The Sustainability of Plastic and its Alternatives

Moderators

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EUROPEAN UNION
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MINISTRY OF EDUCATION, YOUTH AND SPORTS

Panel Speakers

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Lisboa, Portugal

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Croatia

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FAMENA, Zagreb, Croatia

Prof. Aoife Foley
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Belfast, Belfast,
United Kingdom

Dr. Ting Ma
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14th sdewes Conference Dubrovnik 2019

Old Issues Recent Concern

Nearly 50 years ago

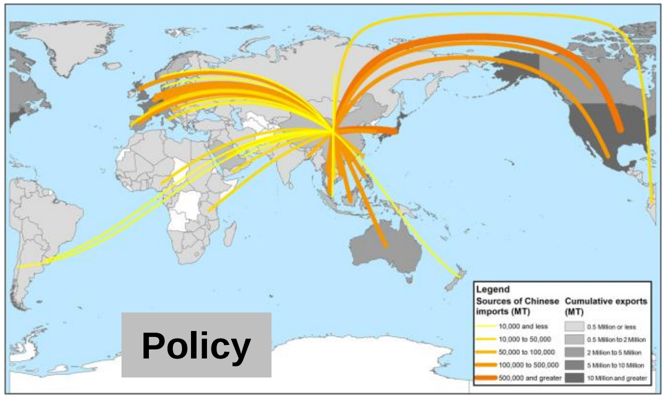
"Increasing production of plastics, combined with present waste-disposal practices, will undoubtedly lead to increases in the concentration of these particles." (Carpenter and Smith, 1972)

Why?

Plastic Tide

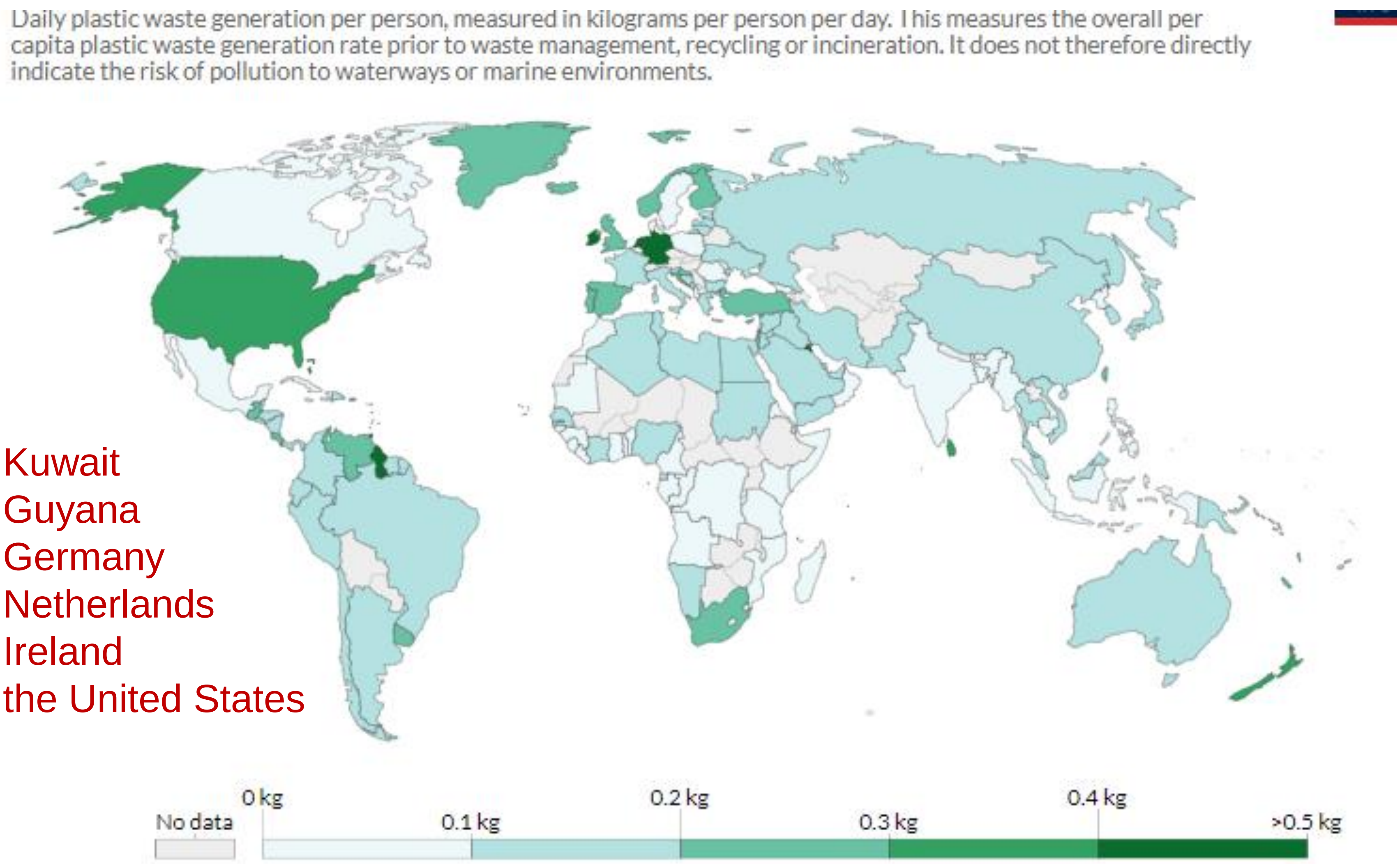
Harm to Wildlife - Ingestion, Entanglement

Plastic Export Ban, Circular Economy



Carpenter, E. J.,Smith, K. L. (1972). Plastics on the Sargasso Sea surface. Science, 175(4027), 1240-1241.
Photo: www.theguardian.com/environment/2018/nov/13/the-plastic-backlash-whats-behind-our-sudden-rage-and-will-it-make-a-difference
Brooks AL, Wang S, Jambeck JR, 2018. The Chinese import ban and its impact on global plastic waste trade. Science Advances, 4(6), eaat0131.

Plastic Waste Generation Per Person

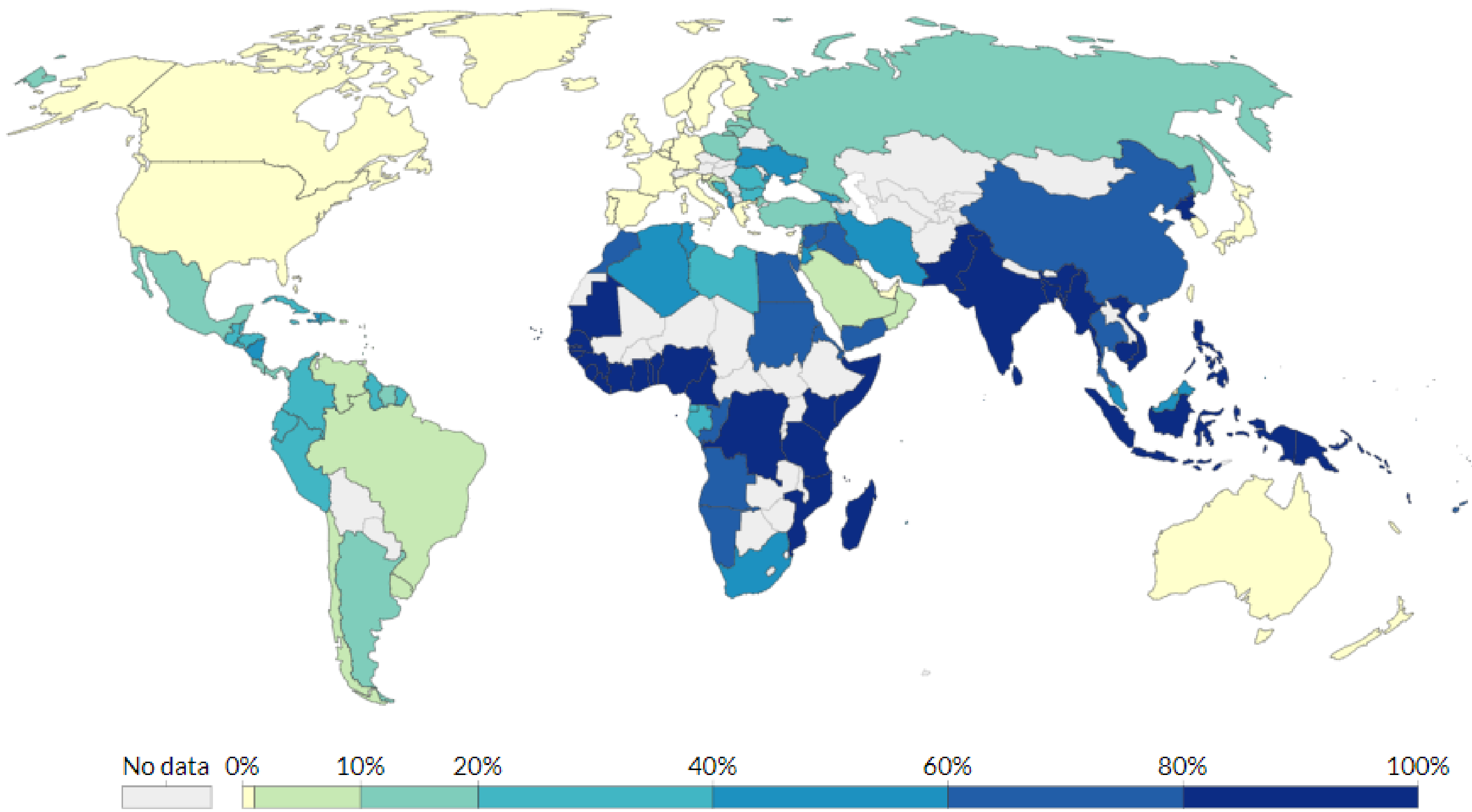


- Kuwait
- Guyana
- Germany
- Netherlands
- Ireland
- the United States

<ourworldindata.org/plastic-pollution>

Share of Plastic Waste That is Inadequately Disposed

Share of total plastic waste that is inadequately managed. Inadequately disposed waste is not formally managed and includes disposal in dumps or open, uncontrolled landfills, where it is not fully contained. Inadequately managed waste has high risk of polluting rivers and oceans. This does not include 'littered' plastic waste, which is approximately 2% of total waste (including high-income countries).



Many countries in South Asia and Sub-Saharan Africa, between 80-90 percent of plastic waste is inadequately disposed of, and therefore at risk of polluting rivers and oceans

<ourworldindata.org/plastic-pollution>

Microplastic

- Plastics less than 5 mm (0.2 inches) in diameter
- Primary: Fibres, pellet, cosmetic - microbeads, capsules
- Secondary

Photo Credit: National Oceanic and Atmospheric Administration

Teabag

Bottle

Biodegradable plastic → **Degradable? Depend on the environment**

Bioplastic

<ourworldindata.org/faq-on-plastics#what-are-microplastics>
<www.nationalgeographic.org/encyclopedia/microplastics/>
<cnn.it/2m4zpXS>

Impacts of Microplastics

- slower metabolic rate and survival in Asian green mussels
- reduced reproducibility and survival in copepods
- reduced growth and development of *Daphnia*
- reduced growth and development of langoustine
- reduced energy stores in shore crabs and lugworms

- Many organisms **do not exhibit changes in feeding** after microplastic ingestion. A number of organisms, including suspension-feeders (for example, oyster larvae, urchin larvae, European flat oysters, Pacific oysters) and detritivorous (for example, isopods, amphipods) invertebrates show no impact of microplastics
- There has been **no evidence** of harmful effects to date

Microplastics in water pose 'no apparent health risk'

<www.bbc.com/news/health-49430038>

<ourworldindata.org/plastic-pollution>

How to Drink?

Plastic

Paper

Wheat

Steel

Glass

Better?

McDonald's new paper straws - described as "eco-friendly" by the US fast food giant - cannot be recycled.

Customers were unhappy with the new straws, saying they **dissolved** before a drink could be finished, with milkshakes particularly hard to drink.

Bubble Tea

No Straw

maximum of a 0.03 % reduction

Frappuccino, Milk Shake

<www.bbc.com/news/business-49234054>

<ourworldindata.org/faq-on-plastics#what-are-microplastics>

Plastic vs Paper Cup

- Consumes **33 g of wood in production per cup**
- Uses **28 % more oil** than a plastic crucible.
- Needs **36 times** more **chemicals**
- Consumes **580 times** more **wastewater**
- Produces 10 to 100 times **more pollutant** residual waste and 3 times **more emissions**
- Incinerate: Paper provides **20 MJ per kg** and polystyrene gives 40 MJ per kg.
- Waterproof plastic layer – **non recyclable**
- Plastic: Cheaper, lighter

Royal Society of Chemistry
<www.rsc.org/education/teachers/resources/inspirational/resources/6.2.2.pdf#targetText=In%20total%20about%2033%20g,polystyrene%20one%20about%201.5%20g.>

The Impacts of Different Materials

Bag type	Number of reuses required for life cycle equivalence with an HDPE bag	Consumption			**Litter marine impacts**	GHG
		Energy	Water	Material		
		Usage			Leakage	
HDPE	-	♦♦	♦	♦♦♦	♦♦♦♦♦	♦♦
Paper	3	♦♦♦♦♦	♦♦♦	♦♦♦♦♦	♦	♦♦♦♦♦
LDPE	4	♦♦♦	♦	♦♦♦♦	♦♦♦♦♦	♦♦
Non-woven polypropylene	11	♦	♦	♦	♦♦	♦

Trade off? Overall Impacts?

Plastic materials might provide far more environmental benefits than drawbacks

NSW EPA, 2016. Plastic shopping bags: Practical actions for plastic shopping bags <www.epa.nsw.gov.au/~/media/EPA/Corporate%20Site/resources/waste/160143-plastic-shopping-bags-options.ashx>

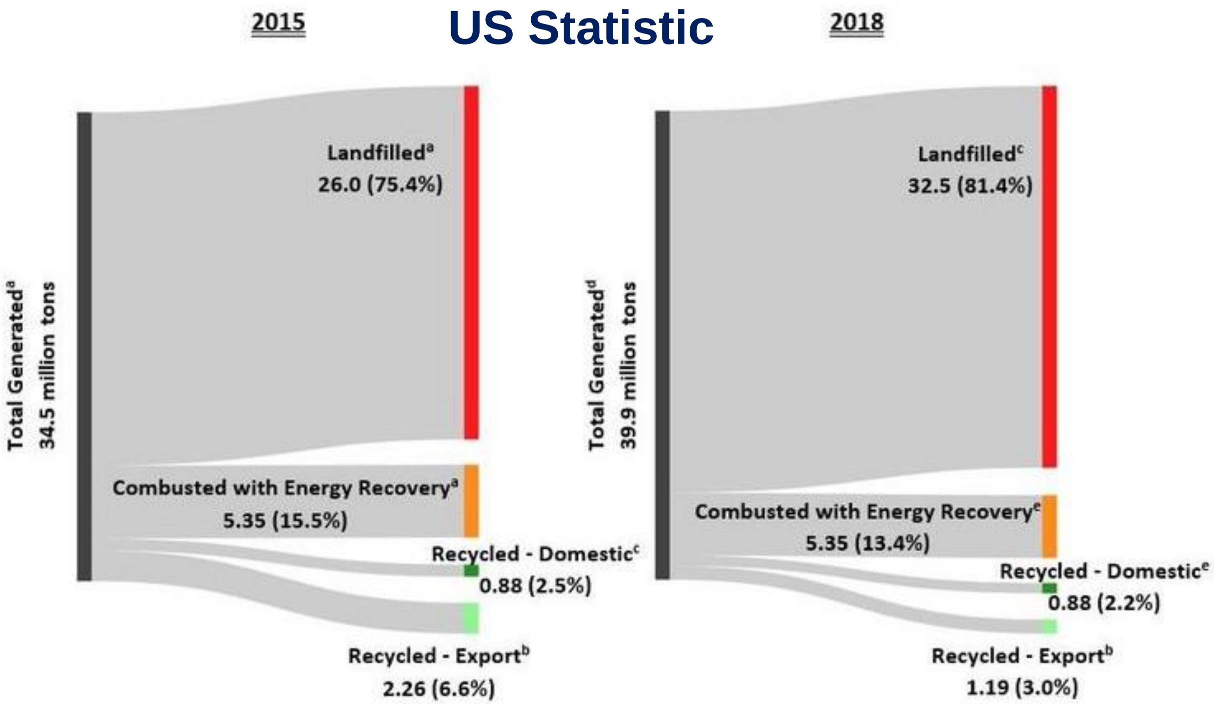
The Accounting and Challenges

Leakage? Marine Litter?

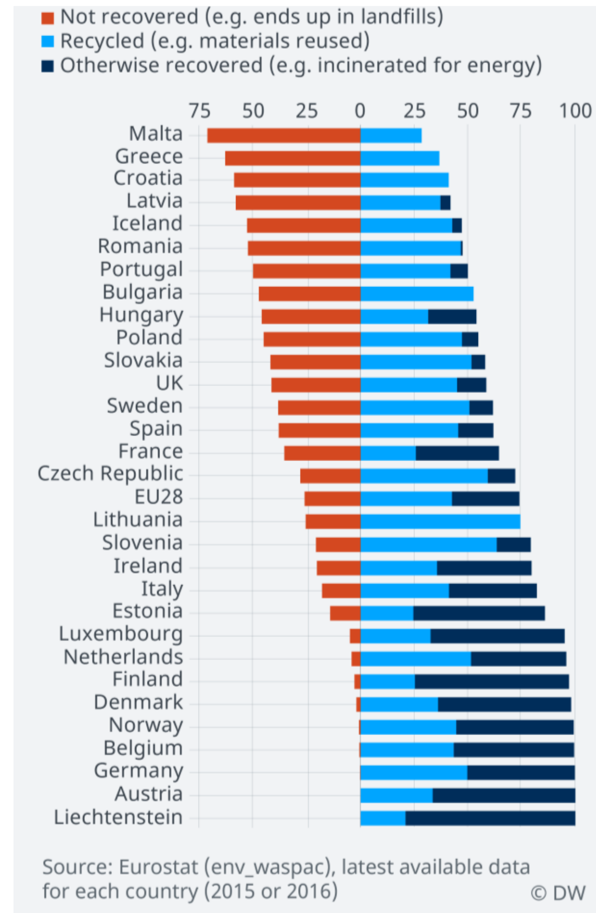
EU Statistic

39 % Incinerated, 31 % Landfilled, 20% Recycled **= 100%**

US Statistic



Recycled = 9.1 % **Recycled = 5.2 %**



Exported/ Separated Recyclable = Recycled?

<www.europarl.europa.eu/news/en/headlines/society/20181212STO21610/plastic-waste-and-recycling-in-the-eu-facts-and-figures>
<www.plasticpollutioncoalition.org/blog/2019/4/29/six-times-more-plastic-waste-is-burned-in-us-than-is-recycled>

Plastic Leakage – Proposed Framework

Integrate with other footprints (e.g. Energy) for a fair comparison

Under-development → Challenge: Data, Fate of macro and microplastics

IUCN, Review of Plastic Footprint Methodologies <portals.iucn.org/library/sites/library/files/documents/2019-027-En.pdf>

Existing and Under Development Plastic Footprint Methodologies & Tools

	Name of Methodology	Link	Include microplastics	Date of release
Corporate / Product	Plastic Scan	http://oceanimpact-quickscan.azurewebsites.net	NO	2017
	Plastic Disclosure Project (PDP)	http://plasticdisclosure.org	NO	2016
	Plastic Footprint for Companies	https://www.plasticsoupfoundation.org/en/psf-in-action/plastic-footprint-3/	YES	2017
	Plastic Scorecard	https://www.bizngo.org/sustainable-materials/plastics-scorecard	NO	2014
	Marine Plastic Footprint	n.a.	YES	n.a. 2019
	Plastic Leak Project	https://quantis-intl.com/metrics/initiatives/plastic-leak-project/	YES	n.a. 2019
	Circularity Indicators Methodology	https://www.ellenmacarthurfoundation.org/programmes/insight/circularity-indicators	NO	2015
	Plastic Drawdown	https://www.commonseas.com/projects/plastic-drawdown	YES	2019
	Marine Impacts in LCA	n.a.	YES	n.a.
	PlastikBudget	n.a.	YES	n.a. 2020
	Plastic Pollution Calculator	n.a.	NO	n.a. 2019
	PET Collection, Landfill and Environment Leakage Rates in South East Asia	https://www.gacircular.com/publications/	NO	n.a. 2019
	Plastic Life Cycle Assessment (LCA)	https://epica.jrc.ec.europa.eu/permalink/plastic lci/plastic lca report/2018.11.20.pdf	YES	n.a. 2020
Countries / Regions	PIPro SEA	n.a.	NO	2019
	National Guidance For Marine Plastic Hotspotting and Shaping Action	n.a.	YES	n.a. 2019
	A Global Roadmap to Achieve Near-zero Ocean Plastic Leakage	n.a.	YES	n.a. 2019
Individuals	Plastic Footprinter	http://www.plasticfootprint.ch	NO	2014
	My Little Plastic Footprint	http://mylittleplasticfootprint.org	YES	2017
	Plastic Calculator	http://secure.greenpeace.org.uk/page/conte	NO	2016

Not included in all methodologies

Scope of the assessment	Plastic use & waste generation
	Circularity
	Plastic leakage
	Environmental impacts (from plastic leakage)
	Microplastics
Granularity of the assessment	Polymer specific (but not related to littering)
	Application specific
	Sector specific
	Country specific
	Archetype specific (by income level)
Description of the tool	Online version
	Labelling/accreditation scheme
	Includes forecasting and scenario analysis
Description of the guidance	Calculation rules transparent and available
	Data collection guidance available
	Dataset available
	Case studies available (related to plastic leakage)

X comparison

IUCN
Review of Plastic Footprint Methodologies
<portals.iucn.org/library/sites/library/files/documents/2019-027-En.pdf>

Are Ban and Reduction a Sustainable Solution?

Plastics are just too efficient to be easily replaced!

Alternative Strategies and the Challenges to Overcome

- **Control Marine Litter**
- Post consumer feedstock (**as metal scrap market**) → e.g. **Upcycling**

ASTM D5033 définitions	Equivalent ISO 15270 (draft) definitions	Other equivalent terms
Primary recycling	Mechanical recycling	Closed-loop recycling
Secondary recycling	Mechanical recycling	Downgrading
Tertiary recycling	Chemical recycling	Feedstock recycling
Quaternary recycling	Energy recovery	Valorization

- **Redesign + Recycling**

Mixed Plastic
Pigments
Additives
Contaminants

Challenges

Regulate the Manufacturer or Consumer?

Most of the time the focus is on consumer

Responsibility of consumer?

Waste separation/ recycling, Blaming

The Arguments of Producers are the Key

- Separating/Collecting is not recycling
- Consumers purchase according to the given choice by the manufacturers
- Manufacturers know the material composition well
- Producers to manage products at the end of its life - Fingerprint
- Encourage redesign (use recycled materials, improve the easiness for recycling) and improvement

The sustainability of plastics and its alternatives

by

Aoife M. Foley,

Reader, Queen's University Belfast

Editor in Chief, Renewable & Sustainable Energy Reviews, Elsevier

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CLEAR GLASS
CLEARLY NOT GLASS


THE BATTLE
VS
GLASS
PLASTIC

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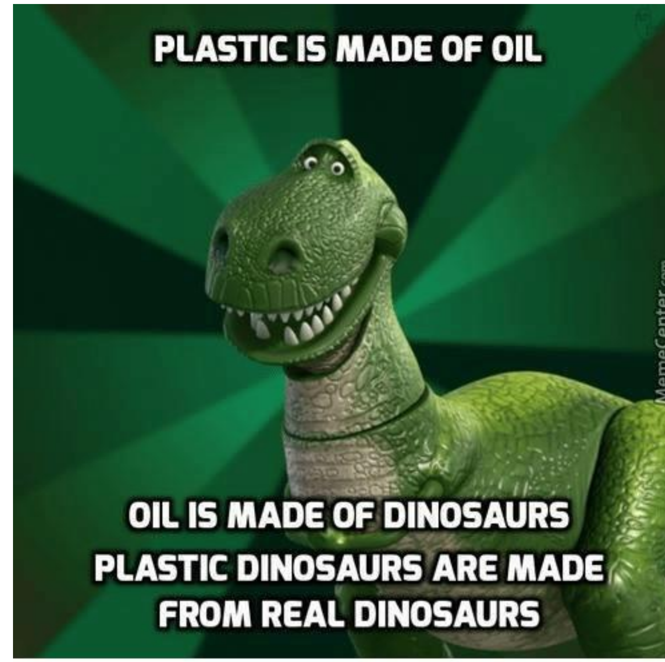

Dead Dinosaur Advice

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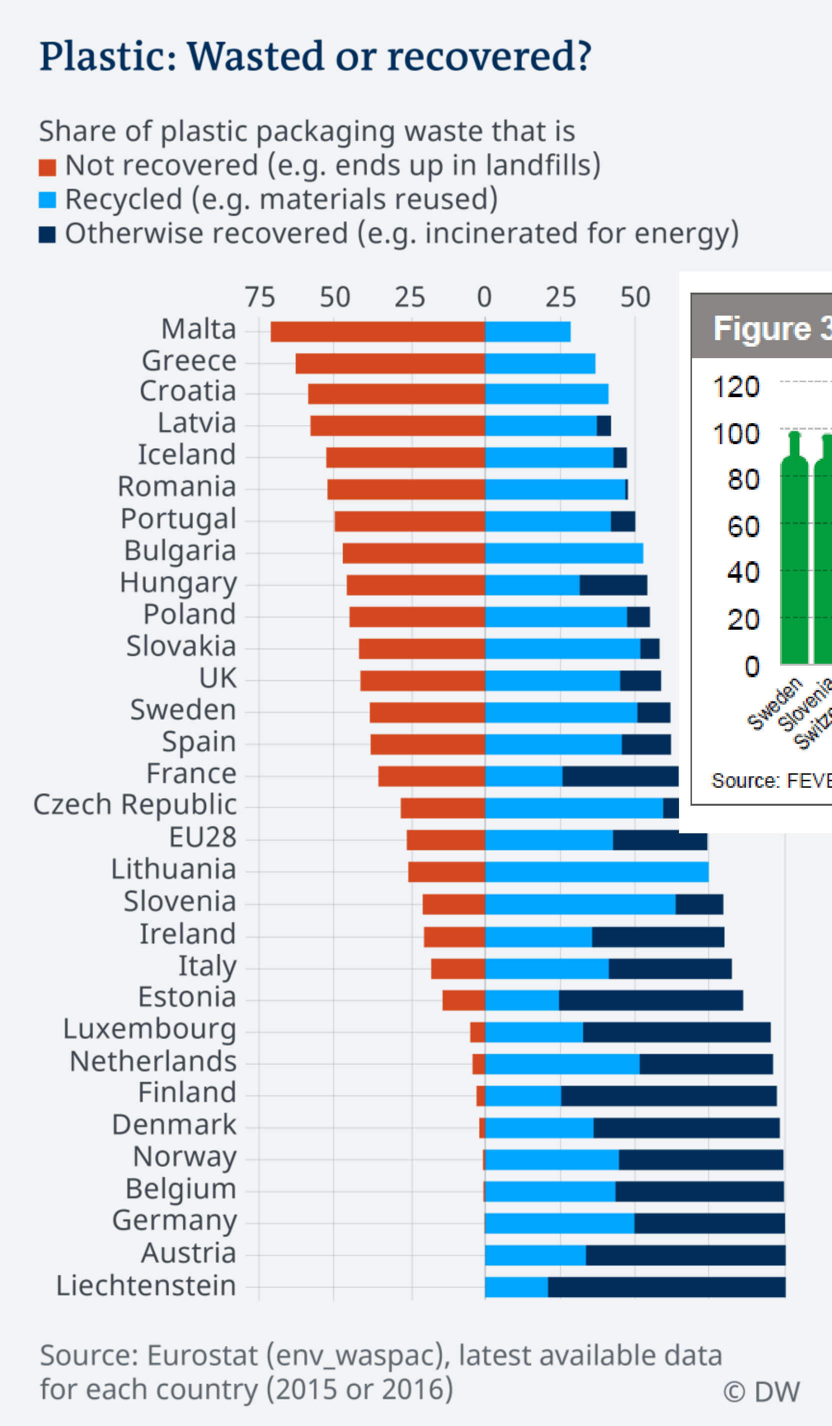
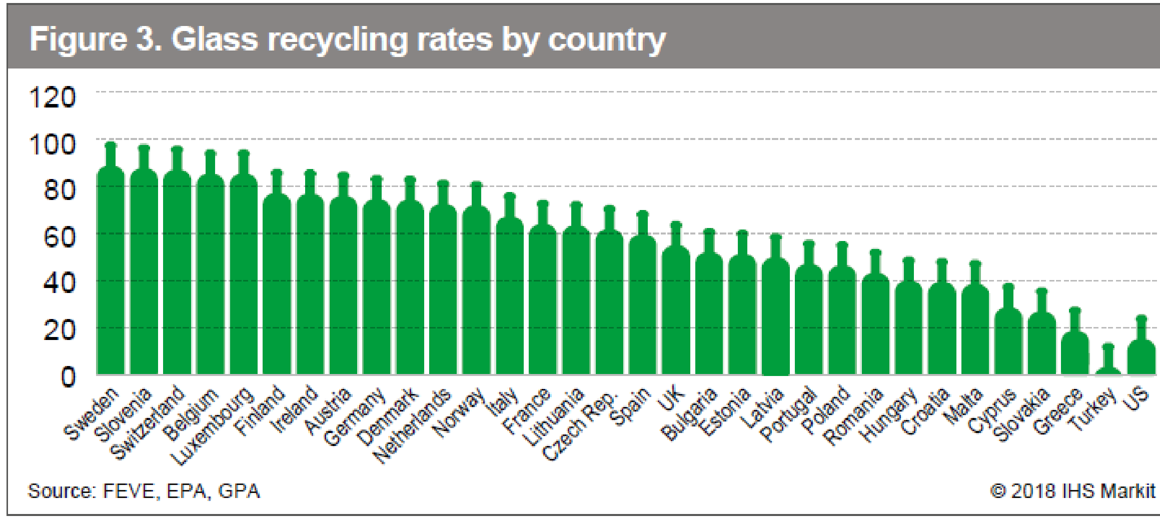




Plastic packaging is made from seven different types and some are recycled more often than others

BBC

Tags # BIN CHARGES # CRISIS LEVELS # DENIS NAUGHTEN # FOOD WASTE

China took 95% of Ireland's plastic waste - but now it's changed its mind and we're in trouble

Ireland is the top producer of plastic waste in the European Union.

Jan 9th 2018, 6:01 AM 121,680 Views 100 Comments Share 2743 Tweet Email 25

IRELAND'S INCREASING WASTE and plastic levels are soon to meet emergency levels following China's ban on imported plastics, according to one government source.

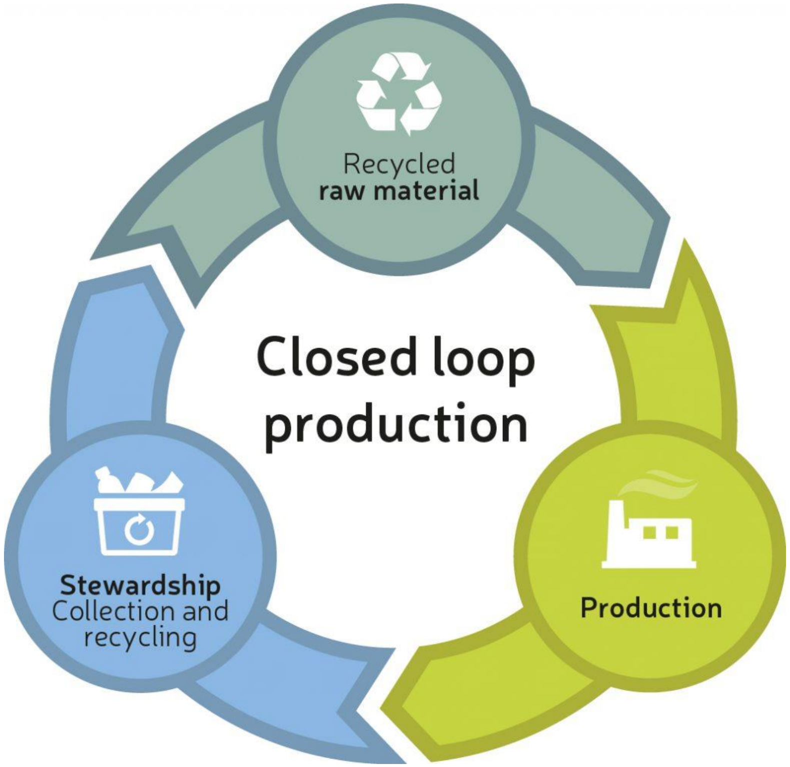
China – the world's largest recyclable materials importer – decided to ban the importing of plastics from European countries, such as Ireland, last year. The policy came into effect on 1 January.

China took 95% of Ireland's plastic waste in 2016, but a ban will mean that's no longer possible. While many other European nations are searching for alternative waste-management solutions, Ireland is in a particularly dire situation.

Source: Statistia

Messages

- No one solution
- It is not a case of glass versus plastic
- It is a **COMPLEX LCA problem**
- Growth in more complicated product
- Composite materials e.g. tetrapak
- Issues include;
  - Knee jerk actions/reactions
  - Human behaviour
  - Industry
  - Environment, energy & equity
  - End of life = **New Product**
  - Circular economy
  - Virtual foot prints
  - **Regulation and governance**



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Society = our choice = our voice = our problem

Plastics in environment – do we look for a solution?

Slaven Dobrović

Plastics – unavoidable material of todays world

335 million tons/year in world, (60 million tons/year in EU)

Leakages to environment:

- **Improper waste management**
- **Tear and wear during the lifecycle**
- **Intentionally added microplastics**

Plastic waste

PLASTIC WASTE - Europe:
Around 25.8 million tons/year
Less than 30% of such waste is collected for recycling
Landfilling and incineration rates of plastic waste– 31 % and 39, respectively

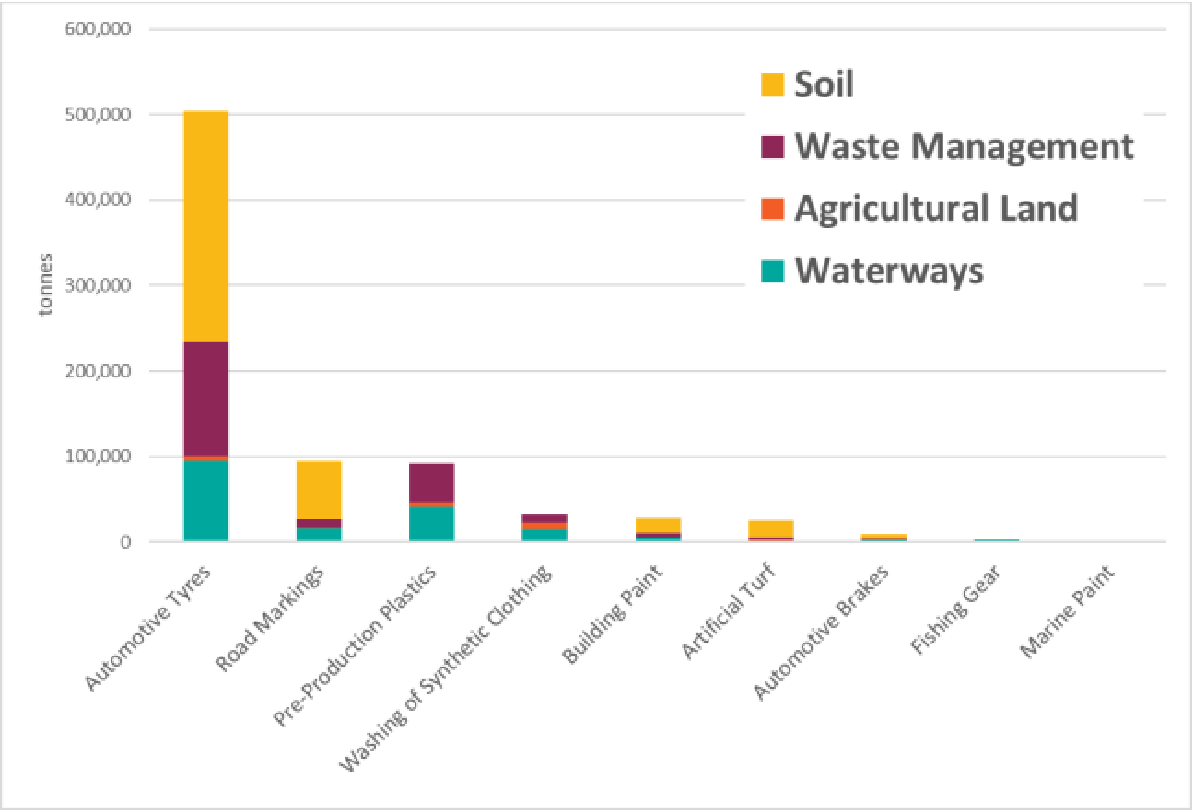
According to estimates, 95 % of the value of plastic packaging material, i.e. between EUR 70 and 105 billion annually, is lost to the economy after a very short first-use cycle.

It was estimated that plastics production and the incineration of plastic waste give rise globally to approximately 400 million tons of CO_2 a year.

Using more recycled plastics can reduce dependence on the extraction of fossil fuels for plastics production and lower CO_2 emissions.

Microplastics that are created during the lifecycle of a product through wear and tear

Figure 1 - Source Generation and Fate of Microplastics from Wear and Tear in the EU (midpoint)



Source: Eunomia modelling

Intentionally added microplastics, designed to be emitted during the lifecyccle

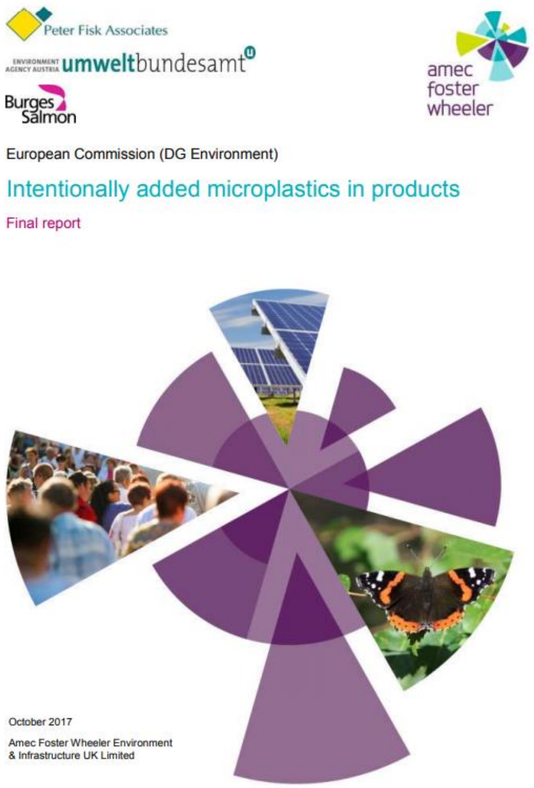

Peter Fisk Associates
umweltbundesamt
Burges Salmon
amec foster wheeler
European Commission (DG Environment)
Intentionally added microplastics in products
Final report
October 2017
Amec Foster Wheeler Environment & Infrastructure UK Limited

Table 2.5 Microplastic functions in different products

Function	Products
Abrasive/exfoliating	Cosmetics, detergents, industrial blasting abrasives
Emulsifier, suspending agent	Cosmetics, detergents, paints
Binding	Cosmetics, paints, inks, concrete
Filler	Construction (wall and joint fillers, self levelling compounds/screeds)
Control release of ingredients	Pharmaceuticals (nanocapsules), cosmetics, fertilisers, crops, detergents (enzymes)
Film forming	cosmetics, polishing agents
Surface coating	paper making, polishing agents,
Improved chemical and mechanical resistance	Coatings, paints, floor coatings, polymer cement
Fluid absorbents	nappies, water retainer for farming, agriculture, horticulture

[22] Deloitte: Technical assistance related to the review of REACH with regard to the registration requirements on polymers, final Report for DG ENV, 2014.
[23] D. Lithner, A. Larsson, G. Dave: Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. Science of the Total Environment, 409, 3309-3324, 2011.

Function	Products
Thickening agent	paints, cosmetics, concrete, oilfield use (drilling fluids)
Aesthetics	coloured microplastics in make-up, structural effects of paints, enhanced gloss level of paints
Flocculant	Waste water treatment, oilfield use, paper making
Dewatering	Paper making, dewatering of sewage sludge, manure
Dispersing agent	Paints, coatings (pigments)
Opacifying agent	Cosmetics
Anti-static agent	Cosmetics / hair care

Table 3.6 Sector-level overview of tonnages and concentrations of microplastics in products

Sector	Product	Total tonnage of microplastics used by the sector in the EU (estimate based on consultation and literature)	Total tonnage of products containing microplastics sold by the sector in the EU	Concentration of microplastics in products that contain microplastics
Personal care	Rinse-off products containing exfoliating and cleansing microbeads (as indicated by Cosmetics Europe) Further product breakdown available (see Appendix B).	714-793 tonnes (exfoliating and cleansing microbeads in rinse-off products)	Unknown. It is estimated based on Eurostat data that the total European market for personal care products (with and without microplastics) comprises around 3-5 million tonnes in the EU28.	Unknown
	Leave on PCPs containing microplastics (as indicated by Cosmetics Europe in reaction to estimates from Eunomia 2016)	540-1 120 tonnes {Synthetic polymers and/or copolymers (plastics); Solid phase materials (particulates, not liquids); Insoluble in water; Non-degradable; and small size (maximum 5 mm, no lower size limit is defined)}.	1.5 million according to Eunomia (2016)	Weighted average calculated from Eunomia (2016): 2.4% Range 0.005%-72% according to Eunomia (2016)
Paints/coatings	Waterborne building paints (as indicated by CEPE)	220 tonnes (Solid non-biodegradable polymeric particles with physical dimensions between 1μ - 5 mm originating from anthropogenic sources)	14 000 tonnes	Weighted average 1.6% w/w. Range approximately 1%-2%.
	All other	Other sources suggest it could be significantly higher, but estimates are very uncertain. Extrapolation from Danish Environmental Protection Agency (2015) (200-350 tonnes of microplastics in building paint sold in Denmark) suggests 22 000-38 000 tonnes.	Unknown. According to Eurostat data, an estimated 14 million tonnes of paints, varnishes and similar coatings, printing ink and mastics (with and without microplastics) are sold in the EU28.	0.4% in building paint sold in Denmark according to Danish Environmental Protection Agency. Unknown for other products.
Detergents	Soaps, Detergents and Maintenance Products Further product breakdown available (see Appendix B).	190-200 tonnes (water insoluble solid plastic particles with a size less than 5mm that can be found as marine litter) suggested by AISE is not contradicted by literature.	3 572 tonnes	Weighted average (all Soaps, Detergents and Maintenance Products): 4.0% Range (of weighted averages per product category): 0.7%-4.9%
Abrasives	Sandblasting	Extrapolation from Danish Environmental Protection Agency (2015) (use in sandblasting in Denmark 5-25 tonnes) suggests 1 000-5 000 tonnes (Persistent, solid particulates composed of synthetic or semi-synthetic polymers and physical dimensions of 1 µm - 5 mm originating from anthropogenic sources), subject to high uncertainty.	Unknown. According to Eurostat data, an estimated 500 000 tonnes of abrasive products (with and without microplastics) are sold in the EU28.	Unknown
	Additional uses of microplastics are suspected in this sector for which no information on tonnage was available. Abrasives industry (FEPA) stated that in its main applications in this sector, microplastics are not present in the final product as they are either cross-linked (as part of the bonding systems) or burned (as technical filler) during the production process.	Unknown	Unknown. According to Eurostat data, an estimated 500 000 tonnes of abrasive products (with and without microplastics) are sold in the EU28.	Unknown
Oil and gas	Off-shore drilling and production	**No precise quantitative estimate possible**, but could be substantial (in the magnitude of hundreds of tonnes) according to some sources.	Unknown.	Unknown.
Agriculture	Nutrient prills / slow-and controlled-release fertilisers	Up to a maximum of about 8 000 tonnes (Trenkel 2010 suggests that 1 700-8 000 tonnes of polymers are used in these products in "Western Europe". no sufficient information is available to estimate what share of these polymers constitute microplastics in the EU)	Up to 40 000 tonnes according to Trenkel (2010) (refers to products containing polymers in "Western Europe").	Polymer coated fertilisers: up to 3-15% Sulphur-coated urea (SCU) / Polymer-coated sulphur-coated urea (PSCU): up to 2% According to Trenkel (2010), refers to polymers (an uncertain share of which constitute microplastics)
	All other	**No quantitative estimate possible.**		
Pharmaceutical industry		**No quantitative estimate possible**, but the industry claims no significant amounts of microplastics are used in the EU currently.		

Risk assessment

		Receptor	
		Organisms in the environment	Humans exposed via the environment
Effects	Physical	?	?
	Toxic	?	?

SOLUTION?


European
Commission
A EUROPEAN STRATEGY
FOR PLASTICS
IN A CIRCULAR ECONOMY

OUR STRATEGY FOCUSES ON 4 AREAS:

PLASTIC WASTE FACTS
FROM AROUND THE GLOBE

FACT 1

90%

Just ten rivers transport more than 90% of river-based plastics to the ocean.

VIEW INFOGRAPHIC →

FACT 2

80%

80% of ocean plastic comes from land-based sources

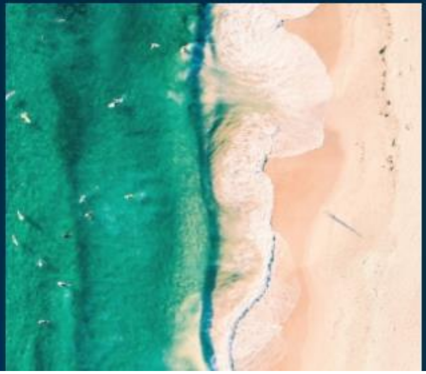
SHARE THIS

FACT 3

**CHINA
INDONESIA
PHILIPPINES
THAILAND
VIETNAM**

Over half of land-based plastic waste leakage comes from just 5 countries

SHARE THIS



FACT 4

Research has identified the most significant sources of unmanaged plastic waste, and key aspects of the solution

FACT 5

Replacing plastics in packaging and consumer products with alternative materials could raise environmental costs nearly fourfold

TÉCNICO LISBOA

Pyrolysis of Non-Recycled Plastics

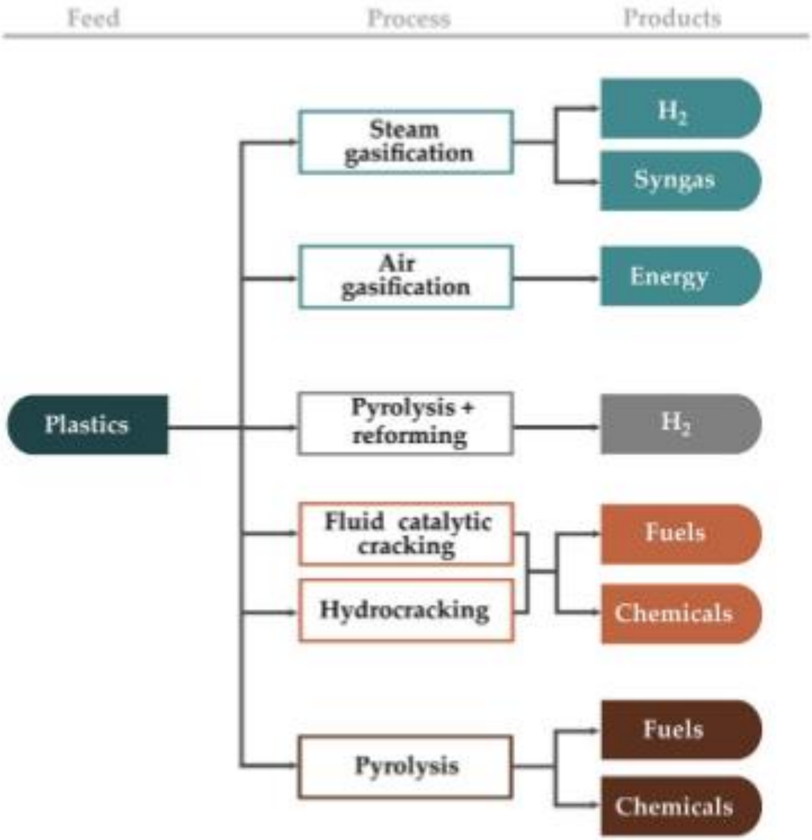
Mário Costa
Instituto Superior Técnico
Universidade de Lisboa, Lisboa, Portugal

14th SDEWES Conference, Dubrovnik, 2019, October 1-6
Panel: The sustainability of plastic and its alternatives

Introduction

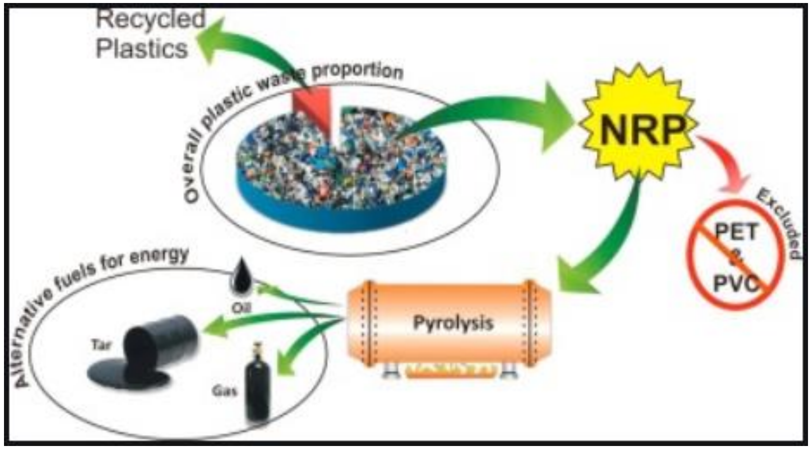
Non-recycled plastics (NRP) cause a huge environmental problem.

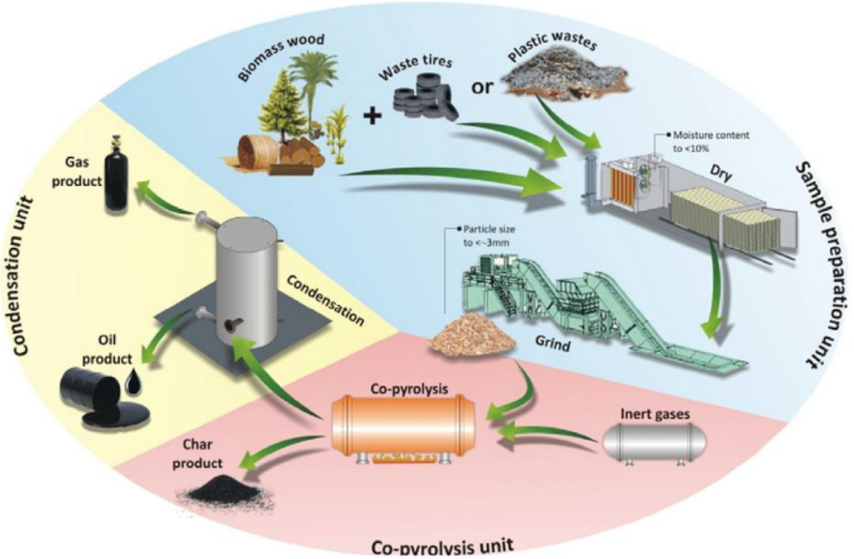
Possible solutions for chemical valorization of NRP (Lopez et al., RSER, 82, 576-596):



TÉCNICO LISBOA

(Co-)Pyrolysis





NRP (co-)pyrolysis main drawbacks:

- High external energy demand, high capital cost, and inconsistent product quality,
- Difficult to stablish one single route for all types of NPR, due to their different composition,
- Define optimal pyrolysis conditions to diminish the release of dioxins, pollutants to soil and underground water,
- Need to purify the bio-oil produced from pyrolysis technology.

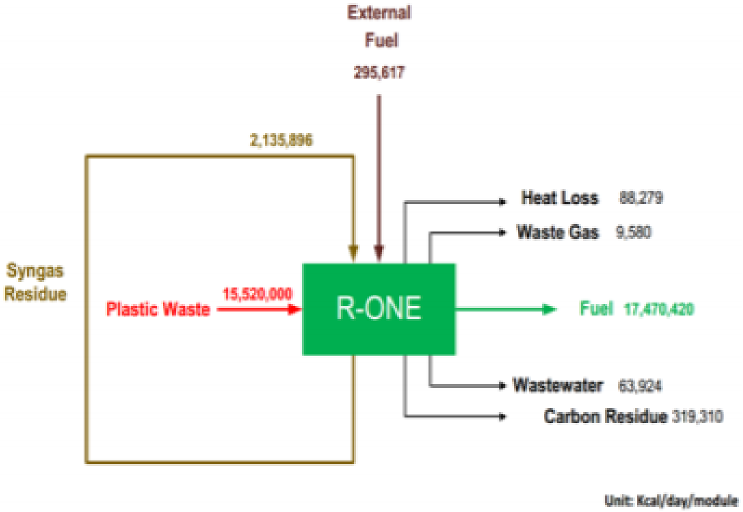
Should these drawbacks solved, pyrolysis of NRP would result in a higher reduction of CO_2 emissions as compared to incineration processes with energy recovery.

Final notes

NRP pyrolysis technology is poorly developed, being the needed economic investment quite high so that competition with current oil production prices is very difficult.

Demonstration facility in Hukou, China (Yu et al., 2018, IJESD, 9, 95-99)

CO2 emissions reduction of about 70x compared to incineration



Co-pyrolysis of plastics with biomass appears to be a promising valorization route due to the positive impact on process performance and greater process flexibility.

Other promising alternative is the pyrolysis and in-line reforming, which allows producing a syngas with high hydrogen content and totally free of tar.

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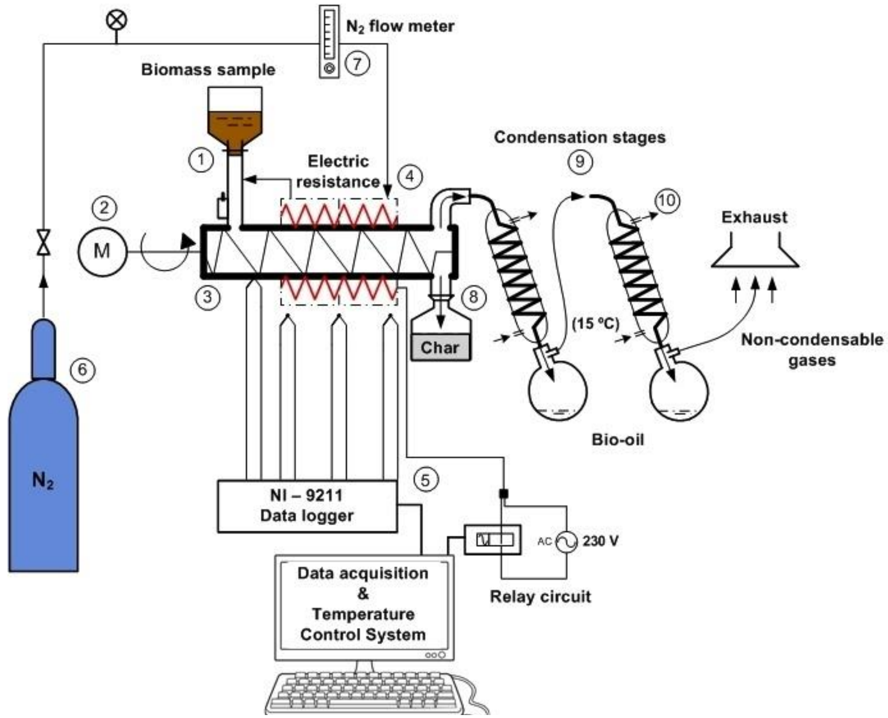
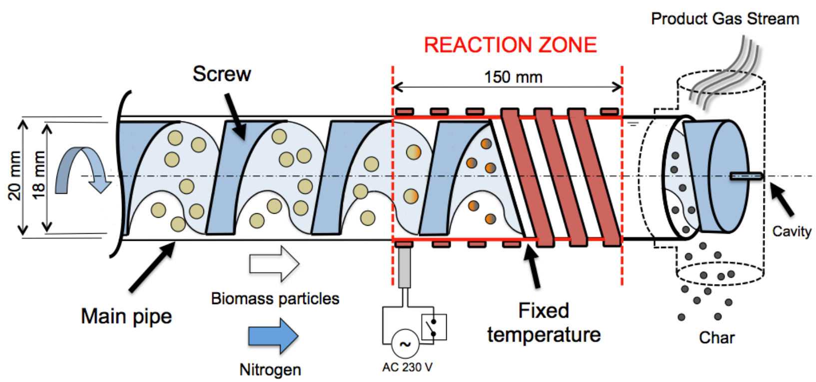
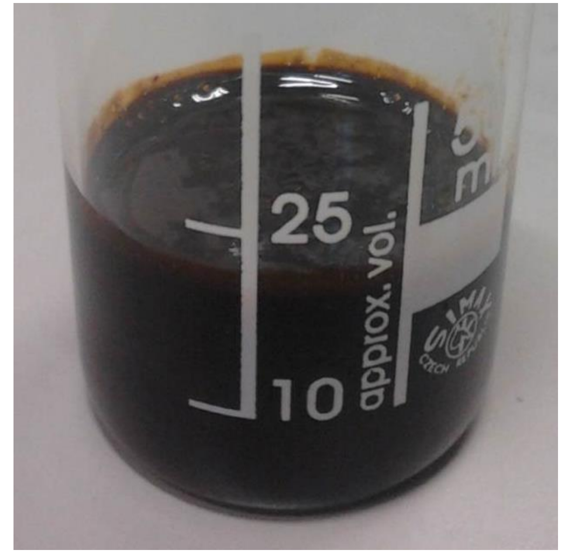
IST: Biomass pyrolysis







FSB 100

100 godina Fakulteta strojarstva i brodogradnje Sveučilišta u Zagrebu

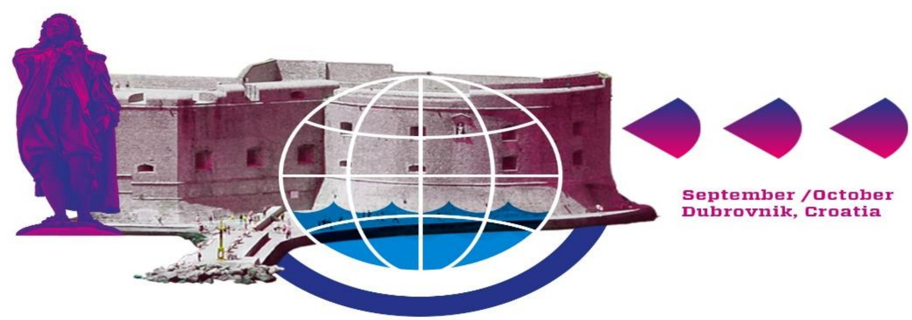
100 Years of Faculty of Mechanical Engineering and Naval Architecture University of Zagreb

Panel: The sustainability of plastic and its alternatives

A small contribution to the debate on the sustainability of plastic waste management

Prof. dr.sc. Daniel R. Schneider
Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb

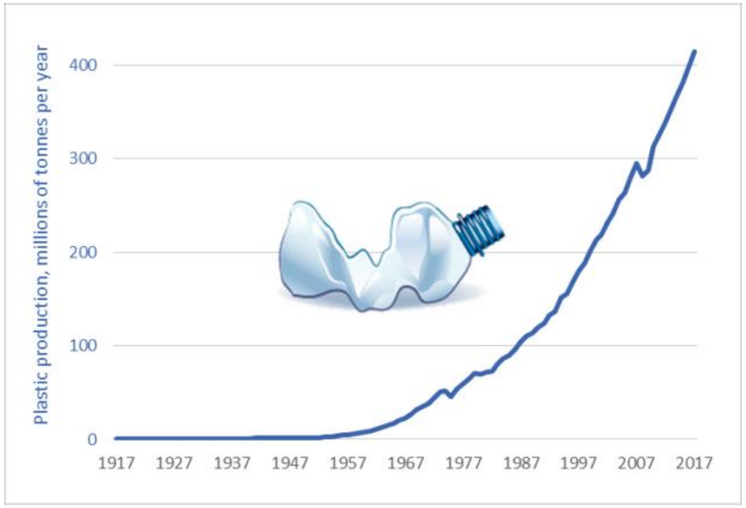
14th sdewes Conference Dubrovnik 2019



Introduction

- The overall plastic production in the world is growing at a steady rate of approximately **4%** per year.

- In 2016, the global production of plastics was 335 million tonnes, while in **2017** that number increased to **348 million** tonnes.



- Plastic production **in Europe** reached almost **65 million** tonnes in 2017.

- The biggest producer of plastic products today is **the packaging industry** which makes up for **almost 40%** of European plastic converter demand.

- In one year roughly **80%** of produced plastic packaging in Europe turns into waste.

- In 2016, for the first time, a larger share of overall collected post-consumer plastic waste in the European Union (EU) was **recycled (31%) than landfilled (27%)**, while the rest was **energy recovered (42%)** mostly by incineration.

Current status and plans

- The EU goals in the field of municipal waste management, as defined in various directives and plans, prescribe an increase of the recycling rate for **municipal waste** to **50% by 2020**, and **65%** for the period up to **2035**.

- At the same time, the share of **packaging waste recycling** in the EU (according to modified goal in 2018 in plans of the circular economy) has to rise to **70% by 2030** (in which **55% of recycling of plastic waste packaging**), which will be difficult to achieve without efficient and comprehensive separate collection and material recovery (recycling) of packaging waste.

- The ban on the import into China of 24 solid waste categories, which includes many types of **recyclable plastics**, paper and textiles, poses new problems for EU Member States (as well as the US and other countries) that have largely addressed their waste recycling by exporting to China → e.g. the EU has so far exported **50%** of its collected and sorted plastic waste, **80%** of which to China), and so EU countries currently do not have enough local capacity or economic reason to recycle all of this recyclable waste. → other Asian countries follow the China's decisions.

Recycling

- Avoidance is at the top of the waste hierarchy. (e.g. light weight bags and single-use plastic cutlery ban.
- Also **certain types of waste** (WEEE, bulky, medical, bio, textile, nappies, etc.) should not enter into the separately collected waste stream. (e.g. via yellow bins and containers), but the reality is different.
- As well as **re-usable waste**, which should not be a part of separately collected waste
- The responsibility is here on households.
- Regarding material recovery of separately collected waste (including plastics), the **recyclable waste** sorted out of this stream is only **20-35%**, as one analysis in the neighbouring country showed.
- The rest is used for energy recovery as a fuel (SRF, RDF) for waste-to-energy and cement plants (if we want to avoid landfilling entirely, or as it is prescribed by EU targets that no separately collected waste is landfilled or to reach maximal 10% of waste landfilling to 2035).
- The situation is much worse for recyclable material recovered from mixed municipal waste where this percentage reaches single digit values, e.g. **8%.**

Material recovery

- **Material recovery facilities** (MRF) face today problems with contamination of (plastic) waste, but also complexity of waste (more different and new materials, and pollutants), which puts limits to the current state of the art in mechanical (but also chemical) technologies for waste sorting, processing, recycling and recovery.

- Data from another country in the region showed that the overall efficiency of performance of a mechanical waste processing plant for non-hazardous mixed waste materials in practice is only **about 30-40%** of the theoretical efficiency, which is not enough to reach (economically) the required rates set by new EU targets.

- In the future, better (online/on-time) tracking (and characterization) of input waste and output material qualities, digitalization, new sensors, imaging-based classification, inteligent robotics, self-optimizing machines all integrated in **smart** material **recovery facilities**, can help to push these limits.

- Question of recyclability of solid recovered fuels in clinker material - the recyclable part of the ash derived from SRF utilized for energy recovery in cement industry – legislation still does not recognize it.

Inteligent Robotics in plastic sorting

- Both systems: ~4000 picks per hour and arm

ZenRobotics Recycler - robotic sorting station

Video 1. Example of application of robots in (plastic) waste sorting industry/recovery – heavy/bulky rigid plastics.

Sorted fractions:

- rigid plastics from mixed waste
- rigid plastics by polymer (PP, PE, PET, PVC)
- rigid plastics by shape and colour
- unlimited sorts

(Source: ZenRobotics, Finland)

Video 2. Sorting system MAX-AI AQC (USA) – lightweight packaging plastics (removing non-PET material)

Inteligent Robotics in plastic sorting

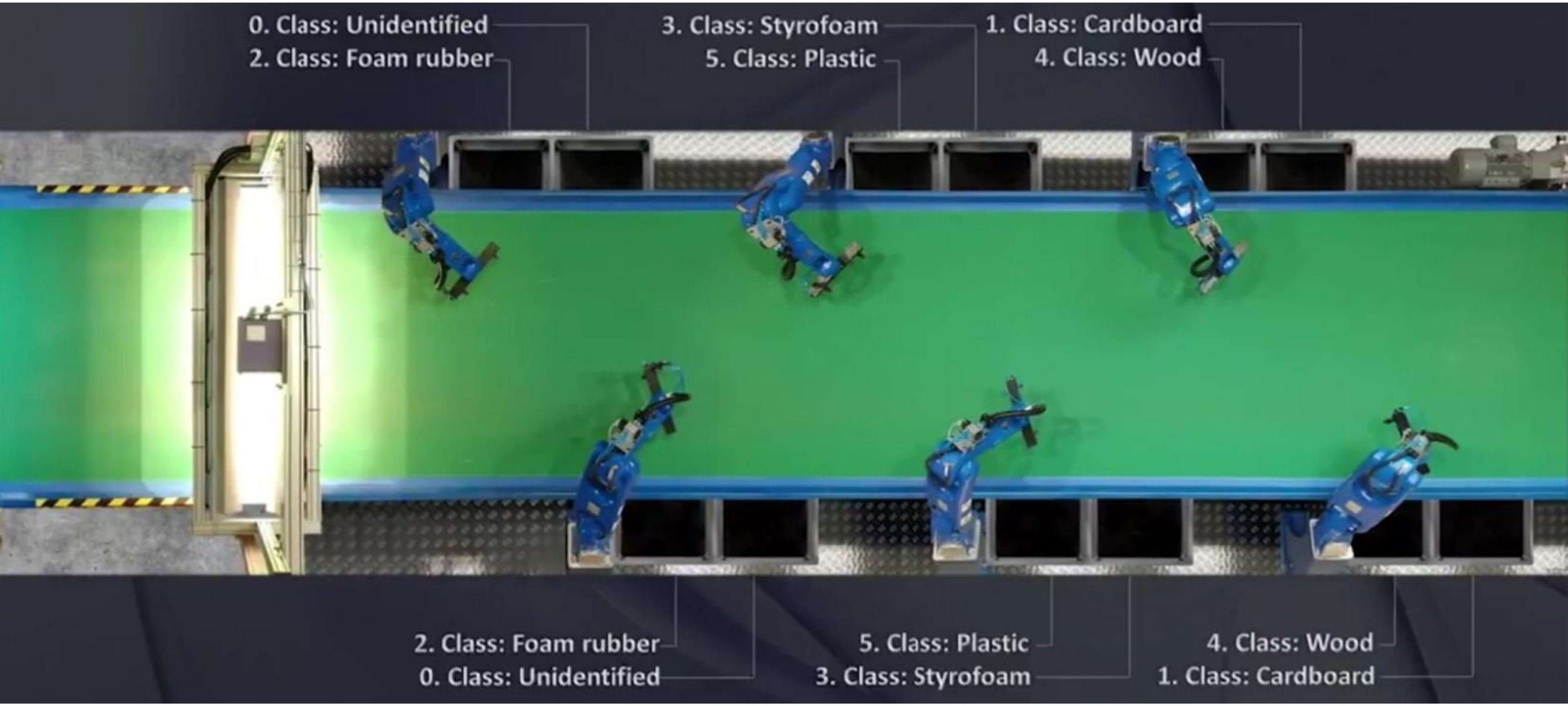


Fig. 1. SELMA sorting system (OP teknik AB)

Inteligent Robotics in plastic sorting

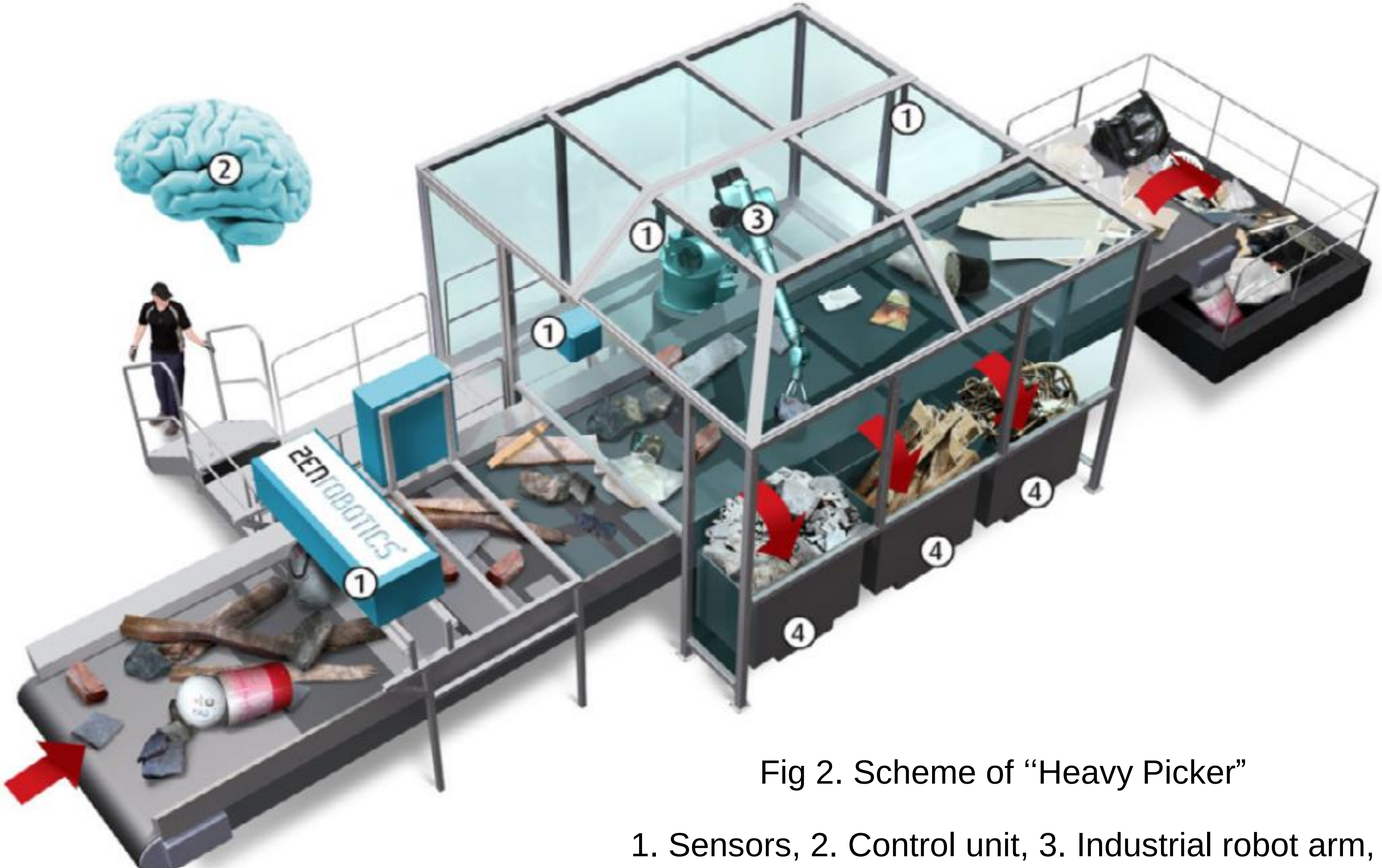


Fig 2. Scheme of ‘‘Heavy Picker”

1. Sensors, 2. Control unit, 3. Industrial robot arm,
4. Containers for sorted fractions

(ZenRobotics)

Extended Producer Responsibility

- Different **Extended Producer Responsibility (EPR)** initiatives can help in collection of lightweight packaging waste (of which around half is a plastic waste).
- Especially successful are **Deposit Refund Systems (DRS)**. → *EC (28 May 2018): Member States will be obliged to collect **90%** of single-use plastic drinks bottles by **2025**, for example through deposit refund schemes;*
- DRSs in Europe regularly achieve collection rates of **80-90%** while systems without deposits (via containers, green dot) have collection rates of **40%** on average.
- Modern DRSs are recognized today as a very efficient instrument to reduce littering and improve recycling;
- they proved themselves with large amounts of collected and recovered waste packaging with a small amount of impurities (contamination) within the collected material, which is a prerequisite for high-efficiency recycling in a **closed loop system** (e.g. bottle-to-bottle).
- Unfortunately, these schemes are usually limited only to one segment of packaging waste – beverage containers.

Deposit vs. Green dot system performance

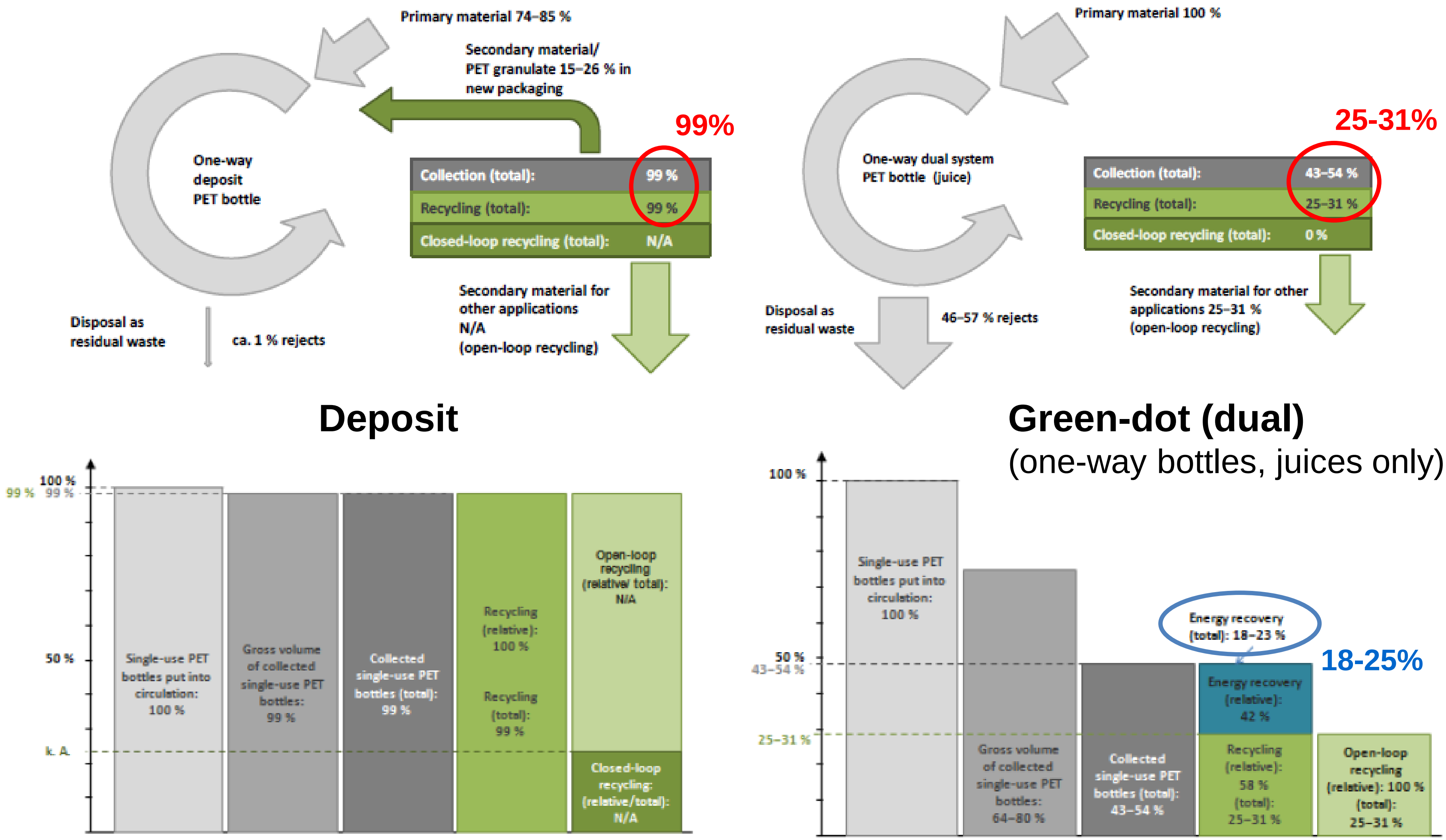


Fig. 3. Comparison of one-way (PET packaging) deposit and dual systems. (PWC, 2011.)

Energy recovery

- Regarding the mentioned energy recovery of plastic waste, which is today predominately done by incineration in dedicated waste-to-energy and cement plants, there are other potentially more advanced ways.

- **Pyrolysis** and **gasification** - thermochemical conversions, are technologies used to valorise plastic waste by converting it into valuable products, such as fuels, chemicals and energy.

- Furthermore, chemical depolymerization, catalytic cracking and reforming, and hydrogenation, among others, are considered as **chemical recycling** in which plastic waste is converted into feedstock, like monomers, oligomers and higher hydrocarbons that can be used to produce new polymers.

- What is currently lacking, is that the EU legislation does not distinguish these more advanced thermochemical conversions, nor for that matter chemical recycling, from the energy recovery processes, which is the matter that should be dealt with in the near future.

- Project „*Smart energy carriers in recovery of plastic waste*” (NEOPLAST) supported by the Croatian Science Foundation (3200).

Gasification of plastic waste

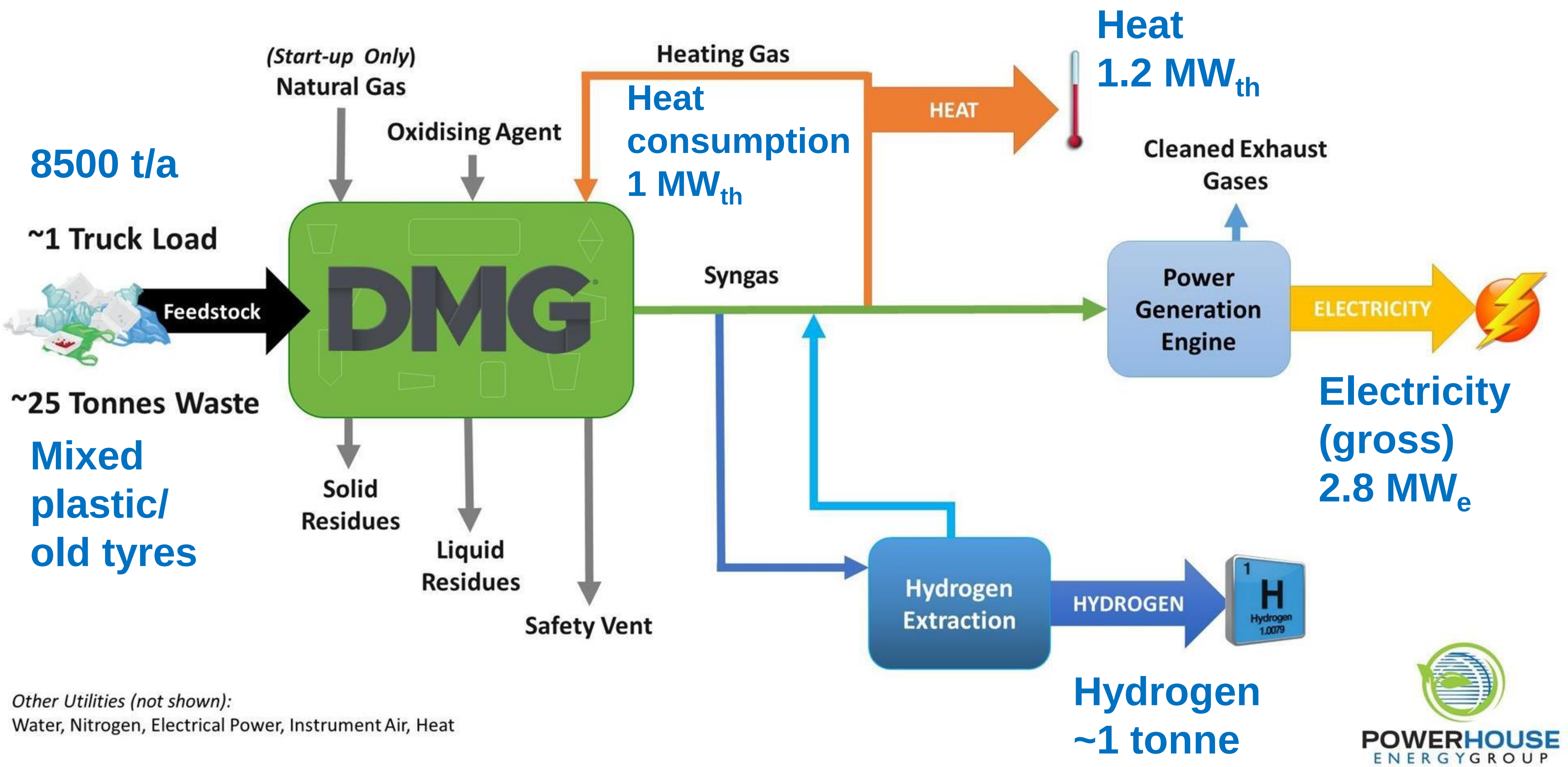


Fig. 4. Simplified flow diagram - distributed modular gasification (DMG®- Distributed Modular Gasification).

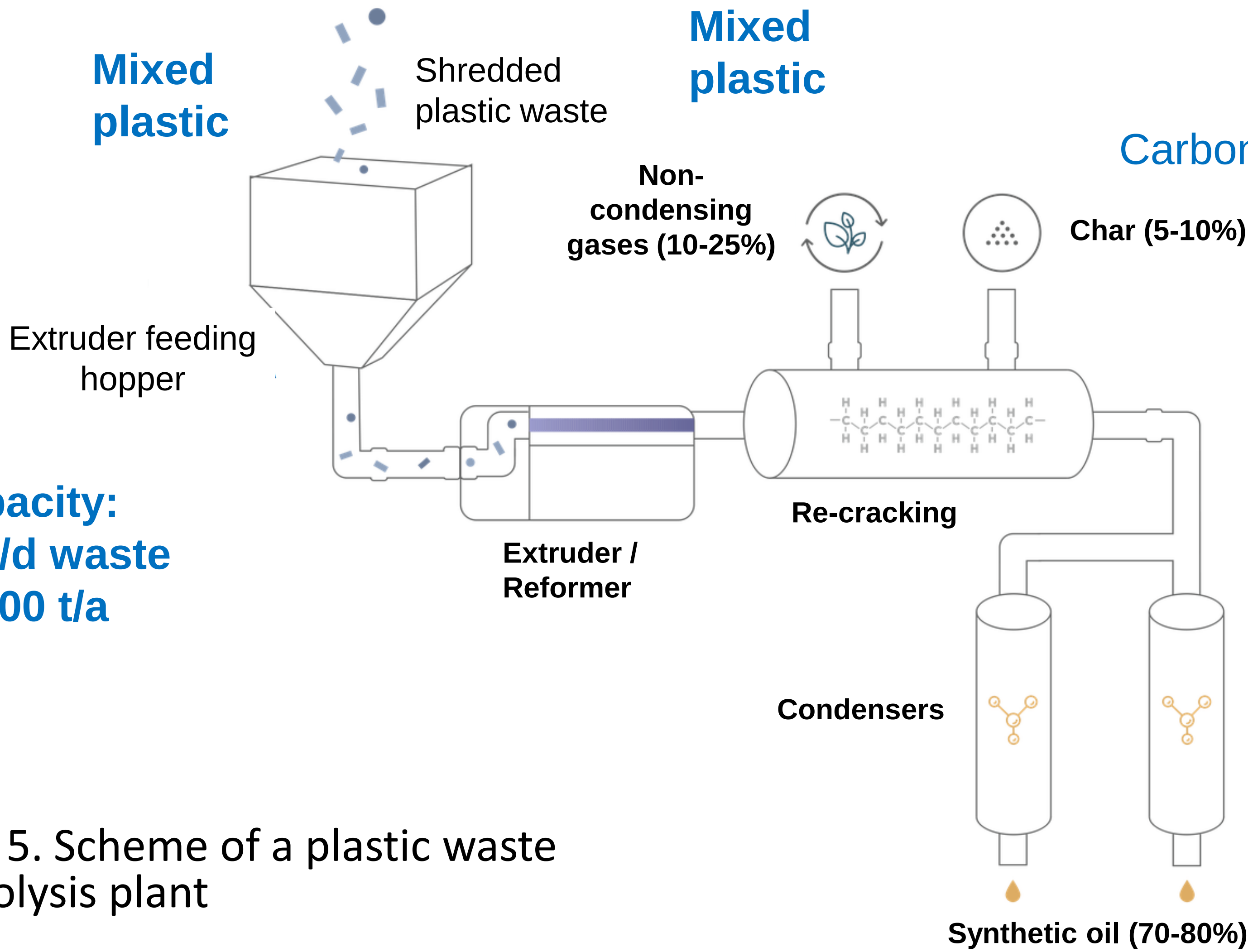
Source: PowerHouse Energy Group plc

Pyrolysis of plastic waste

Mixed plastic

Mixed plastic

Carbonized residue



Capacity:
24 t/d waste
~8000 t/a

~946 $l/t_{plastic\ waste}$

Fig. 5. Scheme of a plastic waste pyrolysis plant

Source: Renewlogy (ex PK Clean)

Naphtha (raw materials for the production of polymers, diesel fuel and other petrochemical products)

西安交通大學
XI'AN JIAOTONG UNIVERSITY

热流科学与工程教育部重点实验室
Key Lab of Thermo-Fluid Science & Engineering, MOE

Panel: The sustainability of plastic and its alternatives
In SDEWES 2019, October 1-6, 2019, Dubrovnik, Croatia

Technologies and challenges of converting waste plastics to fuels

Ting Ma

Key Lab of Thermo-Fluid Science and Engineering, MOE

School of Energy and Power Engineering

Xi'an Jiaotong University

Oct. 04, 2019

Contents

The 70th Anniversary of the Founding of The People's Republic of China

1.Waste plastics Status in China

1.1 Waste status in China

Hong Kong's beach

Lake Taihu in Soochow

A "Mountain" of waste in Hebei

The annual output of municipal solid waste in china is about 400 million tons, with the annual growth rate of about 8%!

Waste incineration flue gas

Air pollution: fog weather

Human healthy

1.2 Ecological and environmental protection in Chinese Dream (中国梦)

- **China highly values ecological and environmental protection. Guided by the conviction that lucid waters and lush mountains are invaluable assets, the country advocates harmonious coexistence between humans and nature, and sticks to the path of green and sustainable development (绿水青山就是金山银山).**

Waste classification education and guidance

1.Waste plastics Status in China

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1.3 Municipal solid waste in China

Organic garbage:63.39;
Plastic:12.70;Paper:11.07;
Glass:1.76;Metal:0.27;
Woodtimber:1.78;Ash:5.87;
Textile fiber:2.46;

Organic garbage:73.70;
Plastic:5.20;Paper:7.76;
Glass:2.40;Metal:0.30;
Woodtimber:1.70;Ash:-;
Textile fiber:0.90;

Organic garbage:66.70;
Plastic:19.98;Paper:4.46;
Glass:2.72;Metal:0.27;
Woodtimber:1.21;Ash:2.77;
Textile fiber:1.80;

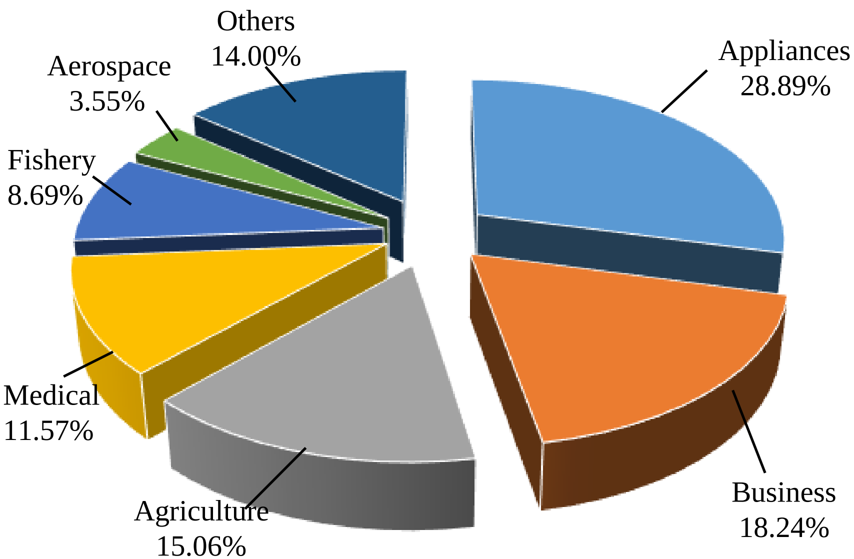
Organic garbage:44.00;
Plastic:18.00;Paper:26.00;
Glass:3.00;Metal:2.00;
Woodtimber:1.00;Ash:-;
Textile fiber:3.00;

Organic garbage:59.20;
Plastic:15.70;Paper:10.10;
Glass:3.40;Metal:1.10;
Woodtimber:4.20;Ash:-;
Textile fiber:6.10;

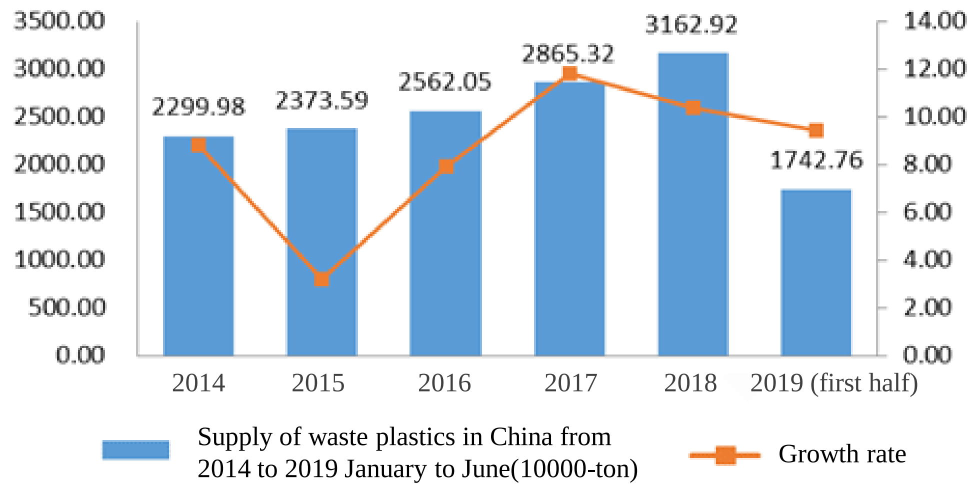
- **High organic and moisture content:** kitchen waste 60%
- **Low calorific values**: 3000-6700 kJ/kg, (developed countries: 8400-17000 kJ/kg)
- **Extremely non-homogenous**: climate, culture, living standards, dietary habits

1.Waste plastics Status in China

1.4 Source of waste plastics in China



Source structure of waste plastics in 2018



The amount of supply of waste plastics in China

- **The appliance industry, business domain and agriculture industry provide more than 60% of the total source of waste plastics.**
- **The amount of supply of waste plastics keeps a rapid increment (>10%), and it reached 31.63 million tons in 2018.**

1.Waste plastics Status in China

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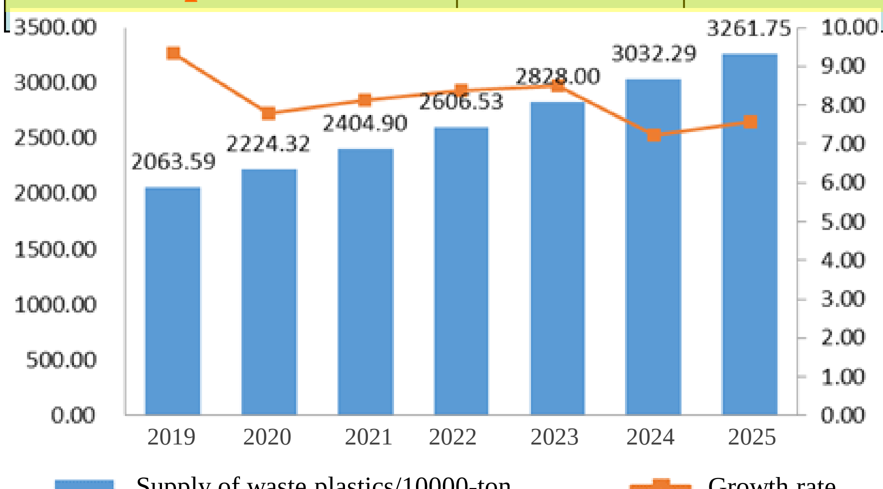
1.5 Commercial demand of waste plastics in China

Revenue of waste plastics in China market

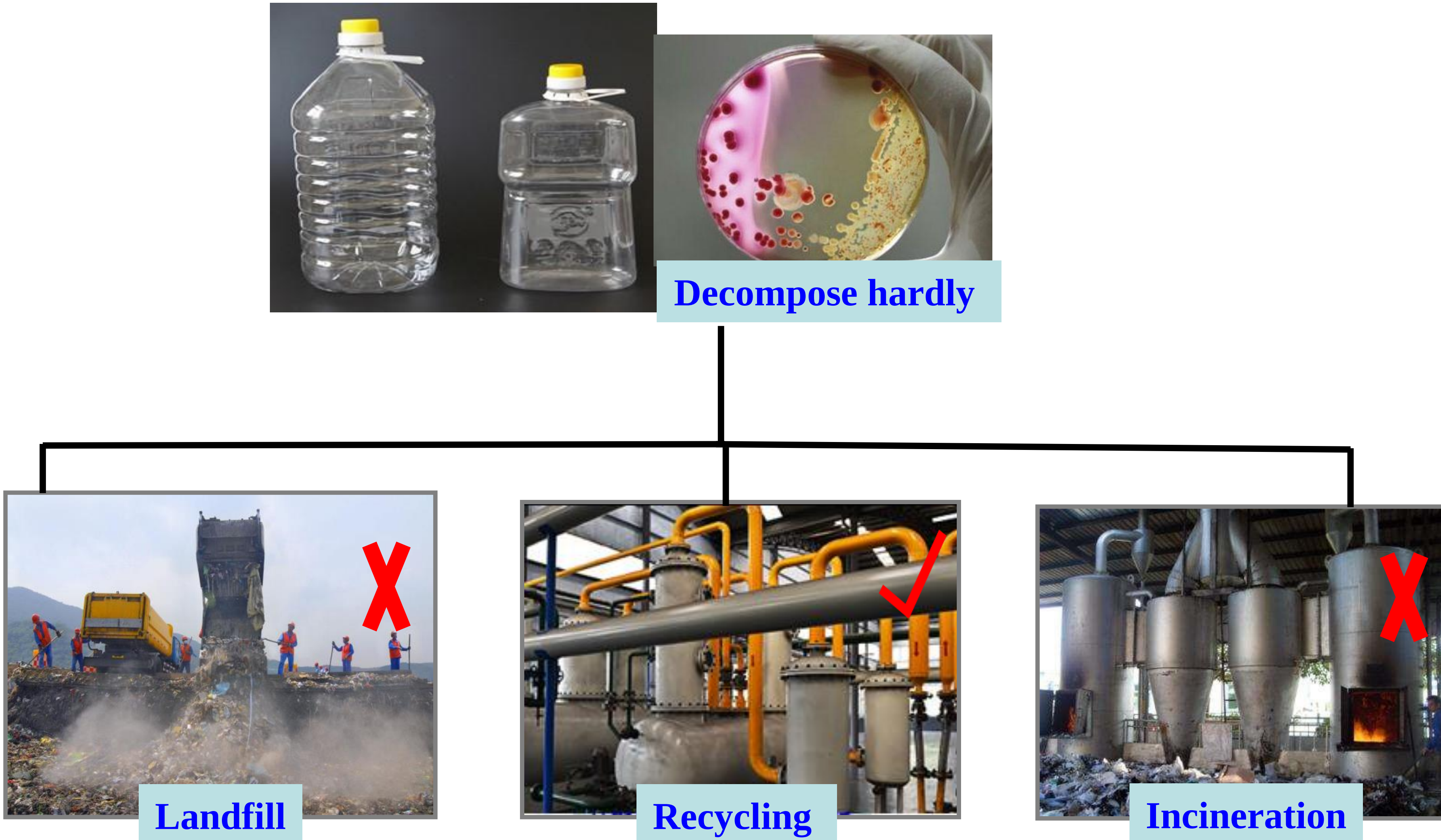
	2014	2015	2016	2017	2018	2019/First Half
Demand /10^4-ton	1350.63	1471.46	1588.29	1588.29	1887.61	1037.99
Growth rate/%	8.83	8.95	7.94	8.77	9.27	9.32
Investment/Billion RMB	24.57	25.65	27.96	31.56	37.39	20.72
Growth rate/%	9.59	4.40	9.01	12.89	18.48	10.41
Rate of profit/%	23.02	22.93	23.07	23.07	23.02	22.98



Estimated demand of waste plastics in China market from 2019 to 2025

- The **demand** and **investment** of waste plastics industry are increasing rapidly.
- The plastics industry has high **profit**, averagely more than **23%.**

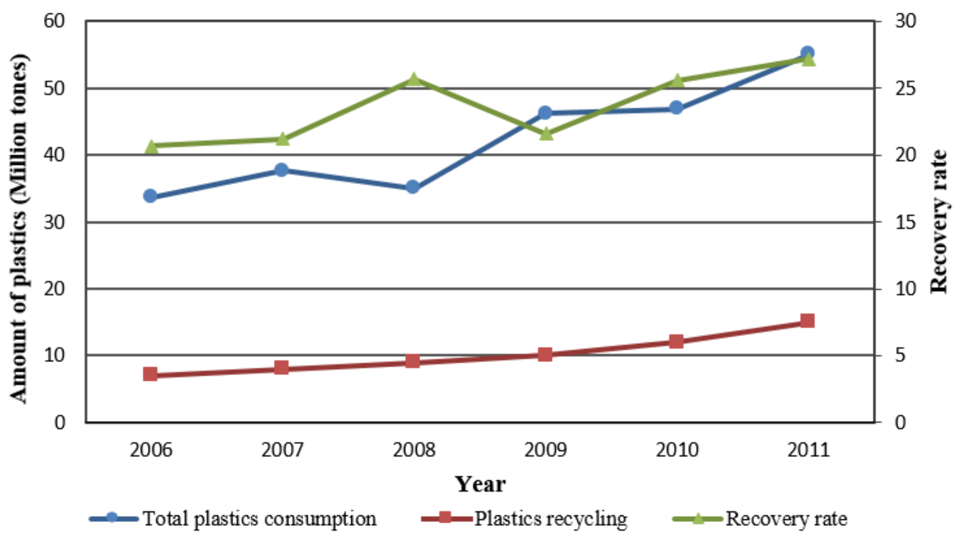
1.6 Waste plastics treatment methods in China



1.7 Waste plastics recycling status in China

Waste plastics consumption, recycling, and recovery rate in China

	Unit	2006	2007	2008	2009	2010	2011
Total plastics consumption	Million tons/year	33.7	37.7	35.0	46.2	46.9	55.1
Plastics recycling	Million tons/year	7	8	9	10	12	15
Recovery rate	%	20.7	21.2	25.7	21.6	25.6	27.2



Waste plastics consumption, recycling, and recovery rate from 2006 to 2011

◆ With the development of economy, ecological environment and sustainable development consciousness, waste plastics recycling has received more attention in china.

1.8 Technologies of waste plastics recycling

Incineration power generation

Recycled plastics particles

Plastics-to-fuel conversion

……

Thermal pyrolysis

Catalytic cracking

2.1 Mechanism of thermal pyrolysis

Thermal pyrolysis

$$C_xH_yO_z + Q \rightarrow Char + Liquid + Gas + H_2O$$

$$\mathbf{M^*_n \rightarrow M^*_{n-1} + M} \quad (1)$$

$$\mathbf{M^*_{n-1} \rightarrow M^*_{n-2} + M} \quad (2)$$

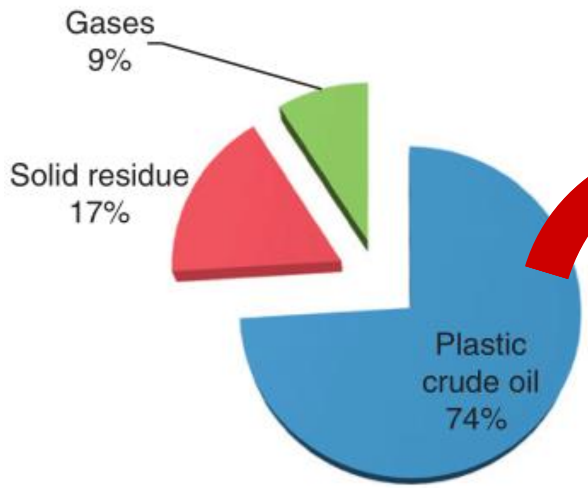
$$\mathbf{M^*_n \rightarrow M_x + M_y} \quad (3)$$

Various steps in random degradation of thermal pyrolysis (Baljit et al., 2008)

- **Thermal pyrolysis is a process of thermally degrading long chain polymer molecules into smaller, less complex molecules through heat and pressure.**
- **Thermal pyrolysis of the polymers follows either chain end degradation (Eqs. 1 and 2) or random degradation routes (Eq. 3)**

2. Thermal pyrolysis used for plastic waste

2.2 Thermal pyrolysis used for plastic waste



Products from thermal pyrolysis of plastic grocery bags (Sharma et al., 2014)

Plastic crude oil

Steel factory | **Boiling heating** | **Heavy oil generator** | **Cement factory**

Pyrolysis oil application

◆ **The thermal pyrolysis of waste plastic grocery bags at temperatures of 420-440°C provides 74% yield of plastic crude oil.**

2.3 Advantages and challenges of thermal pyrolysis used for plastic waste

Contrast of suppliers of wasteplastics oil technology (Predel et al., 2000)

Tech providers	Service area	Cracking process	Max design capability ($t \cdot d^{-1}$)	Oil production ($L \cdot t^{-1}$)
Agilyx	North America	Thermal pyrolysis	45	799~837
Cynar	Europe	Thermal pyrolysis	20	946
Nexus Fuels	USA	Thermal pyrolysis	45	833~1060
Klean Industries	Japan	Thermal pyrolysis	150	unknown
Polymer Energy	India	Catalytic pyrolysis	10	738
Plastics Advanced Recycling Co.	China	Catalytic pyrolysis	60	606

Thermal pyrolysis

Advantages:

① high amount of liquid oil.

② flexible

③ green technology

④ easy to handle

Disadvantages:

① broad product range

② high temperature

③ low octane value liquids

④ high residue contents

◆ **The thermal pyrolysis of waste plastic is simple and mature, but it needs high reaction temperature to get lighter hydrocarbons.**

2.4 Influence factors on thermal pyrolysis

Hydrocarbon products at different temperatures

Boiling point	Use
35 ~ 185°C	motor gasoline
185 ~ 290°C	diesel #1
290 ~ 350°C	diesel #2
350 ~ 538°C	vacuum gas oil
>538°C	residue

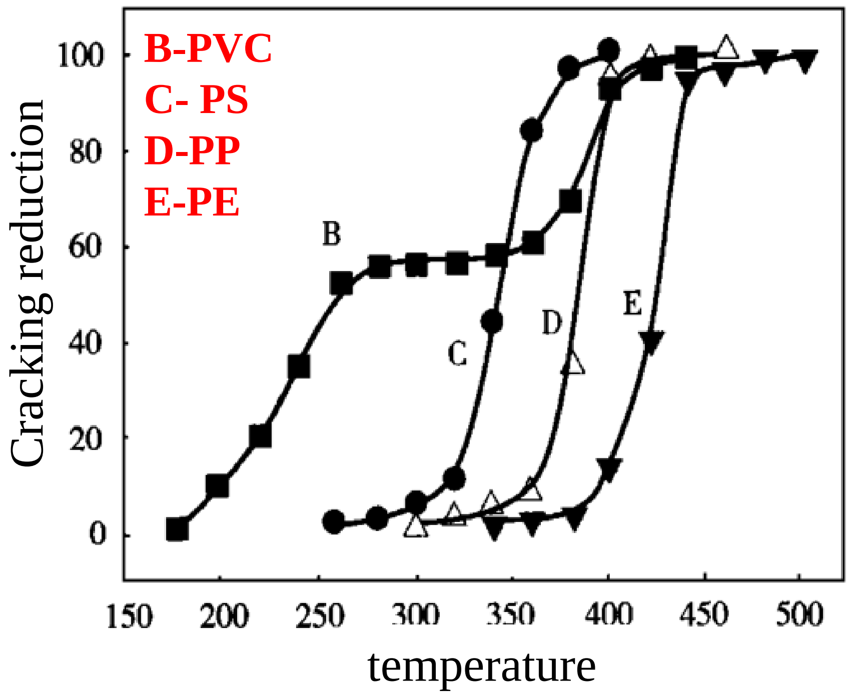



Mass balance of crude oil, residue and gas yields on pyrolysis of PE, PP (Bidhya et al., 2016)

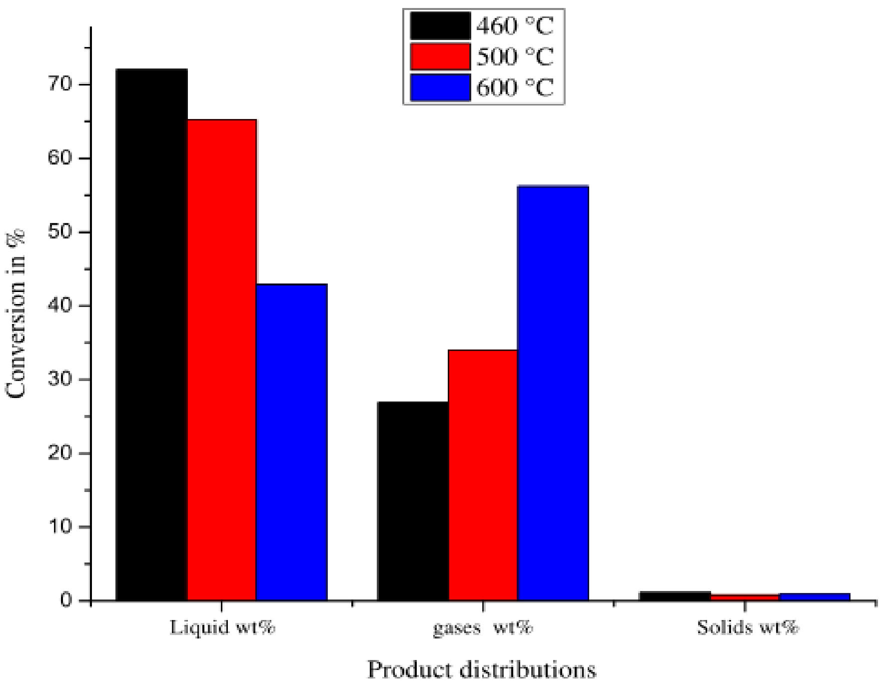
Researchers	Plastics type	Reactor type	Temperature (°C)	Crude oil (wt %)	Residue (wt %)	Gas (wt %)
William et al.	PE	Parr mini bench top	500	93	0.0	7.0
Sarker et al.	MIXED	Proprietary (Natural State Research Inc)	370–420	90	5.0	5.0
Alston et al.	MIXED	-	800	73	23.5	30.4
Sharma et al.	HDPE	2 L batch reactor	440	74	17.0	9
Buekens et al.	PP	-	740	48.8	1.6	49.6
Sarker et al.	PETE-1	Distillation unit	405	14.25 (21.7 H_2O)	51.5	12.4

◆ **The components and yields of products are determined by thermal treatment temperature, plastics type, residence time, and reactor type.**

2.4 Influence factors on thermal pyrolysis---temperature



Temperature characteristics of thermal pyrolysis of various plastics (Li et al., 2001)



Effect of temperature on conversion process (López et al., 2011)

- **Temperature controls the pyrolysis reaction, so that it is one of the most important factors affecting the quality and quantity of pyrolysis products.**
- **The major drawback is the very broad product range and requirement of high temperature.**

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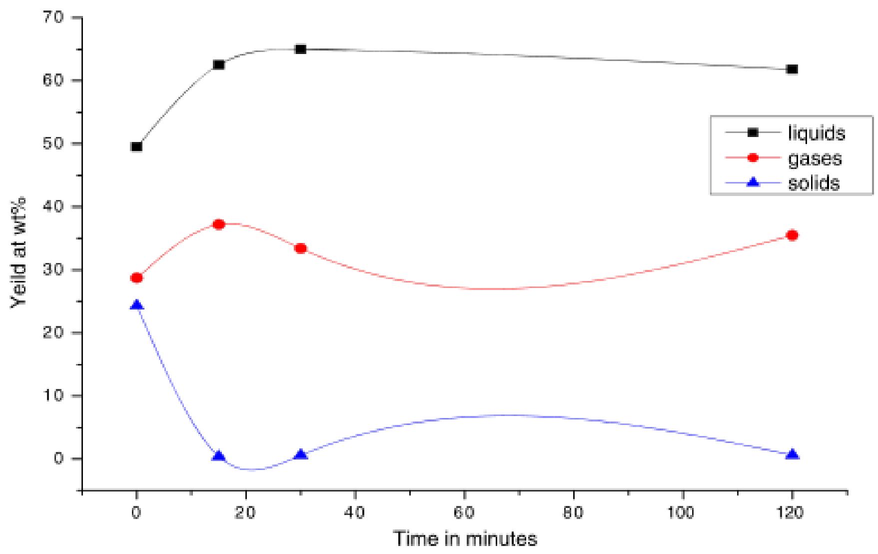
2.4 Influence factors on thermal pyrolysis---plastics type

Proximate analysis of plastics

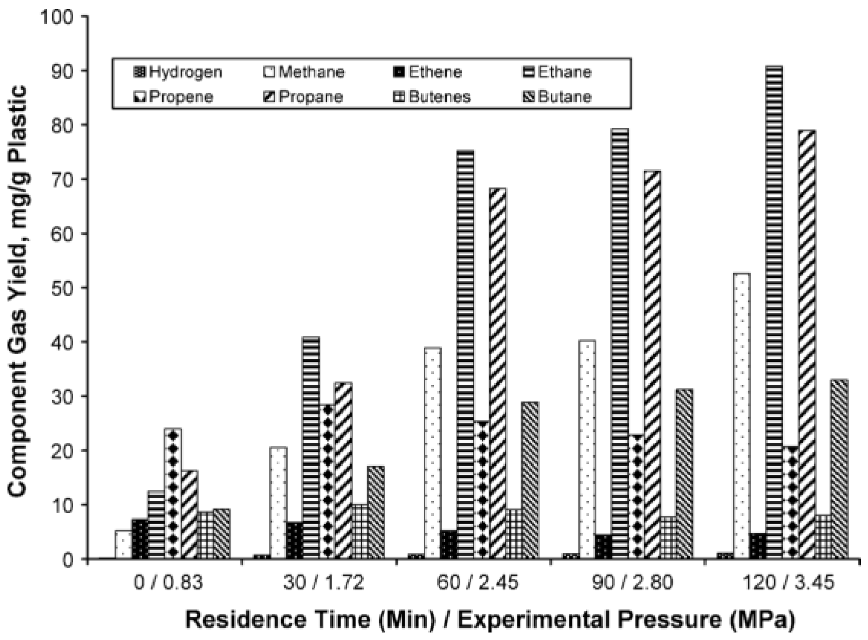
Raw materials	Reaction temperature	Yields in wt.%			Refs.
		Liquids	Gases	Residue	
HDPE (high-density polyethylene):WLO (waste lubricant oil)=(1:1)	460°C	100	-	-	Wang et al.
LDPE (low-density polyethylene):WLO (waste lubricant oil)=(1:1)	460°C	99	-	-	Wang et al.
PP (polypropylene)	420-440°C	96.7	2.2	1.1	Walendziewski et al.
PS (polystyrene)	420-440°C	95.7	0.6	3.7	Walendziewskiet al.
PE (polyethylene)	450°C	81.6	12.1	6.3	Beltramini et al.
ABS (acryloni-trile butadiene styrene)	478°C	79	3	6	Jung et al.

◆ **Thermal pyrolysis produces large amount of liquid oils for different plastics types.**

2.4 Influence factors on thermal pyrolysis---residence time



Effect of reaction time on process
(López et al., 2011)



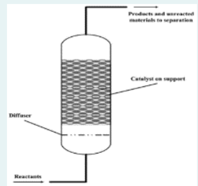
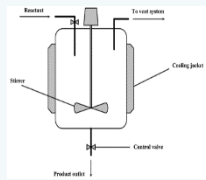
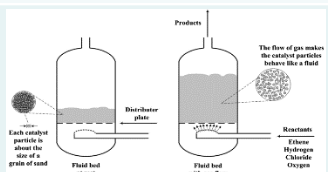
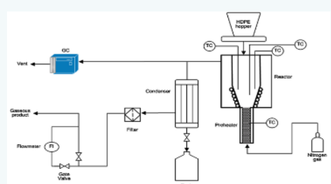
Composition of LDPE pyrolysis gaseous product in relation to residence time
(Jude et al., 2009)

- **Residence time is a temperature-dependent factor that has influence on product components, especially at low temperature.**

2. Thermal pyrolysis used for plastic waste

2.4 Influence factors on thermal pyrolysis---reactor type

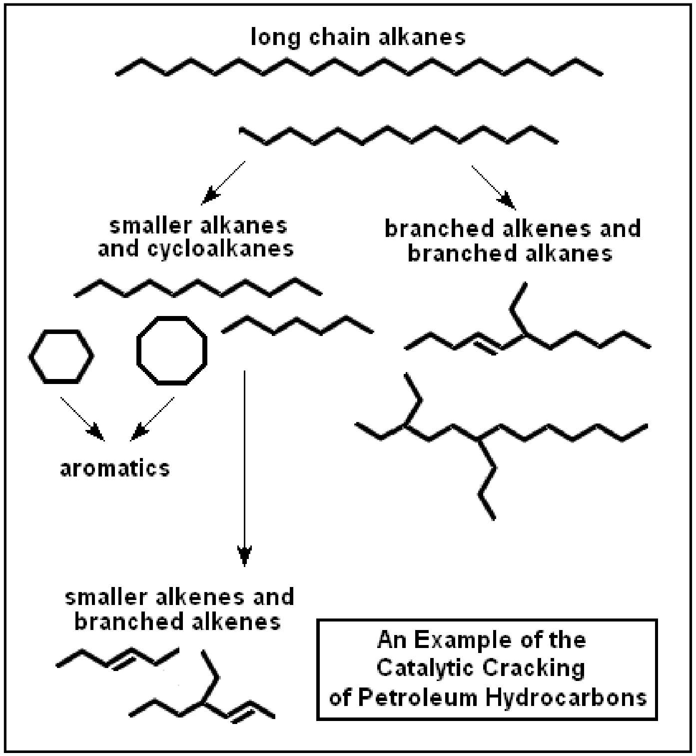
Different reactor types (Shafferina et al., 2016)

Type of reactors	Characteristic
Batch reactor 	• closed system • high conversion • high labor costs
Fixed-bed reactor 	• easy to design • available surface area
Fluidized bed reactor 	• larger surface area • flexible
Conical spouted bed reactor 	• large particle size distribution • larger particles and difference in particle densities

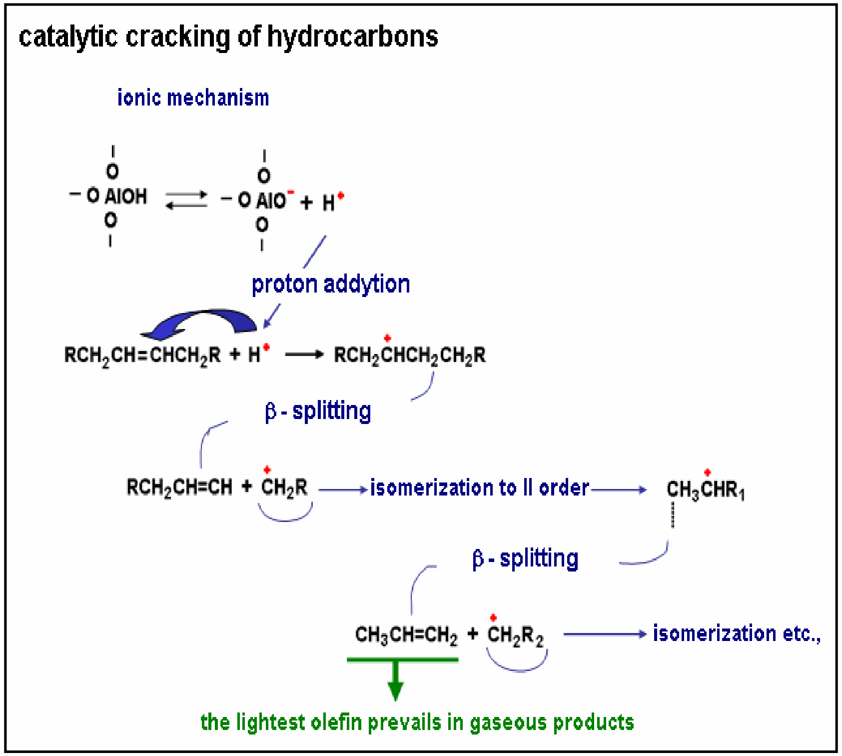
➢ **The reactor type has an important impact in the mixing of the plastics, residence time, heat transfer and efficiency of the reaction towards achieving the final desired product.**

3. Catalytic cracking used for plastic waste

3.1 Mechanism of catalytic cracking



Example of catalytic cracking of petroleum hydrocarbons



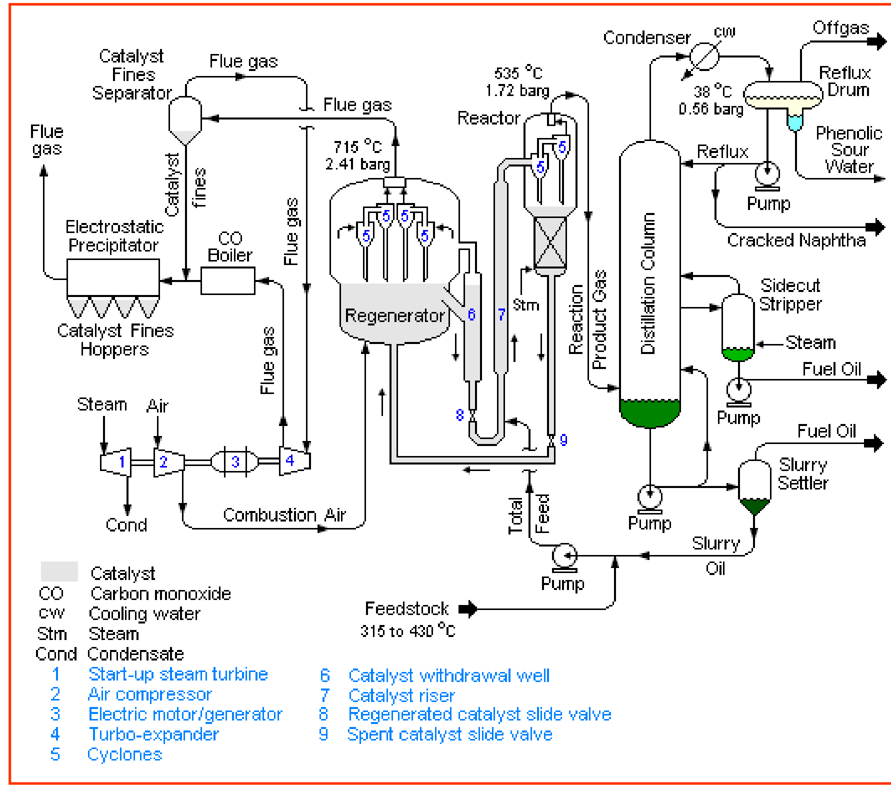
Catalytic cracking of hydrocarbons

◆ **Catalytic cracking is an ionic process involving carbonium ions and are produced by: addition of a proton from an acid catalyst to an olefin and abstraction of a hydride ion from a hydrocarbon by the acid catalyst or by another carbonium ion.**

3. Catalytic cracking used for plastic waste

3.2 Application of catalytic cracking

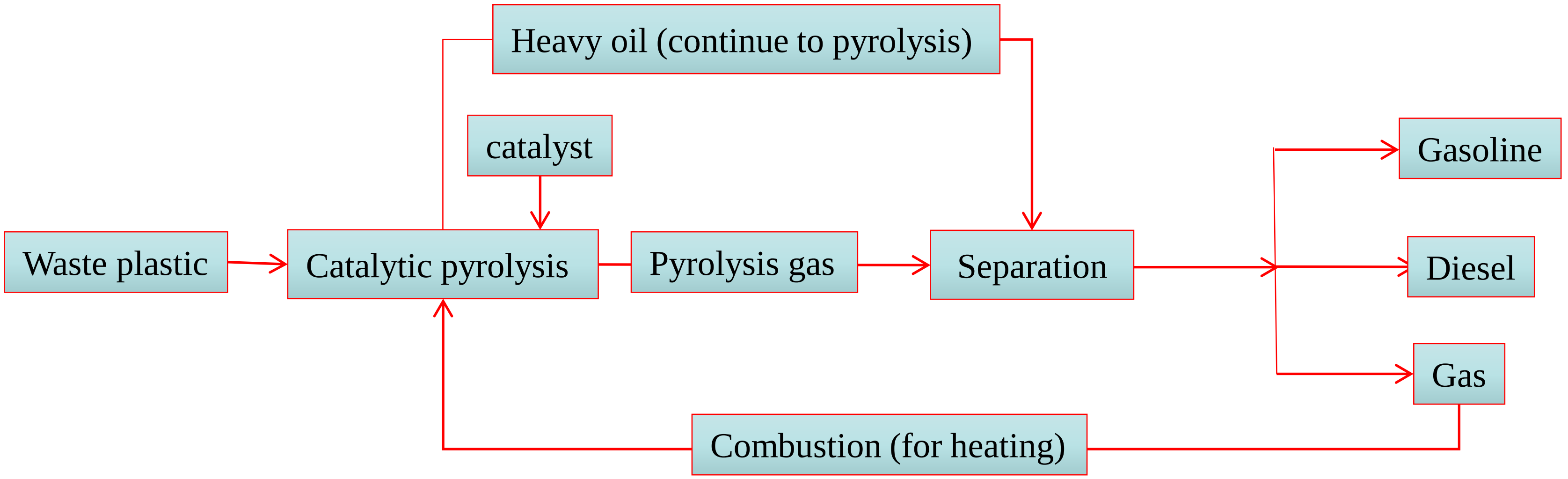
A typical fluid catalytic cracking unit in a petroleum refinery



A schematic flow diagram of a fluid Catalytic Cracking unit used for petroleum refineries

◆ **Fluid catalytic cracking** is one of the most important conversion processes used for petroleum refinery. It is widely used to convert the high-boiling, high-molecular weight hydrocarbon fractions of petroleum crude oils into more valuable gasoline, olefinic gases, and other products.

3.3 Catalytic cracking used for plastic waste

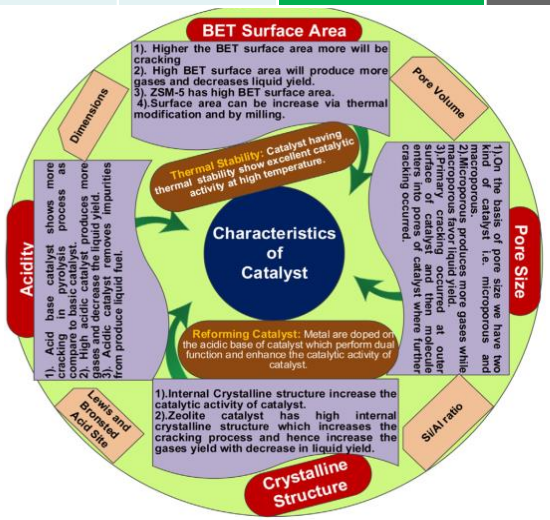


Process of catalytic cracking

- **Waste plastics was originally recycled by thermal pyrolysis, but catalytic cracking shows greater potential because it produces more gasoline with a higher octane rating, produces byproduct gases that have more carbon-carbon double bonds, and hence more economic value than those produced by thermal pyrolysis.**

3.4 Effect of catalyst type on catalytic cracking of plastic waste

Characteristics of catalyst								
Catalyst type	SiO_2/Al_2O_3(w/w)	BET surface area (m^2/g)	Particle Size(μm)	Pore Size (nm)	Micropore Volume(cm^3/g)	Micropore area (cm^3/g)	Pore Volume (cm^3/g)	Reference
HZSM - 5	30	400	NR	NR	NR	NR	NR	Lee (2012)
ZSM - 5		412	NR	NR	0.1	346.1	0.4	Lopez et al.(2011)
ZSM - 5		412	NR	NR	0.1	346.1	0.397	Lopez et al.(2012)
ZSM - 5		412	10 – 30	NR	0.1	346.1	0.397	Lopez et al.(2011c)
Red Mud		27.49	NR	NR	0.009	171	0.184	Lopez et al.(2011c)



Flow chart showing the characteristics of catalysts (Achilias et al., 2007)

- **Catalytic cracking on acid catalysts takes place with the formation of carbocations that require strong acid sites.**
- **Acid strength and textural properties such as BET surface area, acidity, pore size, pore volume, thermal stability, and dimensions are the main characteristics of acid catalysts.**

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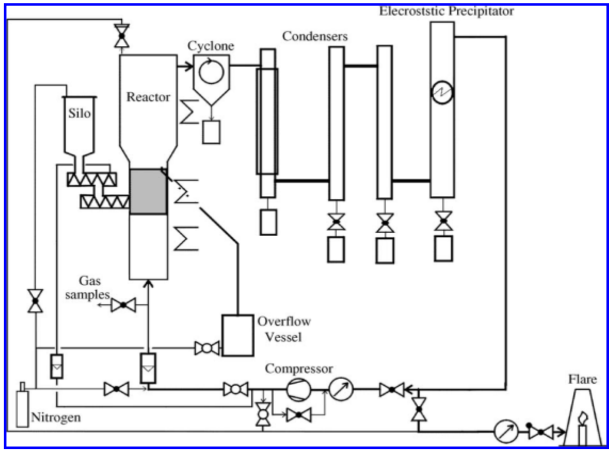
3.4 Effect of catalyst type on catalytic cracking of plastic waste

Effect of catalyst on pyrolysis process

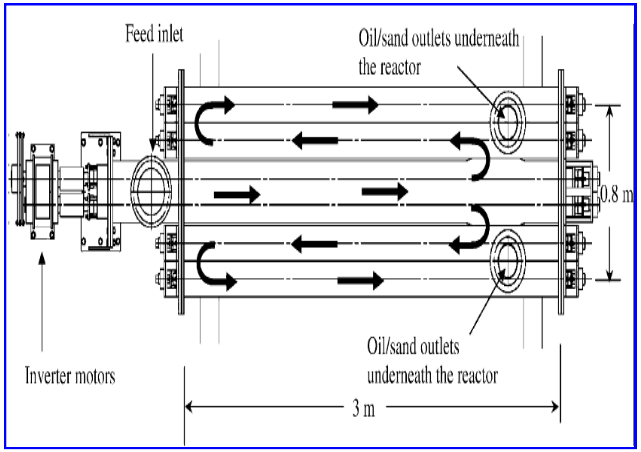
Catalyst type	Quantity of catalyst	Feedstock used	Product yields			
			Liquid	Gases	Char	
FCC	50%	LDPE,HDPE,PP	72.1, 44.2, 64.7	19.4, 52.5, 20.0	8.5, 3.3, 15.3	Achilias et al.(2007)
ZSM-5	5%	HDPE,PP	NR	NR	NR	Miskolczi et al.(2009)
HZSM-5	20%	HDPE	NR	NR	NR	Hemandez et al.(2007)
Natural Zeolite (Ni/Z, NiMo/Z, Co/Z, CoMo/Z)	5%	LDPE	23.88, 12.20, 23.92, 14.91	75.18, 86.30, 76.00, 83.71	0.94, 1.51, 0.92, 1.39	Sriningsih et al.(2014)

◆ **Catalysts have different effects on the pyrolysis process and products.**

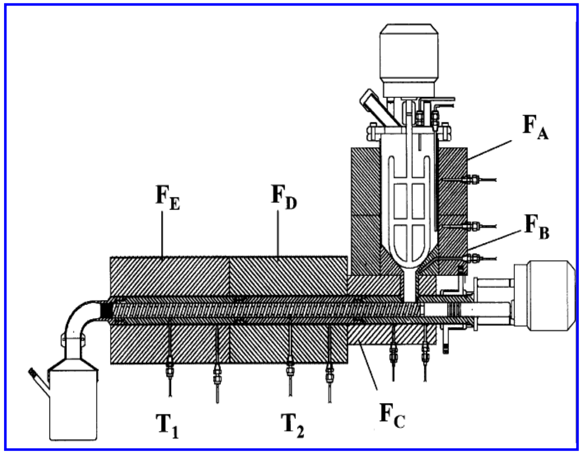
3.5 Effect of reactor type on catalytic cracking of plastic waste



Fluidized bed pyrolysis plant



Moving-bed reactor



Screw kiln reactor

- **Waste plastics have high viscosity and low thermal conductivity, which have a great impact on heat and mass transfer. So a suitable reactor is very important.**

- **The process heat is introduced indirectly into the bed through radiant-heat tubes, in which the pyrolysis gas is incinerated. The exhaust gases are used to preheat the fluidizing gas by means of heat exchange.**

4. Summary

- There are huge needs and markets of waste plastics recycling in China. The waste classification and related environmental policies bring great opportunity for the waste plastics recycling.

- Thermal pyrolysis is a simple and mature technology for the waste plastics recycling. But it needs high temperature and produces more liquid fuels. The thermal treatment temperature, plastics type, residence time and reactor type have significant effect on the thermal pyrolysis.

- Catalytic cracking shows greater potential because it needs lower operating temperature and produces more gas fuels. The catalyst and reactor types have great effect on the catalytic cracking. It is necessary to develop cheap and reused catalysts.

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◆Data sources in section 1 are taken from: Research report on the market survey and development trend of waste plastics in China from 2019 to 2025, Guangzhou Henglue Consulting Co. LTD.

Thank you for your attention!

Welcome comments!

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