The Sustainability of Plastic and its Alternatives

Moderators
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Panel Speakers

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University of Zagreb
FAMENA, Zagreb, Croatia

Prof. Aoife Foley
Queen’s University
Belfast, Belfast, United Kingdom

Prof. Daniel Rolph Schneider
University of Zagreb, Zagreb, Croatia

Dr. Ting Ma
Xi’an Jiaotong University, Xi’an, China
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

Media

Harm to Wildlife - Ingestion, Entanglement

Plastic Export Ban, Circular Economy


Plastic Waste Generation Per Person

Daily plastic waste generation per person, measured in kilograms per person per day. This measures the overall per capita plastic waste generation rate prior to waste management, recycling or incineration. It does not therefore directly indicate the risk of pollution to waterways or marine environments.

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

Teabag

Bottle

Biodegradable plastic

Bioplastic

Degradable? Depend on the environment

Photo Credit: National Oceanic and Atmospheric Administration

<ourworldindata.org/faq-on-plastics#what-are-microplastics>
<www.nationalgeographic.org/encyclopedia/microplastics/>
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’


<ourworldindata.org/plastic-pollution>
How to Drink?

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.

Could McDonald's paper straws be better than plastic ones?

No Straw

maximum of a 0.03 % reduction

<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
## The Impacts of Different Materials

<table>
<thead>
<tr>
<th>Bag type</th>
<th>Number of reuses required for life cycle equivalence with an HDPE bag</th>
<th>Consumption</th>
<th>Litter marine impacts</th>
<th>GHG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Energy</td>
<td>Water</td>
<td>Material</td>
</tr>
<tr>
<td>HDPE</td>
<td>-</td>
<td>♦♦♦♦♦</td>
<td>♦♦♦♦♦♦</td>
<td>♦♦♦♦♦♦♦♦</td>
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<tr>
<td>Paper</td>
<td>3</td>
<td>♦♦♦♦♦♦♦♦♦♦</td>
<td>♦♦♦♦♦♦</td>
<td>♦♦♦♦♦♦♦♦</td>
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<tr>
<td>LDPE</td>
<td>4</td>
<td>♦♦♦♦</td>
<td>♦♦♦♦♦♦</td>
<td>♦♦♦♦♦♦♦♦</td>
</tr>
<tr>
<td>Non-woven polypropylene</td>
<td>11</td>
<td>♦♦♦♦♦♦♦♦♦♦</td>
<td>♦♦♦♦♦♦</td>
<td>♦♦♦♦♦♦♦♦</td>
</tr>
</tbody>
</table>

### 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
The Accounting and Challenges
Leakage? Marine Litter?

EU Statistic
39% Incinerated, 31% Landfilled, 20% Recycled = 100%

US Statistic
2015
- Landfilled: 26.0 (75.4%)
- Recycled - Domestic: 0.88 (2.5%)
- Recycled - Export: 2.26 (6.6%)
- Combusted with Energy Recovery: 5.35 (15.5%)

2018
- Landfilled: 32.5 (81.4%)
- Recycled - Domestic: 0.88 (2.2%)
- Recycled - Export: 1.19 (3.0%)
- Combusted with Energy Recovery: 5.35 (13.4%)

Recycled = 9.1%
Recycled = 5.2%

Exported/ Separated Recyclable = 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

### Existing and Under Development Plastic Footprint Methodologies & Tools

<table>
<thead>
<tr>
<th>Name of Methodology</th>
<th>Link</th>
<th>Include microplastics</th>
<th>Date of release</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic Scan</td>
<td><a href="http://oceanimpact-quickscan.azurewebsites.net">http://oceanimpact-quickscan.azurewebsites.net</a></td>
<td>NO</td>
<td>2017</td>
</tr>
<tr>
<td>Marine Plastic Footprint</td>
<td>n.a.</td>
<td>YES</td>
<td>n.a. 2019</td>
</tr>
<tr>
<td>Circularity Indicators Methodology</td>
<td><a href="https://www.essemacarthurfoundation.org/programmes/insight/circularity-indicators">https://www.essemacarthurfoundation.org/programmes/insight/circularity-indicators</a></td>
<td>NO</td>
<td>2015</td>
</tr>
<tr>
<td>Marine Impacts in LCA</td>
<td>n.a.</td>
<td>YES</td>
<td>n.a.</td>
</tr>
<tr>
<td>PlastikBudget</td>
<td>n.a.</td>
<td>YES</td>
<td>n.a. 2020</td>
</tr>
<tr>
<td>Plastic Pollution Calculator</td>
<td>n.a.</td>
<td>NO</td>
<td>n.a. 2010</td>
</tr>
<tr>
<td>PET Collection, Landfill and Environment Leakage Rates in South East Asia</td>
<td><a href="https://www.gacircular.com/publications/">https://www.gacircular.com/publications/</a></td>
<td>NO</td>
<td>n.a. 2019</td>
</tr>
<tr>
<td>P2Pro SEA</td>
<td>n.a.</td>
<td>NO</td>
<td>2010</td>
</tr>
<tr>
<td>National Guidance For Marine Plastic Hotspotting and Shaping Action</td>
<td>n.a.</td>
<td>YES</td>
<td>n.a. 2019</td>
</tr>
<tr>
<td>A Global Roadmap to Achieve Near-zero Ocean Plastic Leakage</td>
<td>n.a.</td>
<td>YES</td>
<td>n.a. 2019</td>
</tr>
<tr>
<td>Plastic Footprinter</td>
<td><a href="http://www.plasticfootprint.ch">http://www.plasticfootprint.ch</a></td>
<td>NO</td>
<td>2014</td>
</tr>
<tr>
<td>My Little Plastic Footprint</td>
<td><a href="http://mylittleplasticfootprint.org">http://mylittleplasticfootprint.org</a></td>
<td>YES</td>
<td>2017</td>
</tr>
<tr>
<td>Plastic Calculator</td>
<td><a href="http://secure.greenpeace.org.uk/page/content">http://secure.greenpeace.org.uk/page/content</a></td>
<td>NO</td>
<td>2016</td>
</tr>
</tbody>
</table>

**Scope of the assessment**
- Plastic use & waste generation
- Circularity
- Plastic leakage
- Environmental impacts (from plastic leakage)

**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
- Calculation rules transparent and available
- Data collection guidance available
- Dataset available
- Case studies available (related to plastic leakage)

**Description of the guidance**

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IUCN Review of Plastic Footprint Methodologies


Not included in all methodologies

X comparison
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

<table>
<thead>
<tr>
<th>ASTM D5033 definitions</th>
<th>Equivalent ISO 15270 (draft) definitions</th>
<th>Other equivalent terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary recycling</td>
<td>Mechanical recycling</td>
<td>Closed-loop recycling</td>
</tr>
<tr>
<td>Secondary recycling</td>
<td>Mechanical recycling</td>
<td>Downgrading</td>
</tr>
<tr>
<td>Tertiary recycling</td>
<td>Chemical recycling</td>
<td>Feedstock recycling</td>
</tr>
<tr>
<td>Quaternary recycling</td>
<td>Energy recovery</td>
<td>Valorization</td>
</tr>
</tbody>
</table>

- Redesign + Recycling

Mixed Plastic Pigments Additives Contaminants

Challenges

JUST BECAUSE YOU'RE TRASH DOESN'T MEAN YOU CAN'T DO GREAT THINGS.
IT IS CALLED GARBAGE CAN, NOT GARBAGE CANNOT.
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
PLASTIC IS MADE OF OIL

OIL IS MADE OF DINOSAURS
PLASTIC DINOSAURS ARE MADE FROM REAL DINOSAURS

Dead Dinosaur Advice
Plastic: Wasted or recovered?

Share of plastic packaging waste that is
- Not recovered (e.g. ends up in landfills)
- Recycled (e.g. materials reused)
- Otherwise recovered (e.g. incinerated for energy)

Source: Eurostat (env_waspac), latest available data for each country (2015 or 2016) © DW
Plastic packaging is made from seven different types and some are recycled more often than others.

1. **PET**
2. **HDPE**
3. **PVC**
4. **LDPE**
5. **PP**
6. **PS**
7. **OTHER**
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.

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.

Ireland is the EU's top producer of plastic waste

Plastic waste per inhabitant in 2015 (kg)

Europe's top five plastic waste offenders (per inhabitant)

- Ireland: 61kg
- Luxembourg: 52kg
- Estonia: 46kg
- Germany: 37kg
- Portugal: 36kg

Kg of plastic waste per inhabitant

- >60
- 30-39
- 20-29
- 10-19

* Values from Denmark, Cyprus, Malta and Romania are from 2014
Source: Eurostat

Source: Statista
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**
Number of years it took each product to gain 50 million users

@theilluminatinigga

- Airlines: 68yrs
- Cars: 62yrs
- Telephones: 50yrs
- Electricity: 46yrs
- Credit Cards: 28yrs
- TV: 22yrs
- ATMs: 18yrs
- Computers: 14yrs
- Mobiles: 12yrs
- Internet: 7yrs
- iPods: 4yrs
- YouTube: 4yrs
- Facebook: 3yrs
- Twitter: 2yrs
- Porn hub: 19 days

Society = our choice = our voice = our problem
Plastics in environment – do we look for a solution?

Slaven Dobrović
Plastics – unavoidable material of today's 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.
Intentionally added microplastics, designed to be emitted during the lifecycle.
<table>
<thead>
<tr>
<th>Sector</th>
<th>Product</th>
<th>Total tonnes of microplastics used by the sector in the EU (estimated based on consumption and literature)</th>
<th>Total tonnes of products containing microplastics sold by the sector in the EU</th>
<th>Concentration of microplastics in products that contain microplastics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal care</td>
<td>Rinse-off products containing exfoliants and cleansing/scrubbing beads (as indicated by Cosmetics Europe) Further product breakdown available (see Appendix III)</td>
<td>714,753 tonnes (excluding and cleansing/scrubbing beads in rinse-off products)</td>
<td>Unknown. It is estimated based on Eurostat data that the total European market for personal care products containing microplastics consumes around 3.5 million tonnes in the EU28.</td>
<td>Unknown.</td>
</tr>
<tr>
<td></td>
<td>Leaf on FCPs containing microplastics (as indicated by Cosmetics Europe) in action to estimates from Eurostat 2016</td>
<td>564 ± 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)</td>
<td>1.5 million according to Eurostat (2016)</td>
<td>Weighted average calculated from Eurostat (2016): 2.4% Range 0.005%-7% according to Eurostat (2016)</td>
</tr>
<tr>
<td>Paints/coatings</td>
<td>Waterborne building paints (as indicated by CEIPE)</td>
<td>229 tonnes (Solid non-biodegradable polymeric particles with physical dimensions between 5 - 0.1 mm originating from anthropogenic sources)</td>
<td>14,000 tonnes</td>
<td>Weighted average 1.6% w/w. Range approximately 1%-2%.</td>
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<td></td>
<td>Other sources suggest it could be significantly higher, but estimates are very uncertain.</td>
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<tr>
<td></td>
<td>Extrapolated from Danish Environmental Protection Agency (2015) (200-300 tonnes of microplastics in building paint sold in Denmark) suggests 22,000-38,000 tonnes.</td>
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<tr>
<td>All other</td>
<td>Waterborne building paints (as indicated by CEIPE)</td>
<td>193-222 tonnes (water insoluble solid polymeric particles with a size less than 5mm that can be found as marine litter) suggested by ANME is not contradicted by literature.</td>
<td>3,572 tonnes</td>
<td>Weighted average (all Soaps, Detergents and Maintenance Products) 4.5% Range of weighted averages per product category: 2.7%-4.3%</td>
</tr>
<tr>
<td>Detergents</td>
<td>Soaps, Detergents and Maintenance Products Further product breakdown available (see Appendix III)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Sandblasting</td>
<td>Extrapolation from Danish Environmental Protection Agency (2016) (2.05-2.53 tonnes) suggests 1,000-5,000 tonnes (plastics); solid particulates composed of synthetic or semi-synthetic polymers and physical dimensions of 1 mm or less.</td>
<td></td>
<td>Unknown.</td>
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<tr>
<td>Abrasives</td>
<td>Sandblasting</td>
<td>Extrapolation from Danish Environmental Protection Agency (2016) (2.05-2.53 tonnes) suggests 1,000-5,000 tonnes (plastics); solid particulates composed of synthetic or semi-synthetic polymers and physical dimensions of 1 mm or less.</td>
<td></td>
<td>Unknown.</td>
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<tr>
<td>Agricultural</td>
<td>Nutrient prd slow-and controlled-release fertilisers</td>
<td>Up to a maximum of 800,000 tonnes (Trelstad 2015) suggests 1,700-0 000 tonnes of polyethylene in Western Europe. No further information is available to estimate what share of these polymers constitute microplastics in the EU.</td>
<td>Up to 40,000 tonnes according to Trelstad (2015) refers to products containing polymers in ‘Western Europe’.</td>
<td>Polymer coated fertilizers; up to 3-35% Sulphur-coated urea (SCU) Polymer coated sulphur-coated urea (PSCU) up to 2% According to Trelstad (2015), refers to polymers (an uncertain share of which constitute microplastics)</td>
</tr>
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</tr>
<tr>
<td>Oil and gas</td>
<td>Offshore drilling and production</td>
<td>No precise quantitative estimate possible. But could be substantial in the magnitude of hundreds of tonnes.</td>
<td></td>
<td>Unknown.</td>
</tr>
<tr>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Pharmaceutical</td>
<td>No quantitative estimate possible. But the industry claims no significant amounts of microplastics are used in the EU currently.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Risk assessment

<table>
<thead>
<tr>
<th>Effects</th>
<th>Organisms in the environment</th>
<th>Humans exposed via the environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Toxic</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>
SOLUTION?

A EUROPEAN STRATEGY
FOR PLASTICS
IN A CIRCULAR ECONOMY
OUR STRATEGY FOCUSES ON 4 AREAS:

- Improve the economics and quality of plastics recycling
- Curb plastic waste and littering
- Drive investments and innovation towards circular solutions
- Harness global action
PLASTIC WASTE FACTS
FROM AROUND THE GLOBE

FACT 1
90%
Just ten rivers transport more than 90% of river-based plastics to the ocean.

FACT 2
80%
80% of ocean plastic comes from land-based sources.

FACT 3
China
Indonesia
Philippines
Thailand
Vietnam
Over half of land-based plastic waste leakage comes from just 5 countries.

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.
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):
(Co-)Pyrolysis

NRP (co-)pyrolysis main drawbacks:
- High external energy demand, high capital cost, and inconsistent product quality,
- Difficult to establish one single route for all types of NRP, 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 CO2 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.
IST: Biomass pyrolysis
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
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, intelligent 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”

   (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

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

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)
Technologies and challenges of converting waste plastics to fuels

Ting Ma

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School of Energy and Power Engineering
Xi’an Jiaotong University

Oct. 04, 2019
Contents

1. Waste plastics status in China
2. Thermal pyrolysis used for plastic waste
3. Catalytic cracking used for plastic waste
4. Summary
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

The annual output of municipal solid waste in China is about 400 million tons, with the annual growth rate of about 8%!
1. Waste plastics Status in China

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

1.3 Municipal solid waste in China

- **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

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: 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;
1. Waste plastics Status in China

1.4 Source of waste plastics in China

**Source structure of waste plastics in 2018**

- **Appliances**: 28.89%
- **Business**: 18.24%
- **Agriculture**: 15.06%
- **Medical**: 11.57%
- **Fishery**: 8.69%
- **Aerospace**: 3.55%
- **Others**: 14.00%

**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

1.5 Commercial demand of waste plastics in China

Revenue of waste plastics in China market

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Demand /10^4-ton</strong></td>
<td>1350.63</td>
<td>1471.46</td>
<td>1588.29</td>
<td>1588.29</td>
<td>1887.61</td>
<td>1037.99</td>
</tr>
<tr>
<td><strong>Growth rate/%</strong></td>
<td>8.83</td>
<td>8.95</td>
<td>7.94</td>
<td>8.77</td>
<td>9.27</td>
<td>9.32</td>
</tr>
<tr>
<td><strong>Investment/Billion RMB</strong></td>
<td>24.57</td>
<td>25.65</td>
<td>27.96</td>
<td>31.56</td>
<td>37.39</td>
<td>20.72</td>
</tr>
<tr>
<td><strong>Growth rate/%</strong></td>
<td>9.59</td>
<td>4.40</td>
<td>9.01</td>
<td>12.89</td>
<td>18.48</td>
<td>10.41</td>
</tr>
<tr>
<td><strong>Rate of profit/%</strong></td>
<td>23.02</td>
<td>22.93</td>
<td>23.07</td>
<td>23.07</td>
<td>23.02</td>
<td>22.98</td>
</tr>
</tbody>
</table>

- The demand and investment of waste plastics industry are increasing rapidly.
- The plastics industry has high profit, averagely more than 23%.
1. Waste plastics Status in China

1.6 Waste plastics treatment methods in China

- **Landfill**: Decompose hardly
- **Recycling**: Decompose hardly
- **Incineration**: Decompose hardly
1.7 Waste plastics recycling status in China

Waste plastics consumption, recycling, and recovery rate in China

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

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

Waste plastics consumption, recycling, and recovery rate from 2006 to 2011
1. Waste plastics Status in China

1.8 Technologies of waste plastics recycling

- **Incineration power generation**
- Recycled plastics particles
- Plastics-to-fuel conversion

- **Thermal pyrolysis**
- Catalytic cracking
2. Thermal pyrolysis used for plastic waste

2.1 Mechanism of thermal pyrolysis

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)

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

\[ C_xH_yO_z + Q \rightarrow \text{Char} + \text{Liquid} + \text{Gas} + H_2O \]

\[ M_n^* \rightarrow M_{n-1}^* + M \]  \hspace{1cm} (1)

\[ M_{n-1}^* \rightarrow M_{n-2}^* + M \]  \hspace{1cm} (2)

\[ M_n^* \rightarrow M_x + M_y \]  \hspace{1cm} (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)

- Steel factory
- Boiling heating
- Heavy oil generator
- Cement factory

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

2.3 Advantages and challenges of thermal pyrolysis used for plastic waste

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

<table>
<thead>
<tr>
<th>Tech providers</th>
<th>Service area</th>
<th>Cracking process</th>
<th>Max design capability (t·d⁻¹)</th>
<th>Oil production (L·t⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agilyx</td>
<td>North America</td>
<td>Thermal pyrolysis</td>
<td>45</td>
<td>799~837</td>
</tr>
<tr>
<td>Cynar</td>
<td>Europe</td>
<td>Thermal pyrolysis</td>
<td>20</td>
<td>946</td>
</tr>
<tr>
<td>Nexus Fuels</td>
<td>USA</td>
<td>Thermal pyrolysis</td>
<td>45</td>
<td>833~1060</td>
</tr>
<tr>
<td>Klean Industries</td>
<td>Japan</td>
<td>Thermal pyrolysis</td>
<td>150</td>
<td>unknown</td>
</tr>
<tr>
<td>Polymer Energy</td>
<td>India</td>
<td>Catalytic pyrolysis</td>
<td>10</td>
<td>738</td>
</tr>
<tr>
<td>Plastics Advanced Recycling Co.</td>
<td>China</td>
<td>Catalytic pyrolysis</td>
<td>60</td>
<td>606</td>
</tr>
</tbody>
</table>

**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. Thermal pyrolysis used for plastic waste

2.4 Influence factors on thermal pyrolysis

Hydrocarbon products at different temperatures

<table>
<thead>
<tr>
<th>Boiling point</th>
<th>Use</th>
<th>Researchers</th>
<th>Plastics type</th>
<th>Reactor type</th>
<th>Temperature (°C)</th>
<th>Crude oil (wt %)</th>
<th>Residue (wt %)</th>
<th>Gas (wt %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 ~ 185°C</td>
<td>motor gasoline</td>
<td>William et al.</td>
<td>PE</td>
<td>Parr mini bench top</td>
<td>500</td>
<td>93</td>
<td>0.0</td>
<td>7.0</td>
</tr>
<tr>
<td>185 ~ 290°C</td>
<td>diesel #1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>290 ~ 350°C</td>
<td>diesel #2</td>
<td>Sarker et al.</td>
<td>MIXED</td>
<td>Proprietary (Natural State Research Inc)</td>
<td>370–420</td>
<td>90</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>350 ~ 538°C</td>
<td>vacuum gas oil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;538°C</td>
<td>residue</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Researchers: PE = Polyethylene, PP = Polypropylene, MIXED = Mixed Plastics, HDPE = High-Density Polyethylene, PETE = Polyethylene Terephthalate

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

- Influence factors on thermal pyrolysis

- The components and yields of products are determined by thermal treatment temperature, plastics type, residence time, and reactor type.
2. Thermal pyrolysis used for plastic waste

2.4 Influence factors on thermal pyrolysis---temperature

- 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.

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

Effect of temperature on conversion process (López et al., 2011)
## 2. Thermal pyrolysis used for plastic waste

### 2.4 Influence factors on thermal pyrolysis---plastics type

Proximate analysis of plastics

<table>
<thead>
<tr>
<th>Raw materials</th>
<th>Reaction temperature</th>
<th>Yields in wt.%</th>
<th>Refs.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Liquids</td>
<td>Gases</td>
</tr>
<tr>
<td>HDPE (high-density polyethylene):WLO (waste lubricant oil)=(1:1)</td>
<td>460°C</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>LDPE (low-density polyethylene):WLO (waste lubricant oil)=(1:1)</td>
<td>460°C</td>
<td>99</td>
<td>-</td>
</tr>
<tr>
<td>PP (polypropylene)</td>
<td>420-440°C</td>
<td>96.7</td>
<td>2.2</td>
</tr>
<tr>
<td>PS (polystyrene)</td>
<td>420-440°C</td>
<td>95.7</td>
<td>0.6</td>
</tr>
<tr>
<td>PE (polyethylene)</td>
<td>450°C</td>
<td>81.6</td>
<td>12.1</td>
</tr>
<tr>
<td>ABS (acrylonitrile butadiene styrene)</td>
<td>478°C</td>
<td>79</td>
<td>3</td>
</tr>
</tbody>
</table>

◆ Thermal pyrolysis produces large amount of **liquid oils for different plastics types.**
2. Thermal pyrolysis used for plastic waste

2.4 Influence factors on thermal pyrolysis---residence time

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

---

**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)
2. Thermal pyrolysis used for plastic waste

2.4 Influence factors on thermal pyrolysis---reactor type

Different reactor types (Shafferina et al., 2016)

<table>
<thead>
<tr>
<th>Type of reactors</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Batch reactor</strong></td>
<td>• closed system</td>
</tr>
<tr>
<td></td>
<td>• high conversion</td>
</tr>
<tr>
<td></td>
<td>• high labor costs</td>
</tr>
<tr>
<td><strong>Fixed-bed reactor</strong></td>
<td>• easy to design</td>
</tr>
<tr>
<td></td>
<td>• available surface area</td>
</tr>
<tr>
<td><strong>Fluidized bed reactor</strong></td>
<td>• larger surface area</td>
</tr>
<tr>
<td></td>
<td>• flexible</td>
</tr>
<tr>
<td><strong>Conical spouted bed reactor</strong></td>
<td>• large particle size distribution</td>
</tr>
<tr>
<td></td>
<td>• larger particles and difference in particle densities</td>
</tr>
</tbody>
</table>

- 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

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

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. Catalytic cracking used for plastic waste

3.3 Catalytic cracking used for plastic waste

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. Catalytic cracking used for plastic waste

3.4 Effect of catalyst type on catalytic cracking of plastic waste

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.
### 3. Catalytic cracking used for plastic waste

#### 3.4 Effect of catalyst type on catalytic cracking of plastic waste

<table>
<thead>
<tr>
<th>Catalyst type (Catalyst)</th>
<th>Quantity of catalyst</th>
<th>Feedstock used</th>
<th>Product yields</th>
<th>Product yields</th>
<th>Product yields</th>
<th>Product yields</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Liquid</td>
<td>Gases</td>
<td>Char</td>
<td></td>
</tr>
<tr>
<td><strong>FCC</strong></td>
<td>50%</td>
<td>LDPE, HDPE, PP</td>
<td>72.1, 44.2, 64.7</td>
<td>19.4, 52.5, 20.0</td>
<td>8.5, 3.3, 15.3</td>
<td>Achilias et al. (2007)</td>
</tr>
<tr>
<td><strong>ZSM-5</strong></td>
<td>5%</td>
<td>HDPE, PP</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>Miskolczi et al. (2009)</td>
</tr>
<tr>
<td><strong>HZSM-5</strong></td>
<td>20%</td>
<td>HDPE</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>Hernandez et al. (2007)</td>
</tr>
<tr>
<td><strong>Natural Zeolite</strong></td>
<td>5%</td>
<td>LDPE</td>
<td>23.88, 12.20, 23.92, 14.91</td>
<td>75.18, 86.30, 76.00, 83.71</td>
<td>0.94, 1.51, 0.92, 1.39</td>
<td>Sriningsih et al. (2014)</td>
</tr>
</tbody>
</table>

- **Catalysts have different effects on the pyrolysis process and products.**
3. Catalytic cracking used for plastic waste

3.5 Effect of reactor type on catalytic cracking of plastic waste

- 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.
Acknowledgments

Research group leader:
Prof. Qiuwang Wang

Mr. Zirui Xu    Ms. Na Li    Mr. Jie Lian    Mr. Zhenlin Wu

◆ 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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