



2021

Accelerating Singapore's Next Generation Plastic Recycling Value Chain

Insights from a Rapid Plastic Waste Flow Opportunity Assessment

ABOUT THE PLASTIC WASTE OPPORTUNITY ASSESSMENT

Commissioned by Circulate Capital, with AlphaBeta and Kiverdi conducted research to develop an approach to identify and define key plastic waste circularity investment opportunities.

Research included:

- A Rapid Opportunity Assessment* of Singapore's plastic waste flows and recycling value chain.
- Identification of potential investment opportunities to increase circularity.
- Actions-required to capture opportunities and unlock value (e.g., minimum feedstock volume, government regulations).

*The Rapid Opportunity Assessment approach incorporates both top-down and bottom-up modelling for prioritized sectors and polymer groups. The breakdown of plastic waste generation was derived through interviews with companies across Wholesale & Real, Accommodation & Food Services, Transport & Storage, Construction, and Computer, Electronic and Optical Production. The data collectively represent 40% of Singapore's domestic economy and 70% of plastic waste generation in Singapore.

The companies provided information of the volumes of plastic waste generated in daily operations, typical polymers used in these plastics, which was then paired with primary data collected from major plastic recyclers operating in Singapore. The data was then scaled to economic segments and sector level based on market proxies to generate total plastic waste generated.



CIRCULATE CAPITAL

Circulate Capital is a Singapore-based investment management firm dedicated to financing innovation, companies, and infrastructure that prevent the flow of plastic waste into the world's ocean while advancing the circular economy.

αlphaβeta

strategy x economics

AlphaBeta is a strategic economics consultancy that works with governments, businesses, investors, and other institutions to tackle the largest societal challenges we face.

KIVERDI

Kiverdi was founded with a mission to commercialize sustainable resource utilization solutions by transforming carbon to make high-value oils, complete proteins, and other bio-based products.

SINGAPORE IS WELL-POSITIONED TO BE A GLOBAL LEADER IN ADVANCING THE CIRCULAR ECONOMY.

Singapore has the ideal conditions to catalyse a reconfiguration of global supply chains and become a resilience hub for advance manufacturing.

- Individual solutions are now strengthened within the context of the whole system improving.
- Waste management operators are transitioning from slow growth models to entrepreneurial mindsets, supported by the ambitious plans of building Singapore as a digital innovation anchor.
- An institutional policy framework can be leveraged to demonstrate the role of circular plastics in creating healthy cities.



Strong Collection System



Existing Pathways to Education



Government and Private Sector Commitment



Trusted Ecosystem



Enabling Policy Environment



Existing Responsive Population Incentives



THREE INVESTMENT INTERVENTIONS TO POWER FUTURE ECONOMIC GROWTH



Intervention 3



DISRUPTIVE INNOVATION

Technology Creation

Develop Zero Plastic Waste Demonstrator to allow for **real world learning on new, unproven interventions** to test and scale new material and reuse business models.



Intervention 2



DEPLOY UPCYCLING TECH

Technology Adoption

Invest in advancing recycling technologies and niche businesses for plastics not collected for MRFs.

\$35M capital investment to process 10,000 tonnes per annum of contaminated plastic waste into alternatives to polypropylene and BioStimulants.

Intervention 1



COLLECTION & SORTING INFRASTRUCTURE BOOST

Invest in regional hub-and-spoke opportunities.

Improve domestic value creation for rPET and leverage innovation ecosystem.

\$8M investment to capture additional 114,800 tonnes of plastic into recycling and generate \$1 billion in trade value over 10 years.

INVESTMENT INTERVENTION 1:



Collection & Sorting Infrastructure Boost

Short-term investment in collection and sorting will increase quantity and quality of feedstock and drive mid-term investment opportunities in processing (<12 months time horizon) for LDPE, HDPE and PP.

An \$8M investment to improve sorting technology and increase quality collections could add 114,800 additional tonnes of plastic recycling feedstock to Singapore's recycling value chain.

1

QUALITY COLLECTION AND SORTING

1. Increase quality collections from 4% to 30% by targeting post-commercial and post-industrial streams.
2. Boost Material Recovery Facility (MRF) efficiency from 50% to 80% to meet global benchmarks and improve profitability.
3. Integrate closed loop business models targeting sectors that use flexible packaging.



CASE STUDY

Closed-Loop Business Model

\$5m flexible plastics processing investment to grow capacity from 1,000 tonnes per annum to 32,000 tonnes per annum, India.

Circulate Capital Ocean Fund invested in a company expanding recycled tertiary packaging offerings (shrink wrap and recycled granules). To source quality feedstock the company operates a closed loop supply cycle where protective plastic covers and packaging material are made out of recycled material collected from their clients' distribution channels and is recycled back into new products for the same clients' reuse.

INVESTMENT INTERVENTION 1:



Collection & Sorting Infrastructure Boost

2

ROUTE OPTIMIZATION

1. Sensor solutions to optimize route tracking for collections efficiency and maintenance.
2. Asset management software on collection bins and gross pollutant traps to improve operational efficiency.



CASE STUDY

Optimized Collection Route

\$15M investment in collection and sorting to increase quality recyclable collections from 9,000 tonnes to 600,000 tonnes per annum, India.

Collection routes are optimized with geolocation digital locks and predictive analytics to minimize downtime and match waste loads with appropriate driver scheduling. The Circulate Capital Ocean Fund investment will enable this model to be expanded at scale.

Weight of the collected waste is reported in real time and matched with the prices of different materials for consistency and control. Route based on time and distance and makes recommendations to the driver.

INVESTMENT INTERVENTION 1:



Collection & Sorting Infrastructure Boost

3

TECHNOLOGY INVESTMENTS

1. Capital investments to improve sorting technology to increase current yield from 30-50% to become in line with global benchmark of 80-90%.
2. Semi-automate all four operating MRFs to increase capacity from 4,200 tonnes to at least 17,200 tonnes through improved and expanded machining.
3. Reduce the over-reliance on manual labor, to reduce cost per tonne and plug the existing labor gap. Efficient pelletizing only requires three staff per line.
4. Labor and land cost for bailing and aggregating is 3x that per metric tonne in neighboring countries.



CASE STUDY

Installed Optical Sorting

\$2M to improve efficiency of material recovery facilities to add 30,000 new tonnes of recyclable plastic feedback to the market, Indonesia

Expand MRF capacity to 70-80% yield within first two years of investment. Achieved through improved optical sorting technology to reduce contamination and enhanced cost efficiencies through process improvements.

INVESTMENT INTERVENTION 1:



Collection & Sorting Infrastructure Boost

Based on the study, there are several quick wins that both recyclers and surveyed companies can pursue that will complement upcoming EPR and DRS policy interventions and the Singapore Green Plan 2030.

These quick wins are underpinned by Singapore recyclers' proactive and entrepreneurial nature, having contributed to the development of the existing recycling landscape.

QUICK WINS

1. **Implement plastic waste recycling targets:** Support training for the office staff of surveyed companies (especially in the back-end) to identify plastics materials that can be recycled (e.g. retail apparel stores should not throw unused hangers into the general waste), with a strong focus on HDPE and LDPE and PP materials.
2. **Track plastic waste generation and end-of-life treatment of plastic waste:** Companies can collaborate with recyclers to provide detailed breakdown and feedback about the recycling rates of plastic materials to provide visibility on impacts of proactive recycling measures e.g. improved segregation of materials.
3. **Develop partnerships between recyclers and companies:** Recyclers can develop value proposition to support companies to identify opportunities for closed-loop plastic waste streams.

For example - engaging with stakeholders through this study, resulted in companies and recyclers coming together to collaborate in the identification and replacement of difficult to recycle plastic materials in stock keeping units and daily business processes, such as reducing the use of PVC and composites.



INVESTMENT INTERVENTION 2:



Deploy Upcycling Technology

Strengthen local offtake market by developing market for secondary materials. Invest in advancing recycling technologies and niche businesses for plastics not collected for MRFs.

TARGETED FOCUS ON ADVANCED RECYCLING TECHNOLOGY ADOPTION FOR DIFFICULT TO RECYCLE PLASTICS

Advanced recycling technologies should complement mechanical recycling solutions and be fit for the local market. Currently multiple pilot projects are underway in Singapore that can provide detailed insights on suitable technologies, such as:

- PP Solvent Solution - PureCycle (P&G)
- Pyrolysis - NewOil, NEA PRF
- Reverse Plastics Gasification - Biostimulant &PHB (InEnTec/Kiverdi)

CASE STUDY

Collaborative Industry Partnership

Dow Chemical and Lucro Plastecycle Pte Ltd entered into a memorandum of understanding to develop and launch polyethylene films using post-consumer recycled plastics in India

Under the MOU, Dow will share its expertise on material science and application development, while Lucro will develop and manufacture recycled flexible film. This partnership is a great example of how catalytic financing can connect players in the plastic eco-system to collaborate on market solutions for the benefit of the environment.

CASE STUDY

Gasification Technology

Techno economy modeling demonstrated strong results combining plasma enhanced melter technology in gasification, with reverse plastics platforms

Evaluation of 87 gasification technologies based on carbon utilization from recycled plastics, gas generation, and small-scale deployment capabilities given space constraints.

Kiverdi Reverse Plastic Gasification Technology

- Technology provides an innovative approach to convert plastic waste gasification output into a biostimulant products.
- Produces PHB copolymers and biostimulants. Fatty alcohol and natural oil production are alternative product verticals.
- PHB is a coproduct of biostimulant production and aligns most closely with a circular plastics technology, Reverse Plastics and Revive Soil are presented as the most feasible platforms.
- Output fixes Carbon Dioxide into an agricultural product that improves land use, plant resiliency, and crop yields.
- Existing research partnership between InEnTec Gasification provider and NTU-NEWRI Labs

INVESTMENT INTERVENTION 3:



Disruptive Innovation

Leverage Singapore's unique position of strong consumer confidence to develop a trade hub in circular economy goods, services and systems.

Enhance upcoming infrastructure development through development of a Zero Plastic Waste Demonstrator to become a powerhouse innovator, radically changing plastic use alongside promoting decarbonization technology.

ZERO PLASTIC WASTE DEMONSTRATOR

The world's first location to test and deploy circular solutions across the value chain, from scaling new material to reuse business models, in a real world learning environment.

- Develop solution simulation models such as a Digital Twin technology to bring together the value chain, recycling companies, equipment and material manufacturers, brand owners and consumers to run virtual experiences on new business ecosystem models.
- Leverage Circular Materials Lab as the central R&D Collaboration with A*STAR, P&G, Nestle, J&J and Kimberly-Clark.
- Establish a Sustainable Chemicals Pathway to foster innovative chemical solution, e.g. link new resin for post-consumer recycled product offerings with IMRE PET Depolymerisation and NTU Pyrolysis.
- Systems support to infrastructure interventions, e.g. digital tracers for plastics in packaging, new MRF sorting technology and flake-to-preform technology.

SUPERCHARGING TUAS NEXUS

There is potential to augment Singapore's plans for the world's first integrated energy self-sufficient waste and water treatment facility by incorporating extended commercial value creation opportunities.

CASE STUDY

Extended Commercial Value Creation

Phoenix, Arizona, USA — Ecopark (US\$4.5M) incentivizes entrepreneurs to build waste processing businesses in a single location, proximate to waste transfer for the region.

Upgraded via a \$3M no-interest loan from Closed Loop Fund.

This increased public waste management company revenues by \$250,000/monthly and achieved 40% landfill diversion in the first year, thanks to:

- technology upgrades;
- processing efficiencies; and
- improved management of MRF residuals.

"Insights from the study enabled us to develop the circular material lab and the zero waste digital twin demonstrator which we will be using to support our global packaging decisions."

- Global FMCG

INSIGHTS INTO ACTION

Scaling Singapore's Plastic Waste Reduction Pathway

The 2026 and 2030 Green Plan waste-to-landfill targets are achievable by pairing investments in infrastructure and innovation.

Global research¹ has clearly found systems change can only be achieved by combining behavioral interventions to reduce overall consumption alongside keeping products and materials in use. These combined interventions create the economic conditions that scale circular outcomes.

The data indicates that investments to boost existing infrastructure will achieve over half of Singapore's Zero Waste target. However, to achieve the targets, an accelerated year-on-year reduction of 0.5% annual plastic packaging consumption is required.

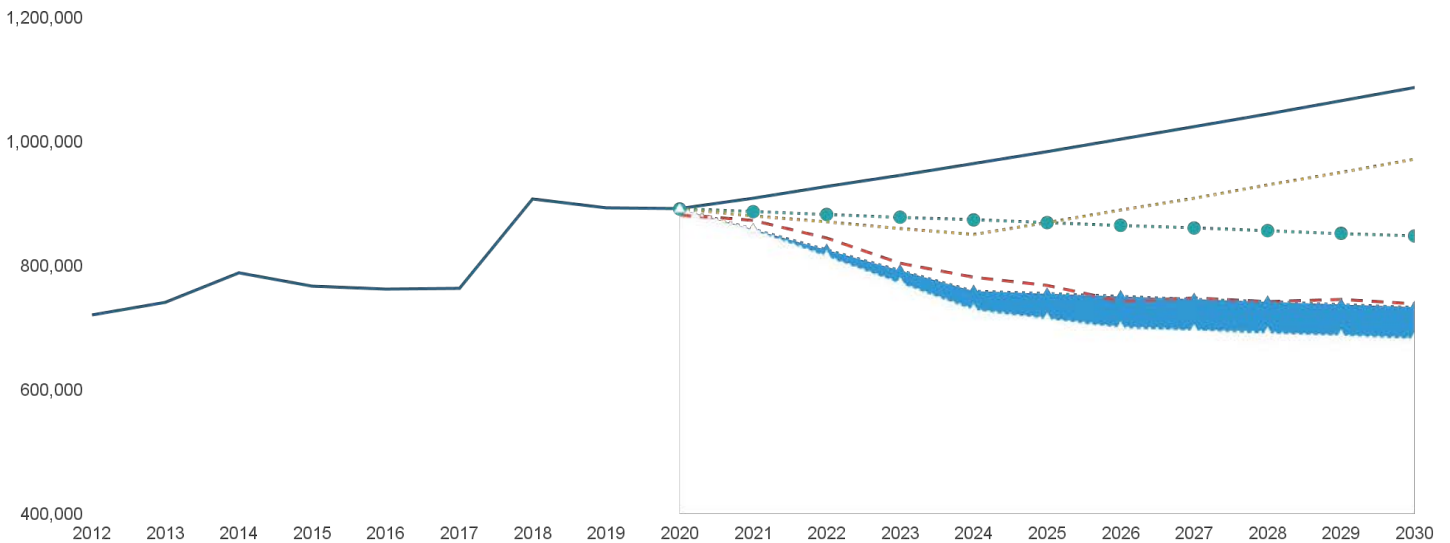
¹[The Ellen Macarthur Foundation](#) and [Pew Charitable Trusts/SYSTEMIQ](#)

"This is the study industry has been needing to make informed decisions."

- Industry Association

Singapore Plastic Waste Not Kept in Circular Systems

(tonnes not reused or recycled)



Pre-Intervention Scenario

(EXCLUDES Green Plan, EPR and DRS Policy interventions)

Intervention 1: Infrastructure Boost

(Mechanical recycling capacity boost)

Zero Waste Plan Plastic Reduction Target

Intervention 3: Disruptive Innovation

(Innovative materials and reuse models, assumed minimum 0.5% year-on-year reduced plastic consumption)

Intervention 1, 2 and 3: Infrastructure Boost, Upcycling Technology, Disruptive Innovation

(Innovative materials and reuse models, assumed minimum 0.5% year-on-year reduced plastic consumption)

INSIGHTS INTO ACTION

Scaling Singapore's Plastic Waste Reduction Pathway

Under a pre-intervention scenario, Singapore would generate

OVER 12 MILLION TONNES OF PLASTIC WASTE FROM 2020 to 2030

At the current recycling rate **only 4%** of this plastic waste **will be recycled**.

However, there is significant potential to increase feedstock through simple targeted investments to improve the efficiency and capacity of the local system.

83%

from packaging

55%

of recycled plastics are flexibles



INDUSTRY FINDINGS

Singapore could capture over **\$180M ANNUAL TRADE VALUE**

Only **10% OF POST-INDUSTRIAL PLASTIC WASTE IS RECYCLED**

Only **2% OF POST-CONSUMER PLASTIC WASTE IS RECYCLED**

While over **3% OF POST-CONSUMER PLASTIC WASTE IS SENT TO RECYCLING**

Based on developed economy benchmark recycling rates

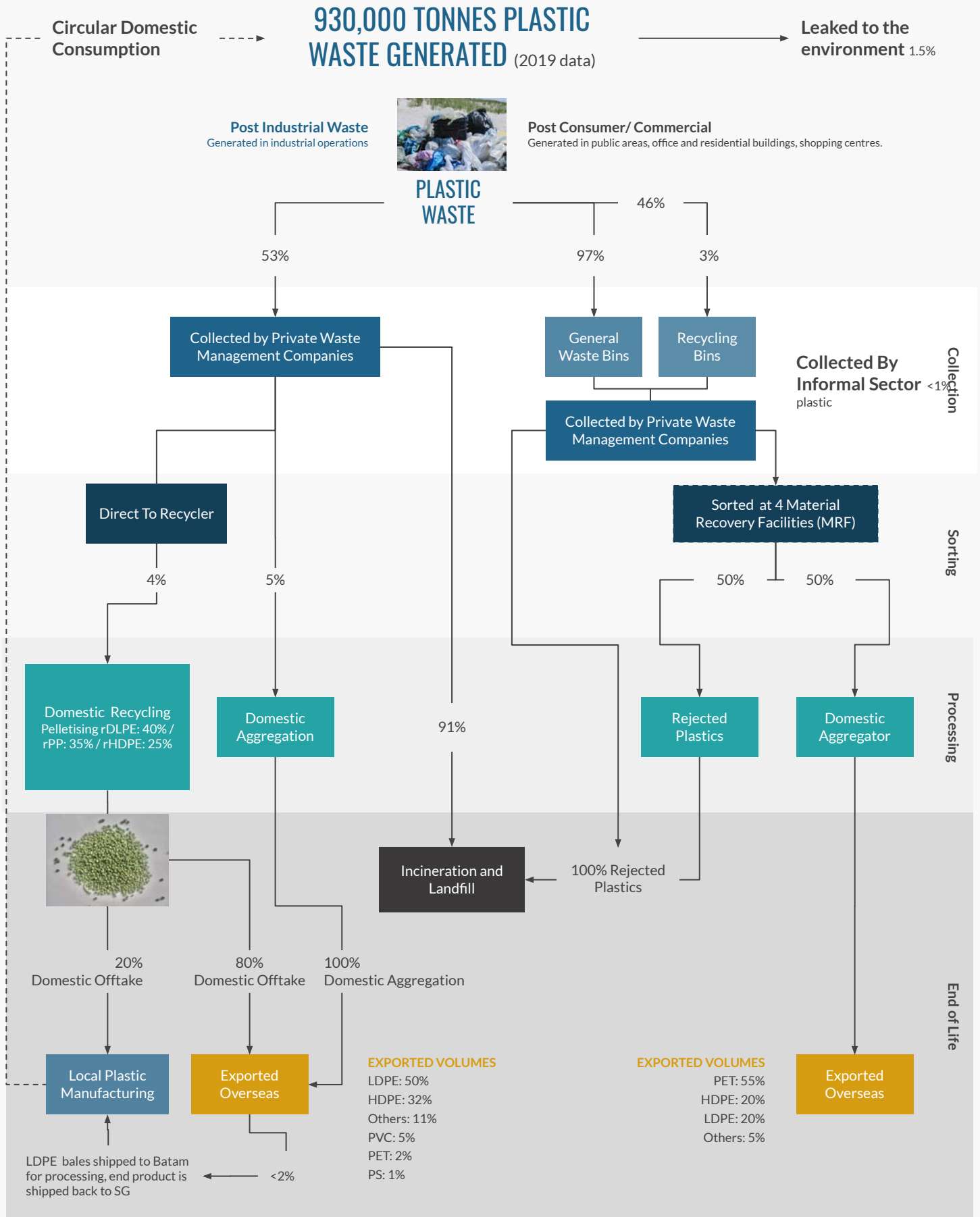
Of this, **92% IS EXPORTED**

Of this, **100% IS EXPORTED**

Most materials are **REJECTED**



HOW PLASTIC GETS RECYCLED IN SINGAPORE



The wholesale and retail sector contributed to 38% of all plastic waste generation, the majority of plastic waste generated in most sectors is packaging waste.

83%

of all plastic waste

93%

of wholesale and retail plastic waste

79%

of transport and storage plastic waste

71%

of accommodation and food service plastic waste



Wholesale and Retail Sector

62% of waste consists of primary packaging (containers, refill packs, bottles, wrappers, tubs and bottle caps).



Accommodation and Food Services

29% of plastic waste is attributed to plastic consumables (gloves for food preparation, hotel slippers) and 32% to primary packaging (food containers, cups).



Electronics

74% of plastic waste is attributed to the outer casing of electronic units (i.e., when a computer is thrown away, the metals are extracted for recycling but plastic casing of computer is thrown away).

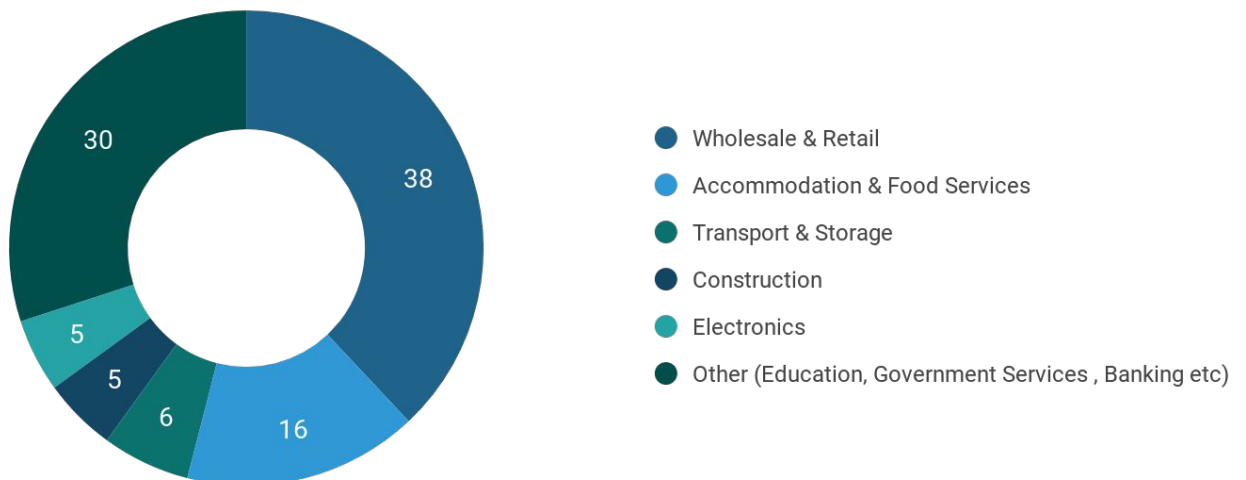


Transport and Storage

62% plastic waste from tertiary packaging used to facilitate transport of goods = shrink wrap (LDPE) used to protect goods from any damage.

EXHIBIT A:

Plastic Waste Generated by Industry Sector (percentage)



"We didn't participate in the initial survey but heard of it through word of mouth, after reaching out found it to be effective matchmaking to identify recycling solutions and industry collaboration."

- Pharmaceutical Company

LDPE represents the largest plastic waste volume generated, while polystyrene has one of the highest recycling values.

Baled prices from Singapore are competitive with neighboring ASEAN countries.

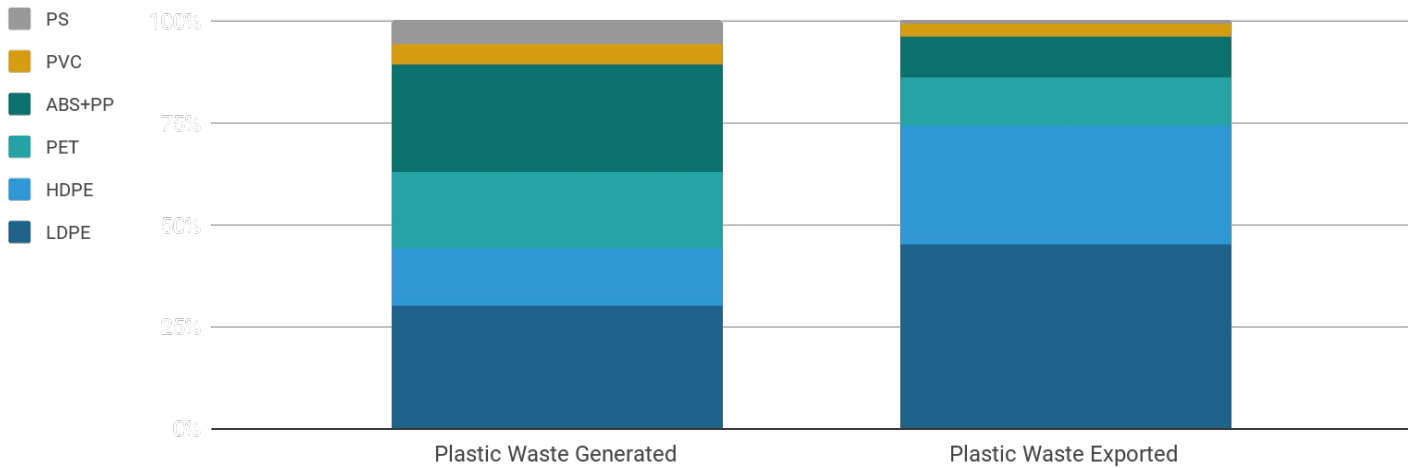
However, mechanical recycling in Singapore could be up to 2.6x that of the cost in other ASEAN countries due to the higher costs of labor, rent and water for recycling operations.

Export plastic waste trade value

S\$17.3M annually

EXHIBIT B:

Plastic Waste Generated and Exported (percentage)



“We signed a new closed loop agreement after finding out recyclers in Singapore are well adept at supporting logistics companies manage LDPE, this has doubled our recycling rate.”

- eCommerce Company

The value of the plastics will decrease by up to 20% if it is: (1) contaminated and (2) colored.

PS - Polystyrene | Take-away containers, foam cups

PVC - Polyvinyl chloride | Piping, cables, health care applications

ABS - Acrylonitrile Butadiene Styrene | Piping, electronic casings, LEGO®

PP - Polypropylene | Bottle caps, Straws, Beauty care, Yoghurt pots, 3D printing

PET - Polyethylene terephthalate | Water bottles, clam shell packaging, Polyester yarn

HDPE - High Density Polyethylene | Milk jugs, cleaning/hygiene bottles

LDPE - Low Density Polyethylene | Shrink wrap, bubble wrap

Unsorted plastic waste

NEXT STEPS TO ACCELERATE SINGAPORE'S CIRCULAR ECONOMY

Singapore can be a global leader in advancing the circular economy.

By accelerating the circular economy through collaboration and investment, Singapore can capture S\$180M in export trade value, more than 10-fold than what is currently being realised. To achieve this plastic recycling value chain must act in concert. Greater participation and collaboration among industry and governmental actors will be crucial.

How you can help Singapore capture this opportunity for the benefit of industry, society and the environment

1 SHARE STUDY INSIGHTS AT INDUSTRY CONVENINGS

Leverage insights from this research and promote the opportunity and potential for the circulate economy in Singapore and the ways actors can get involved.

2 SUPPORT THE CIRCULAR MATERIALS LAB

Get involved with the launch of the Circular Materials Lab and share your experiences and insights.

Collaborate with A*STAR, P&G, Nestle, J&J and Kimberly-Clark to actively participate in the industry's advancement.

3 SUPPORT THE ZERO PLASTIC WASTE DEMONSTRATOR

Help the development and launch of the Zero Plastic Waste Demonstrator, led by A*STAR.

Contribute to and get involved with the world's first location to test and deploy circular solutions across the value chain, from scaling new material to reuse business models, in a real-world learning environment.



GLOSSARY

A*STAR - Agency for Science, Technology and Research, Singapore

Biostimulant - Natural or synthetic substances and/or microorganisms that stimulate growth of plants. Protein production can be an output of applied biostimulant.

Depolymerisation - The process of converting a polymer into a monomer or a mixture of monomers.

DRS - Deposit Refund/Return Scheme. Singapore will introduce a DRS policy for beverage containers by 2022, for implementation in 2023.

EPR - Extended Producer Responsibility. EPR policy schemes can be mandatory or voluntary, imposing physical, organisational, financial or informative responsibility on plastic packaging producers

FtoP - Flake-to-Preform. A technology in which “flake” created by pulverizing and washing recovered PET bottles is treated at high temperature and low pressure for a fixed period and that, after being melted and filtered, enables the preform to be manufactured directly.

HDPE High density polyethylene

IMRE - Institute of Materials Research and Engineering, A*STAR Singapore

InEnTec - Plasma gasification technology provider to Nanyang Environment & Water Research Institute (NEWRI), NTU

LDPE - Low-density polyethylene

MRF - Material Recovery Facility

NEA - National Environment Agency, Singapore

NTU - Nanyang Technological University, Singapore

PE - Polyethylene

PET - Polyethylene terephthalate

PHB - Polyhydroxybutyrate, a bio-based and biodegradable polymer belonging to the polyhydroxyalkanoates (PHA) family.

PP - Polypropylene

PRF - Plastics Recovery Facility. Pilot study by the NEA is identifying the technologies and equipment required to recover up to 72,000 tonnes of plastic waste per year for recycling.

PureCycle - Patented recycling process, developed by Procter & Gamble, separates color, odor and contaminants from plastic waste feedstock to transform it into ultra-pure recycled polypropylene.

Pyrolysis - Thermal decomposition of materials at elevated temperatures in the absence of oxygen (inert atmosphere). The technique can be used to convert certain plastics into solid, liquid or gaseous fuels.

Wavelli - A new method for recycling thermoset and thermoplastic waste and reutilize the product after recycling





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