Supporting Singapore's Recycling Efforts with Artificial Intelligence

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GENERAL ASSEMBLY

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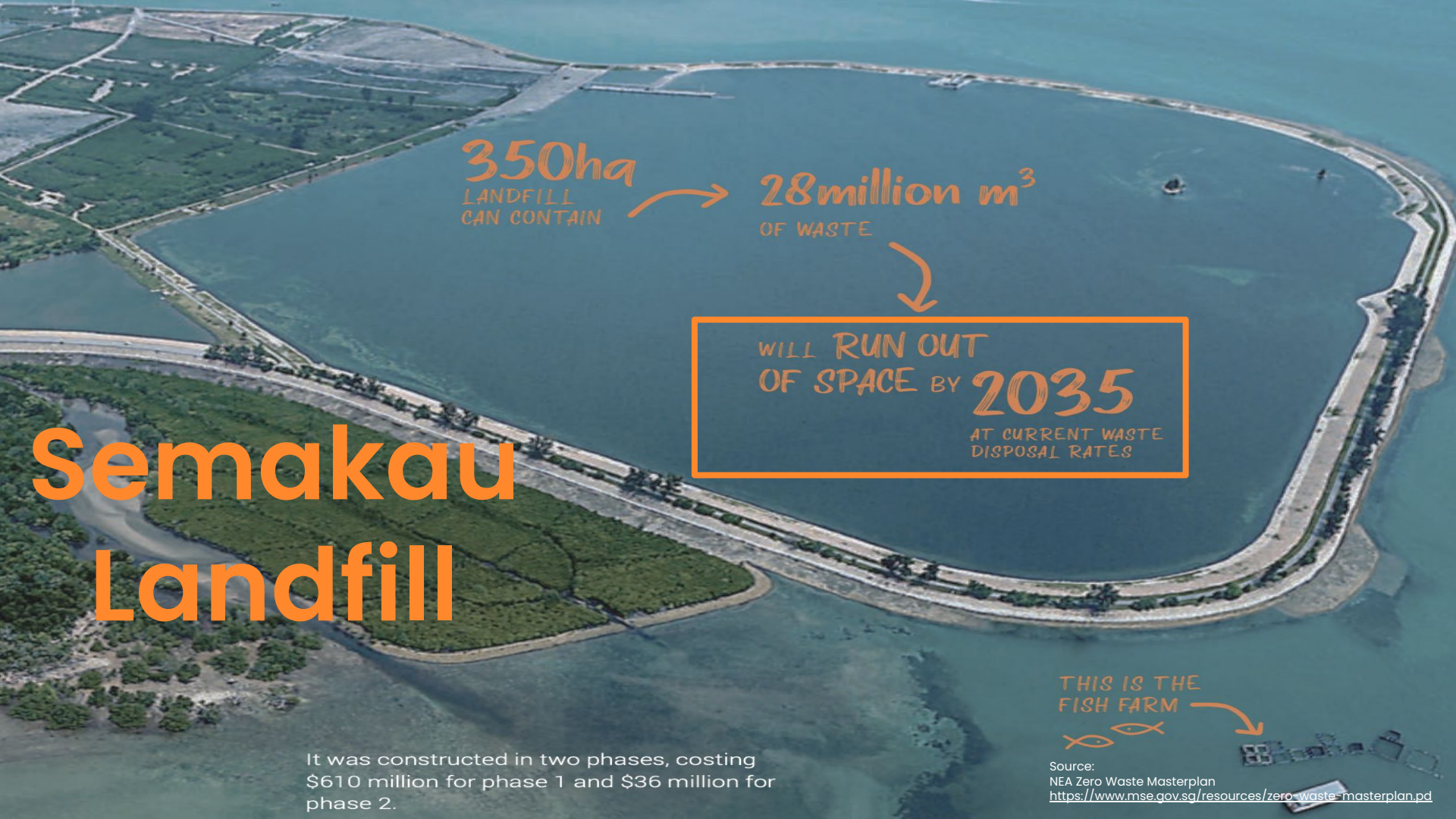


Semakau Landfill

It was constructed in two phases, costing $610 million for phase 1 and $36 million for phase 2.

Source:
NEA Zero Waste Masterplan
https://www.mse.gov.sg/resources/zero-waste-masterplan.pd

“40% of what goes into recycling bins cannot be recycled. This is because some people throw in items which are unsuitable for recycling.”

MSE / NEA

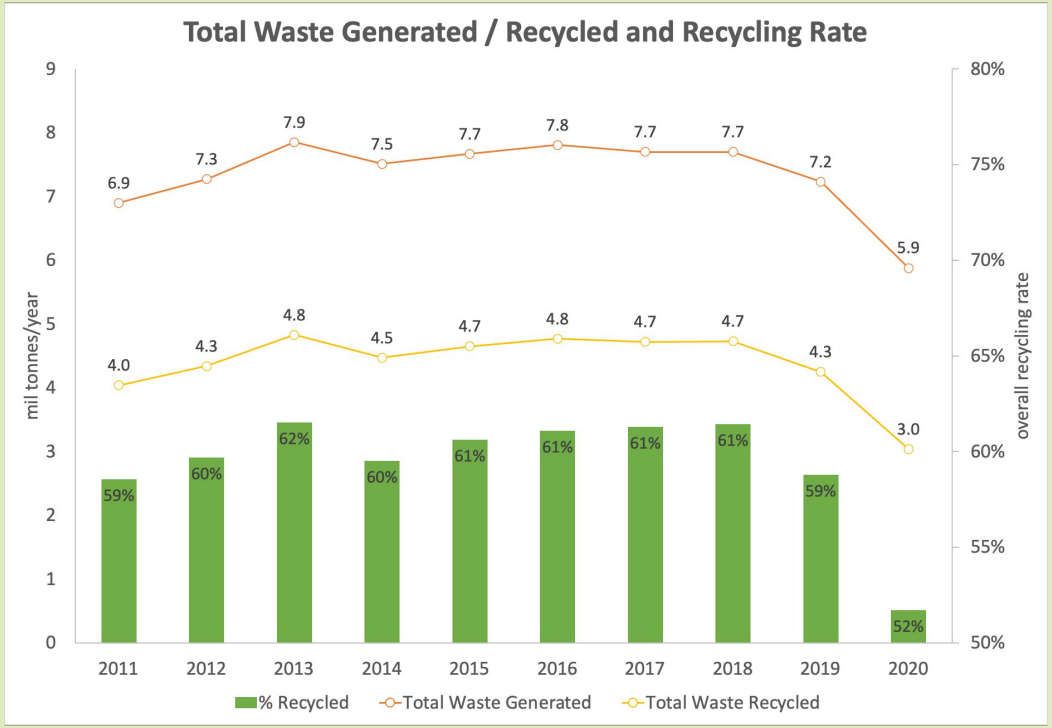
Source:
https://www.towardszerowaste.gov.sg/recycle-right/

Singapore's waste generation & recycling

2020 saw less waste due to reduced activity from Covid-19 curbs but also less recycling

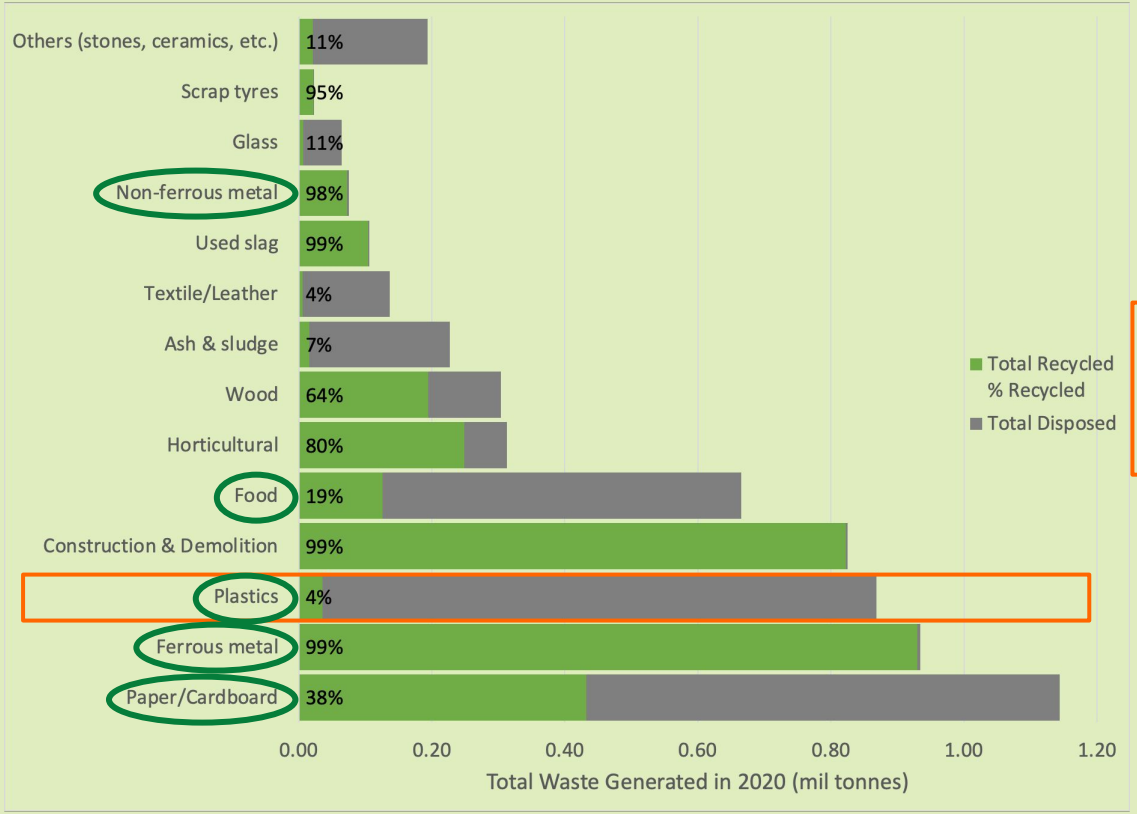
Apart from 2020, two apparent trends:

- Waste generation remained stable over the years
- Recycling rate stagnated in 60% over past 10 years



Sources:
https://www.channelnewsasia.com/singapore/in-focus-singapore-recycling-sustainability-blue-bins-waste-1339091
https://www.mse.gov.sg/resources/zero-waste-masterplan.pdf

Recycling Rate by Waste Class in 2020



Insights

- Metals recycling is well established
- Plastic waste recycling opportunity (biggest contributor to landfill)
- Other areas of concern - Paper/Cardboard & Food waste, recycling options include composting

Issues plaguing Recycling

Non-recyclables mixed with Recyclables

Contamination by food and liquid waste

Image source:
https://www.todayonline.com/singapore/singaporeans-want-go-green-need-learn-how-recycle-properly-survey-finds

Possible Solutions using AI

Smart Blue Bins Redesign	Use of camera and AI-assisted sorting mechanism could mitigate indiscriminate dumping of recyclables (wish-cycling)
HDB Recyclables Chute	Use of camera and AI-assisted sorting mechanism to separate recyclables by class and reduce contamination. This could: (1) minimize sorting at centralized facility (2) improve quality of recyclables
Educational Tool	Recycling app with camera feature to educate users on recyclables identification and handling (separating mixed materials, cleaning, etc) Improved recyclables collection and quality can achieve circular economy by reducing downcycling

Etc ...

Downcycling is the recycling of waste where the recycled material is of lower quality and functionality than the original material. Often, this is due to mixing materials, e.g. PP bottle caps + PET plastic bottles such that the recycled material can only be used for a lower quality application instead of the same/higher application.

Capstone Journey

(3.5 weeks)

Further Development
(Post Capstone)

This could be just a start than the end...

Ideation / Seeking Data — 0.5 weeks

Human Learning — 3 weeks

Machine Learning — 2 weeks

Validation, Testing — 1 week

Proof of Concept / Presentation — 2 days

Many more days?!

Dataset

Data source:
TACO - Trash Annotations in Context
http://tacodataset.org/

- Open image dataset of waste contributed by public
- Images are **manually (yes, by humans)** labeled and segmented (with bounding boxes and masking) into 60 categories
- *Challenges*:
  Data (images/background) not localized to Singapore's context
  Model ability to generalize to local / use-case context?
  Managing minority classes?

Human Learning

DSI course provides guided learning, foundational knowledge and springboard for further and deeper exploration

- Object Detection involves locating the presence of objects with a bounding box (Localization) and types or classes of the located objects (Classification) in an image.
- Hours spent on literature, documentation and online tutorials on computer vision (not a course topic)
- *Challenges*:
  Deep sense of inadequacy
  Umpteen trial and error on debugging and troubleshooting from adapting open-source codes

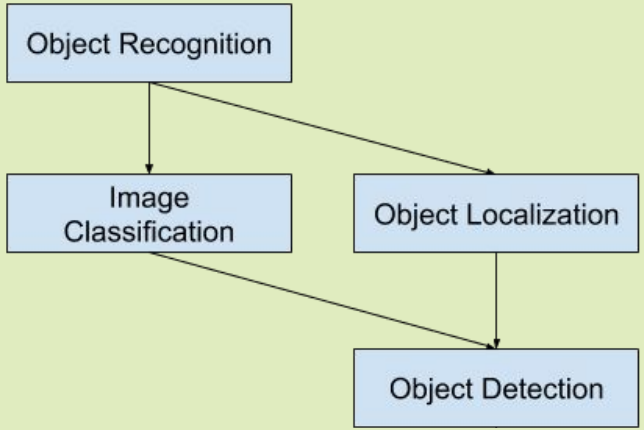


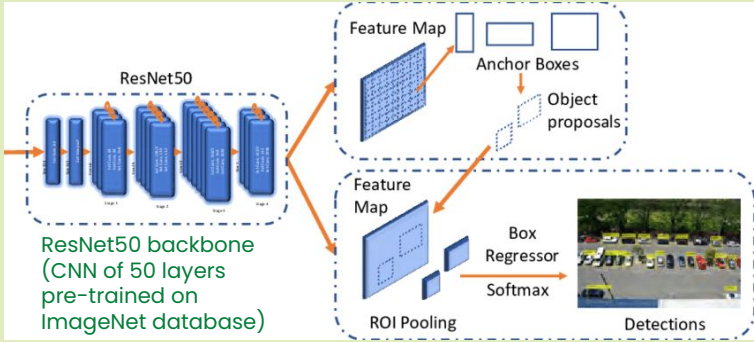
Image Source:
https://machinelearningmastery.com/object-recognition-with-deep-learning/

Machine Learning

Model training with pretrained Faster R-CNN / RetinaNet with ResNet-50 FPN backbone

- Down the abyss of deep learning with many jargons… More sophisticated codes to decipher and implement, i.e. classes for Pytorch dataset

- *Challenges:*
  Tensorflow/Keras libraries issues with Macbook M1 chip
  Pytorch library, can run natively on M1 chip but no GPU support
  Training Faster R-CNN model for 10 epochs on M1 CPU takes ***~24hrs!*** *(1200 images/epoch)*
  'Your system has run out of application memory'
  Google Colab GPU use restricted due to quota limit



Validation and Testing

How to tell if the model is satisfactory?

- Is the model able to locate objects (with bounding boxes) correctly?
  Is the model able to classify the detected object correctly?
- What do the percentages really mean in tangible terms?
- *Challenges*:
  Unable to install 'FiftyOne' support library for built-in object detection evaluation
  Attempts to develop custom metrics on object localization rate and classification rate

Model	Object Localization Rate	Object Classification Rate
Faster RCNN w/ ResNet50	40%	40%
Faster RCNN w/ MobileNetv3	33%	31%
RetinaNet w/ ResNet50	41%	38%

Proof of Concept

How many recyclables can you identify?

Plastic Recyclables
Other Recyclables
NON-Recyclables

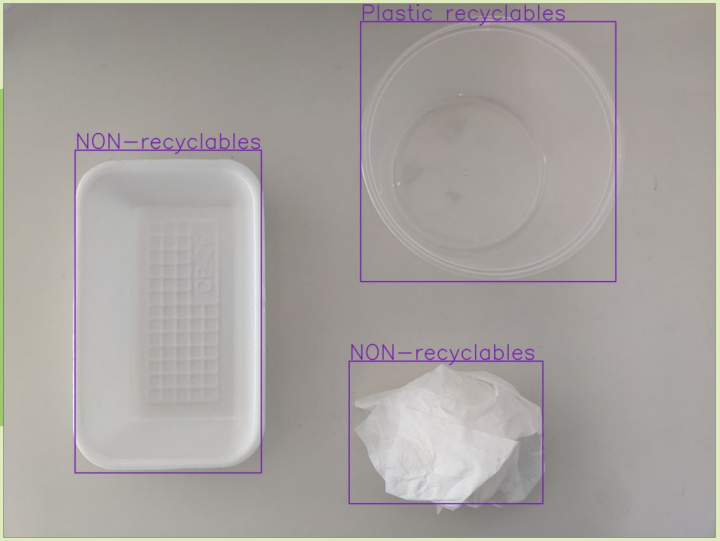
Proof of Concept – Plastic Recyclables

- Able to correctly identify 5 Plastic Recyclables, i.e. 2 bottles, 3 plastic caps
- Also able to correctly identify 2 Other Recyclables, i.e. drink can, drink carton

Proof of Concept – Change in orientation

- Able to correctly identify 4 out of 7 recyclables
- Somewhat impacts model ability to generalize

Could be addressed by image augmentation prior to further training

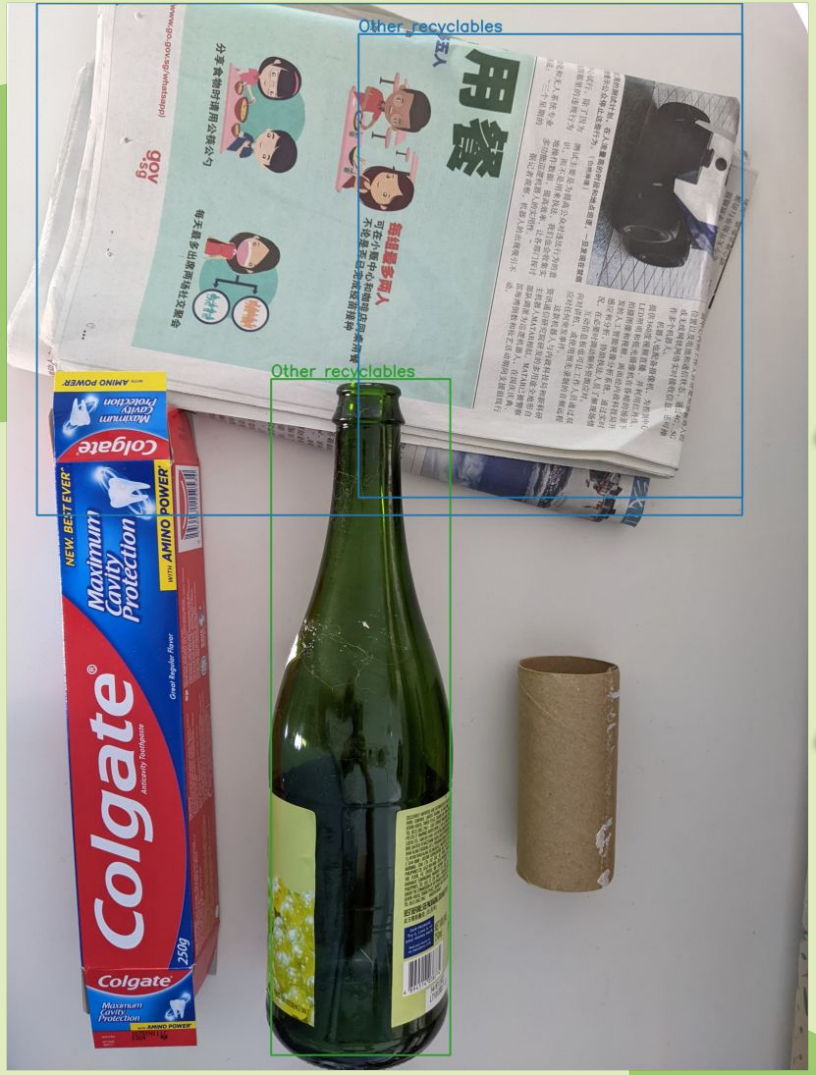


Proof of Concept – Change in background

White background:
Able to correctly identify NON-Recyclable, i.e. styrofoam, tissue paper

Darker background:
Erroneously identifies styrofoam as Plastics Recyclables

Could be addressed by increased training epochs and providing different backgrounds



Proof of Concept – Other Recyclables

- Able to correctly identify Other Recyclables, i.e. newspaper, glass bottle
- Unable to identify some Other Recycles, i.e. paper box, toilet roll

Could be addressed by supplementing more images of these minority classes

Proof of Concept – NON-Recyclables

Able to correctly identify NON-recyclables, i.e. used bubble tea cup, used straw, used plastic utensil

Unable to identify some NON-recyclables, i.e. transparent plastic fork and spoon

Could be addressed by further training the model on these items

Conclusion – Promising Signs

Able to detect and classify Plastic recyclables despite non-local data

Could also detect beyond Plastic recyclables

Some ability to generalize irrespective of orientation and background noise

Future Improvements

Localizing Context

- Collect additional data (images) from local context to improve detection

Training & Tuning

- Limited <40 epochs training runs due to computing and time constraints
- Room for further training/tuning to improve performance

Address Imbalanced Class

- Unequal number of objects in each class in training dataset
- Could leverage on image augmentation to close gap on class imbalances

Summary

How can AI support recycling?

Detect

Autonomous eyes to screen waste/ recyclables

Classify

Pinpoint waste vs. recyclables class

Sort

Use in tandem with Robotics to separate waste by class

Educate

As a tool to educate recyclables class, possibly plastic material and pre-recycling handling

PP - Polypropylene
PET - Polyethylene Terephthalate

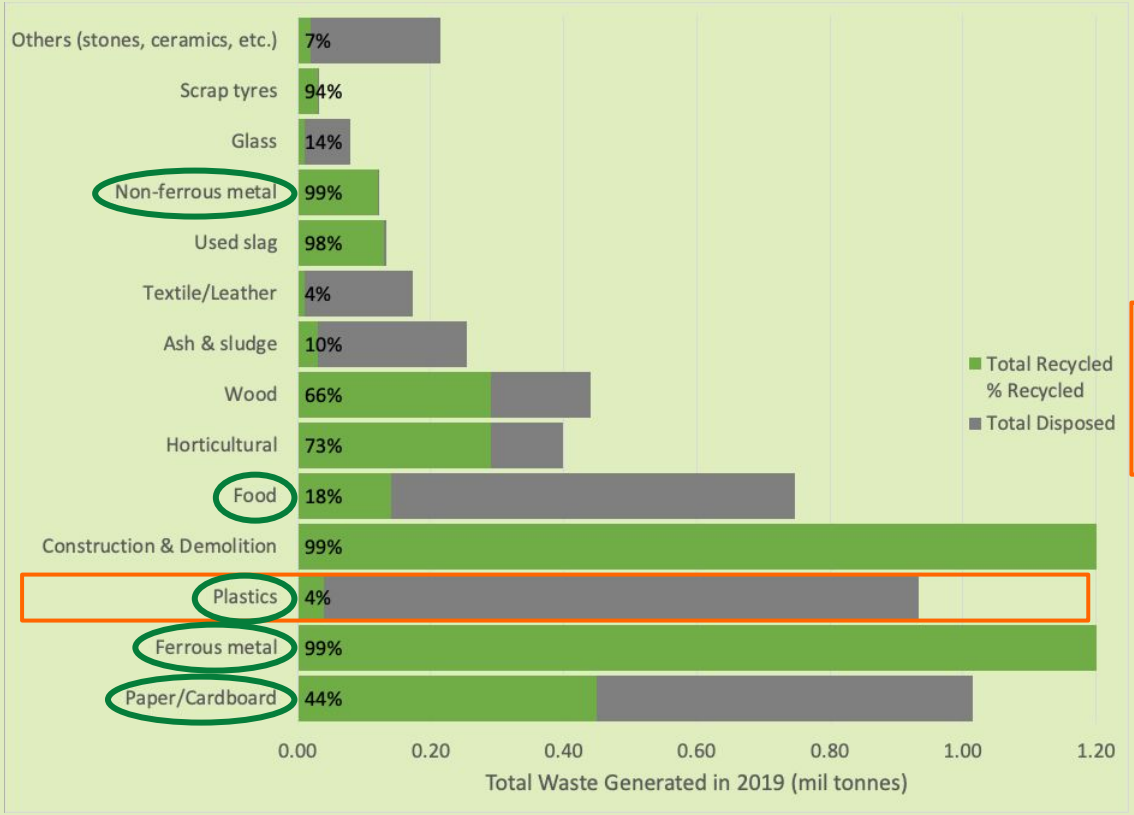
Thank You!

Do you have any questions?

Glossary

Faster R-CNN	RPN (region proposal network) algorithm + Fast R-CNN as detector network
RPN	An algorithm used to propose multiple objects that are identifiable within a particular image
Fast R-CNN	Instead of feeding region proposal to the CNN, input image is fed to the CNN to generate a convolutional feature map, and region of proposals are identified henceforth
R-CNN	Region CNN where 2000 regions are generated using selective search algorithm instead of classifying huge number of regions in an image The CNN acts as feature extractor and extracted features are fed into a SVM to classify the presence of object within that candidate region proposal
ResNet50	CNN that is 50 layers deep trained on ImageNet database
FPN	Feature pyramid network is a feature extractor that takes a single scale image of an arbitrary size as input and outputs proportionally sized feature maps at multiple levels, in a fully convolutional fashion
ROI	Region of Interest is a proposed region from the original image
ROI Pooling	ROI pooling produces the fixed sized feature maps from non-uniform inputs by doing max-pooling on the inputs
Softmax	The Softmax regression is a form of logistic regression that normalizes an input value into a vector of values that follows a probability distribution whose total sums up to 1. The output values are between the range [0,1] which is nice because we are able to avoid binary classification and accommodate as many classes or dimensions in our neural network model. This is why softmax is sometimes referred to as a multinomial logistic regression.
Bounding box regressor	Bounding-box regression is a popular technique to refine or predict localization boxes in recent object detection approaches. Typically, bounding-box regressors are trained to regress from either region proposals or fixed anchor boxes to nearby bounding boxes of a pre-defined target object classes.

Recycling Rate by Waste Class in 2019



Insights

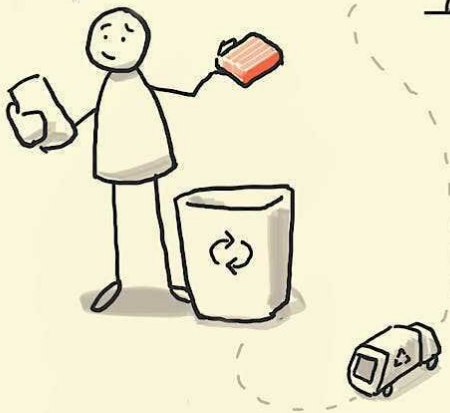
- Metals / Construction waste was higher in 2019 than in 2020
- Plastic waste recycling opportunity (biggest contributor to landfill)
- Recycling rate drop mainly due to reduced construction / industrial activity from COVID curbs

WISHCYCLING

HOPING SOMETHING CAN BE RECYCLED

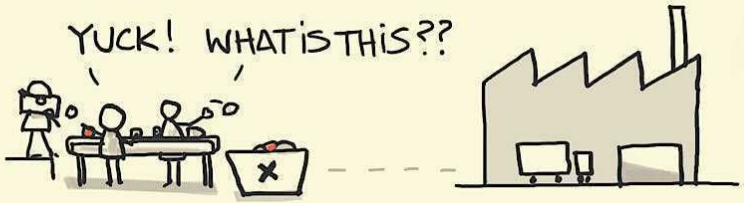
INTENTION

HMM, MAYBE THEY CAN?



EFFECT

YUCK! WHAT IS THIS??



THE QUALITY'S AWFUL, WE CAN'T SELL IT AND IT'S COSTING TOO MUCH TO SORT

✓ CHECK WHAT YOU CAN RECYCLE LOCALLY

✓ IF IN DOUBT KEEP IT OUT

sketchplanations

3 Rs of Waste Management

Reduce

Can the single-use applications (e.g. packaging) be avoided?

Reuse

Can it be used again for same or new applications?

Recycle

Finally, after you have contemplated the above points...
Can it be converted back to useful products?