocos (Keeling) Islands (CKI) confirmed that marine trash significantly affects every beach in the southeast. One region in particular, on the island's northern side, had much higher plastic accumulation than others.

The main types of macro plastics found on the coast of CKIs include shoes (especially polyurethane "flip-flops") and single-use plastics such as PET plastic drink bottles, straws, containers, lighters, and food packaging. PET items have a high market value and significant recycling potential in the Indian Ocean Territories (IOT), but plastics must not exhibit biofouling or severe UV deterioration to be suitable for recycling. Since PET bottles on the beaches of CKIs are generally clean, recycling them would only require low-energy washing techniques. The highest densities of plastic products per square meter were recorded on Home Island (Taylor Simpkins, 2021b), followed by South Island and Hornsburgh Island. The significant variation in plastic abundance across the islands suggests that the distribution of plastic items on any given beach is patchy.

Direction Island and South Island recorded the highest mean mass of plastic debris per square meter, likely due to large amounts of plastic rope washed ashore (Taylor Simpkins, 2021b). In 2020, Sea Shepherd collected 4,500 kg of rope over 400 meters of South Island beach. Special logistical measures will be required to remove such large quantities of debris from these two islands.

4. Current Waste Management Scenario – Plastics

The Home Island Transfer Station is managed by the Shire of the Cocos (Keeling) Islands, which also operates a green waste burn facility, an incinerator, and a landfill. Due to the remoteness of the location, managing waste has been challenging. The WR1T Incinerator, built in 2015, was intended to address these challenges. Historically, controlled burning has been the most cost-effective method of disposing of plastic waste, given the high cost of shipping waste to mainland Australia and the risk of contaminating freshwater lenses (the islands' primary source of drinking water) if waste were buried. This assessment will propose an alternative method to burning plastic waste, as the Shire is currently seeking a better solution. Presently, West Island and Home Island municipalities collect and burn

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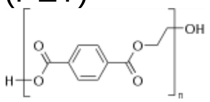
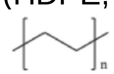
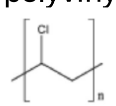
approximately 12,000 kg of polyethylene terephthalate (PET) and 16,000 kg of high-density polyethylene (HDPE) annually.

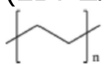
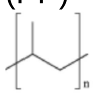
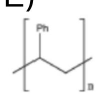
5. Plastic types and management requirements

Surveys conducted on CKI beaches indicate that the majority of plastic objects from offshore sources retain undamaged Resin Identification Code (RIC) labels. RIC labeling is the most cost-effective and time-efficient method for identifying polymers, which is crucial for selecting plastics suitable for recycling. While there are more advanced techniques, volunteers can easily identify RIC labels if provided with separate bins for each polymer type. Organizing beach cleanups and sorting by volunteers would prevent the need for IOT shires to divert staff and resources from public works projects.

Sorting becomes more difficult for plastics without labels. Visual identification of polymers is unreliable, except for expanded polystyrene (EPS) (#6), which is exceptionally lightweight and low in density (#7). A density separation test can be used to differentiate plastics based on whether they float or sink in water. For instance, PVC will sink in freshwater, while LDPE and HDPE will float. Flame tests can also be used to classify plastics: for example, both nylon and polyolefins burn with a blue flame with a yellow tip, but nylon sinks in water.

Table 1. Properties and characteristics of widely used polymers in plastic packaging, which is suspected to be the major constituent of the plastics of the marine debris (Hossain et al., 2022b, Hossain et al., 2022a).

Polymer type and chemical structure	**Resin identification code**	**General Application as virgin material**	**Properties**	**Toxic chemical present**	**Advantage**	**Challenges**	**Recycled products**
Polyethylene terephthalate (PET) 	1 PETE	Bottles application because they are inexpensive, lightweight, and shatter- resistant	Clarity, strength, toughness, barrier to gas and moisture	BPA, leach antimony	Less extraction of fossil fuel, reduced volume to landfill, less dependance on petrochemical production, more convenient (less energy intensive) for chemical recycling (catalytic methods) than thermolysis, lucrative applications in multiple advance technologies	Costly thermochemical process and hazardous byproduct generation, fibers quality is less purified as recycled material, expensive conversion process (isolation and purification), less effective mechanical properties as conventional recycled material, toxic production process for nanoparticles	Mineral/ Drinking Water Bottles, Cosmetic Bottles)
High density polyethylene (HDPE, or PE-HD) 	2 HDPE	bottles, carry bags, milk pouches, recycle bins, etc.	Stiff, strength, tough, moisture resistance, permeability to gas	Not confirm	Less extraction of fossil fuel, less dependance on petrochemical production, more convenient (less energy intensive) for chemical recycling (catalytic methods) than thermolysis,	Expensive conversion process (isolation and purification), less effective mechanical properties as conventional recycled material	Tubes, sewer pipes, pallets, boxes, buckets, toys, bottles for detergents, construction, cable insulation, packaging of food products
polyvinyl chloride (PVC) 	3 PVC	for pipes and fittings, Tarpaulins, Medical Apps., etc.	Versatility, ease of blending, strength, toughness	Phthalates	Less extraction of fossil fuel, reduced volume to landfill, less dependance on petrochemical production, more convenient (less	Fibers' quality is less purified as recycled material, expensive conversion process (isolation and purification), less effective mechanical	Sewer Pipes, Window frames, Construction, Flooring, Wallpaper, Bottles, Car Interiors, Medical

					energy intensive) for chemical recycling (catalytic methods) than thermolysis,	properties as conventional recycled	products, Planks, etc.)
Low / linear low-density polyethylene (LDPE/LLDPE) 	LDPE	Plastic bags, various containers, dispensing bottles, wash bottles, tubing, etc.	Ease of processing, strength, tough, flexibile, ease of sealing, barrier to moisture	Not confirm	Less extraction of fossil fuel, utilized as mixed plastic, ink affinity, hydrophobicity, durable, less dependance on petrochemical production, more convenient (less energy intensive) for chemical recycling (catalytic methods) than thermolysis,	Relatively complex process for the reduction of variability in thermal and mechanical properties, hazardous solvent utilization, expensive conversion process (isolation and purification), less effective mechanical properties as conventional recycled material,	Flexible packaging, bin liners, carrier bags, tubes, agricultural mulch film, agricultural sheet, construction film, cling-film, heavy duty sacks
Polypropylene/polypropene (PP) 	PP	Auto parts, Industrial Fibers, Food containers, etc	Strength, toughness, resistance to heat, chemicals, grease and oil; versatile, barrier to moisture	Not confirm	Less extraction of fossil fuel, Utilized as mixed plastic, reduced volume to landfill, convenient and less toxic component utilization in processing, lucrative applications in multiple advance technologies	Relatively complex process for the reduction of variability in thermal and mechanical properties, fibers quality is less purified as recycled material, unwanted wax production affects equipment, toxic production process for nanoparticles	Pipes, pallets, boxes, furniture, car parts, pots of yoghurt, buckets, butter, margarine, fibers, milk crates
Polystyrene (PS) / expended Polystyrene (PS-E) 	PS	food service packaging, disposable cups, tray pitchers, refrigerators, liners, etc. It may also be used as cushioning materials for fresh	Versatility, clarity, easily formed	Leaks toxic chemicals when heated	Less extraction of fossil fuel, Utilized as mixed plastic, less dependance on petrochemical production, more convenient (less	Relatively complex process for the reduction of variability in thermal and mechanical properties, expensive conversion process (isolation and	Clothes Hangers, Park Benches, flower Pots, Toys, Spoons, Cutlery, Picture Frames, Seeding containers

		produce, electronic or appliance industries, etc			energy intensive) for chemical recycling (catalytic methods) than thermolysis,	purification), less effective mechanical properties as conventional recycled material,	
Thermoset plastics		Thermoset Plastics, Multilayer and laminates, Bakelite, Polycarbonate, etc	Stiff, hard, brittle, chemical and stains resistant, good electrical insulators, non-remouldable.	BPA			CDs, Pallets, Floors, Roofs, Furniture, Sheeting, Benches, Shoe soles

5.1 Difference between New and Aged Plastics

Two main characteristics distinguish old marine plastics from new polymers: biofouling and photothermal deterioration. Plastics may become brittle at sea due to exposure to heat and UV radiation, a process known as photothermal oxidation or photothermal deterioration. This process can cause the original product to break into many smaller fragments, making it difficult to identify the polymer type. Identifying polymer types is a critical step in recycling, as virgin and unfragmented plastics are easier to recycle.

Biofouling occurs when aquatic organisms attach themselves to hard surfaces like plastic. Plastics intended for recycling must be free of bivalves (shelled organisms such as mussels) or algae before shredding. Large plastic items washed ashore on CKIs are likely to exhibit biofouling, whereas small polypropylene (PP) and polyethylene (PE) items, such as lids, bags, and straws, are less likely to show biofouling, as accumulated organisms would cause them to sink.

6. Waste Strategy Considerations

Determining the amount and type of waste produced by different activities (such as those in the immigration detention center and defense portfolios) is challenging due to varying activity levels. However, the following waste categories should be addressed in the IOT Waste Strategy:

1. Plastics
2. Plastic and timber
3. Tyres
4. Textiles
5. Glass
6. Household and commercial waste
7. Pesticides and garden chemicals
8. Paints
9. Pharmaceuticals and medical waste
10. Swimming pool chemicals
11. Construction and demolition waste
12. Asbestos
13. Cardboard and paper
14. Scrap vehicles
15. Car batteries
16. Motor oils
17. Petrol and kerosene
18. Obsolete electronic equipment
19. Phone batteries
20. White goods
21. Metal and aluminium

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The current waste policy and legislation present in IOT are summarised below:

Table 2 Waste policy and legislative frameworks for IOT

Policy and strategy context	Impact	Waste / resource type
	Christmas Island	
Waste minimisation and recycling strategies (2024)	At present the Shire of Christmas Island does not operate any waste minimisation and recycling strategies.	N/A
Waste Collection Services (2024)	Shire of Christmas Island collects Domestic garbage is collected twice weekly.	All waste types
The Shire of Christmas Island Waste Local Law (2019)	Local law that provides regulation and control of waste management activities including the collection and disposal of waste throughout the district.	All waste types
The Shire of Christmas Island Health Local Law (2019) (2019)	Health legislation that governs the safe disposal/deposit of liquid, butcher and other waste types, receptacle management, butcher waste and conditions that apply to some waste infrastructure.	Various wastes
Shire of Christmas Island Plastic Bag Reduction Local Law (2018).	Restricts the supply of single use plastic shopping bags within CI. Retailers do not provide single use plastic shopping bag. Person must not represent that supplied single use plastic shopping bag is not a single use plastic shopping bag	Single use shopping bags
	Cocos (Keeling) Islands	
Waste minimisation and recycling strategies	At present the SoCKI does not operate waste minimisation and recycling strategies.	N/A

7. Future Growth Areas

The Indian Ocean Territory faces significant waste management challenges due to its remoteness and low-lying islands, making them vulnerable to rising sea levels. Understanding the amount and types of waste is crucial for effective management. Unlike mainland Australia, Christmas and Cocos Islands have no connection to Indigenous cultures but are instead Federal Parks managed by Traditional Owners of Indonesian origin. Rangers on these islands could assist in waste management consultations, and Parks Australia likely has existing policies in place. Additionally, new research data could help assess broader waste impacts on mainland Australia. Waste management on Christmas Island is overseen by a local council, and conducting a literature review could help identify existing systems and areas for improvement. Cocos Island is less populated, with a strong Indonesian presence. Rangers familiar with the island could provide valuable insights for further research.

Paper, glass, and plastics are currently not recycled on Christmas Island (CI). At the former Shire Depot site, a small experimental plastic recycling program is run by the private company Eco-Crabs. This initiative has been an interesting development.

The Shire expects that the IOT Strategy will explore expanding this plastic recycling program to a municipal level and building infrastructure to support plastic recycling, such as for boardwalk planks and signage. A similar analysis on the feasibility of recycling glass and paper is also needed.

In the future, developing new facilities would enable more sustainable waste management. The existing incinerator is no longer fit for its intended purpose, and there is an urgent need for new, functional waste processing facilities. Incorporating the best available science into recommendations is crucial to providing sustainable solutions tailored to the Shire's waste generation levels. Funding for such scientific research is essential.

Table 3 Prime concerns of waste types and reasons

Waste types	Reasoning
Plastic pollution i.e. marine debris	Because of the IOT's geography, plastic pollution is now a serious issue.
	Because of the IOT's position and the dominant ocean currents, marine plastic waste is regularly dumped on the islands, where it takes a very long time to decompose and degrade.
	Frequent removal and collection could help the travel and tourist sector.
	Recovery could offer chances for business or resource savings.
Scrap metals	Significant amounts of scrap metal has built up or been disposed of within the IOT. Additionally, a lot of metal assets will need to be disposed of in the future.
	Offers relatively valuable products with a secured market
Hazardous waste, biosolids, quarantine and biomedical waste	Poses a risk to human health
	Danger connected to the landfill disposal
	Review of the present procedures could reveal areas for improvement.
Batteries	Batteries are reportedly being stockpiled and kept on the islands.
	Poses a risk to human health
	Danger connected to the landfill disposal
	Wet cell batteries have secured market and considered valuable products for recycling
	Suitable techniques and equipment can be implemented to address safety concerns
	Review of the present procedures could reveal areas for improvement.
E-waste	Toxic leaching polluting the environment while stockpiling or improperly disposed
	Fire hazards while stockpiled
	Many untapped valuable metals and nonmetals
Rubber tyres unsuitable for recycling/re-treading	Many tires are currently available that are not ideal for shredding.
	Tire piling can pose a major risk to the environment's health.
	Review of the present procedures could reveal areas for improvement.

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