NEWMOA

NORTHEAST WASTE MANAGEMENT OFFICIALS' ASSOCIATION

Materials Management 101:

Chemical Recycling

August 19, 2026

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NEWMOA *Materials Management 101* : Chemical Recycling

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Mike Fowler, Research Scientist

Agenda

1. Terminology

2. Technologies
- Mechanical Recycling
- Pyrolysis
- Gasification
- Methanolysis
- Dissolution
- Others

3. NJDEP Life Cycle Assessment

Navigating Terminology

Different rationale by organization, literature, legislation, and policy

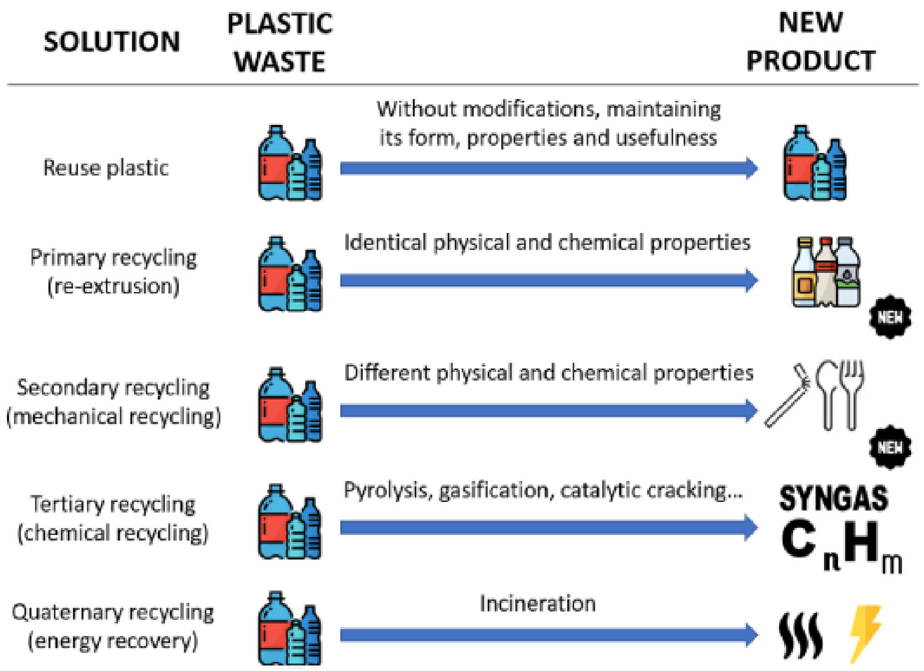
- Chemical recycling, solvolysis, alternative recycling, plastic conversion technology, chemical plastic processing
- Physical, chemical, mechanical
- Solid waste process, recycling, manufacturing
- **Marketing/Trademark names**
- Molecular Recycling
- Carbon Renewal Technology
- SolvoGenesis, Tritan Renew, Exxtend

Different technologies, synonyms, varieties of technologies

- Pyrolysis: slow/fast/flash, catalytic, plasma, microwave assisted
- Gasification: air, steam
- Methanolysis: Supercritical, microwave assisted, catalytic
- Dissolution: supercritical dissolution, solvent-purification, solvent-assisted recycling, selective dissolution precipitation (SDP)

Mechanical Recycling

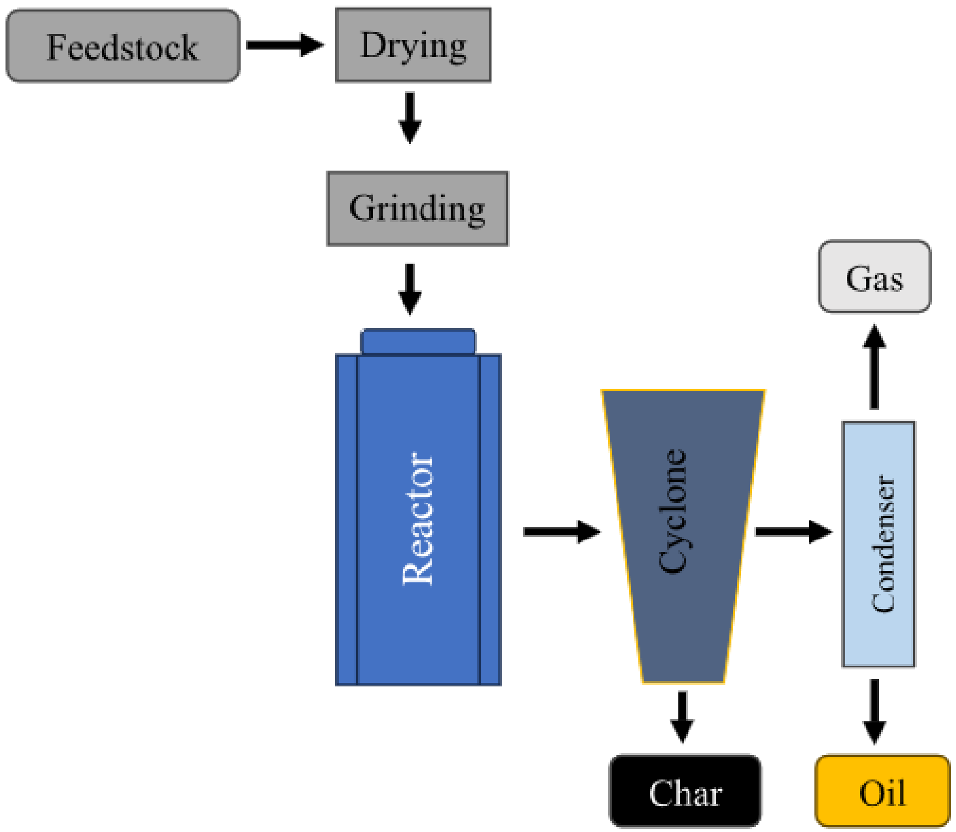
- Physical treatment of the plastic to achieve a consumer product from plastic waste; involves sorting, shredding, washing, melting and re-extruding extrusion of postconsumer plastic.
- Preferred Plastic Type: RICs Code #1 PET, #2 HDPE, PP #5
- Conditions: Sorting/washing may occur in a different order, multiple times. Hot washing with caustic soda, surfactants, and detergents
- Products: a single type of polymer pellet, granule, or flake
- Pros: economical, low energy, low impact/emissions, accessible, infrastructure
- Cons: Inconsistent systems, limited feedstock types, loss in material quality, potential food safety concerns, blending



Hasan, M. M., Haque, R., Jahirul, M. I., & Rasul, M. G. (2025). Pyrolysis of plastic waste for sustainable energy Recovery: Technological advancements and environmental impacts. *Energy Conversion and Management*, *326*, 119511.

Pyrolysis - Thermochemical Conversion

- Thermal decomposition (depolymerization/breaking down of chemical bonds of plastic waste) of materials at elevated temperatures in the absence of oxygen.
- Preferred Plastic Type: #2 HDPE, #4 LDPE, #5 PP and #6 PS. Mixed plastic waste*. No #3 PVC.
- Conditions: No oxygen, 300–900°C or novel 1200°C
- Products: oil, waxes, vapor, and char. Distribution and quality varies based on feedstock and conditions.
- Pros: Tolerances to contamination and degraded material, landfill diversion, 'value-added' material
- Cons: Complex reactions, feedstock sensitivity, low-quality oil, high energy demand, costly, environmental impacts



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Gasification - Thermochemical Conversion

- Thermal decomposition (depolymerization/breaking down of chemical bonds of plastic waste) under pressure and high temperature *with* oxygen and/or steam as gasification agents.
- Preferred Plastic Types: #2 HDPE, #4 LDPE, #5 PP and #6 PS. Mixed plastic waste*, no #3 PVC*.
- Conditions: Contains small amount of oxygen, steam, or C02. Temperatures between 700°C -1200°C.
- Products: Vapor (syngas: mix of carbon monoxide (CO) and hydrogen (H2)), char/tar. Syngas can be used as a natural gas substitute or transformed into commercial products and chemicals
- Pros: Electricity generation, ‘value-added’ H2 or chemicals
- Cons: Complexity, feedstock sensitivity, higher energy demand for process than pyrolysis and conversion to chemicals, toxic gases (NOx)/environmental impact, costly

	Pyrolysis	Gasification
Heat	300-800°C	700-1200°C
Oxygen	No Oxygen	Oxygen
Products	Vapor, Oil, Char	Syngas (H2, CO), Tar

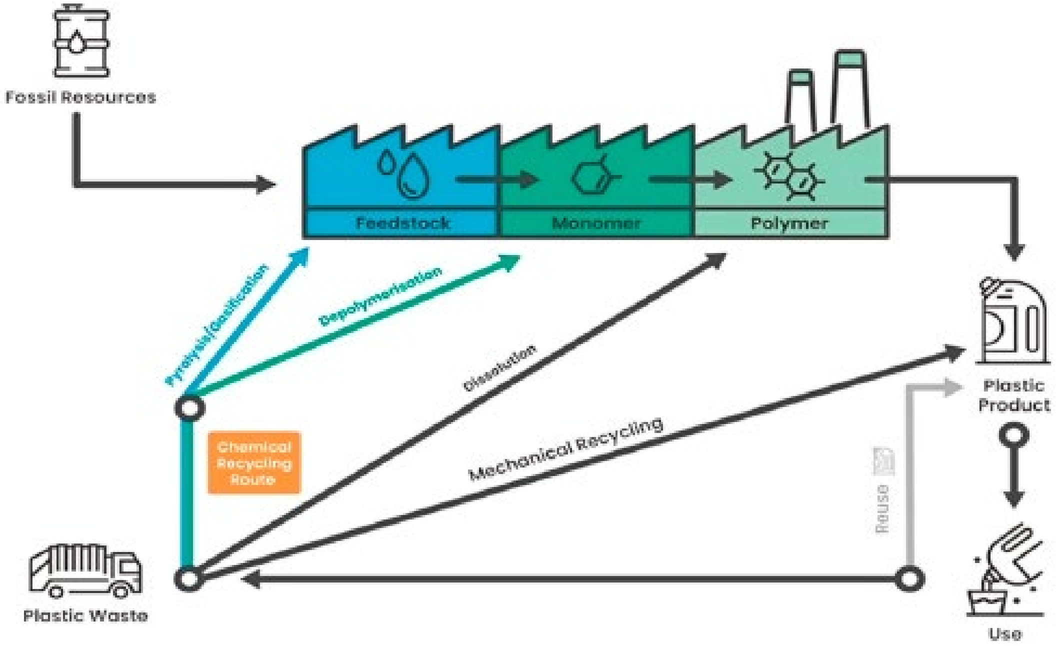
Methanolysis – Solvolysis

- Depolymerization of polyesters to monomers in methanol.
  - Unlike thermochemical conversion, solvolysis reaction attempts to yield the monomeric equivalent to virgin material.
- Preferred Plastic Types: polyesters. #1 PET, PLA
- Conditions: Mixture of PET flake and vaporized or liquid methanol, between 180°C and 280°C, under mild to extreme pressure.
- Products: Dimethyl terephthalate (DMT) monomer and ethylene glycol. DMT is a precursor for PET production.
- Pros: Pathway for degraded PET or other sources (clothing, carpets), faster reaction times than other PET solvolysis methods, high PET conversion, high DMT yield and purity
- Cons: Complexity, sorting issues and feedstock sensitivity, energy consumption, high methanol consumption, purification, cost

Dissolution

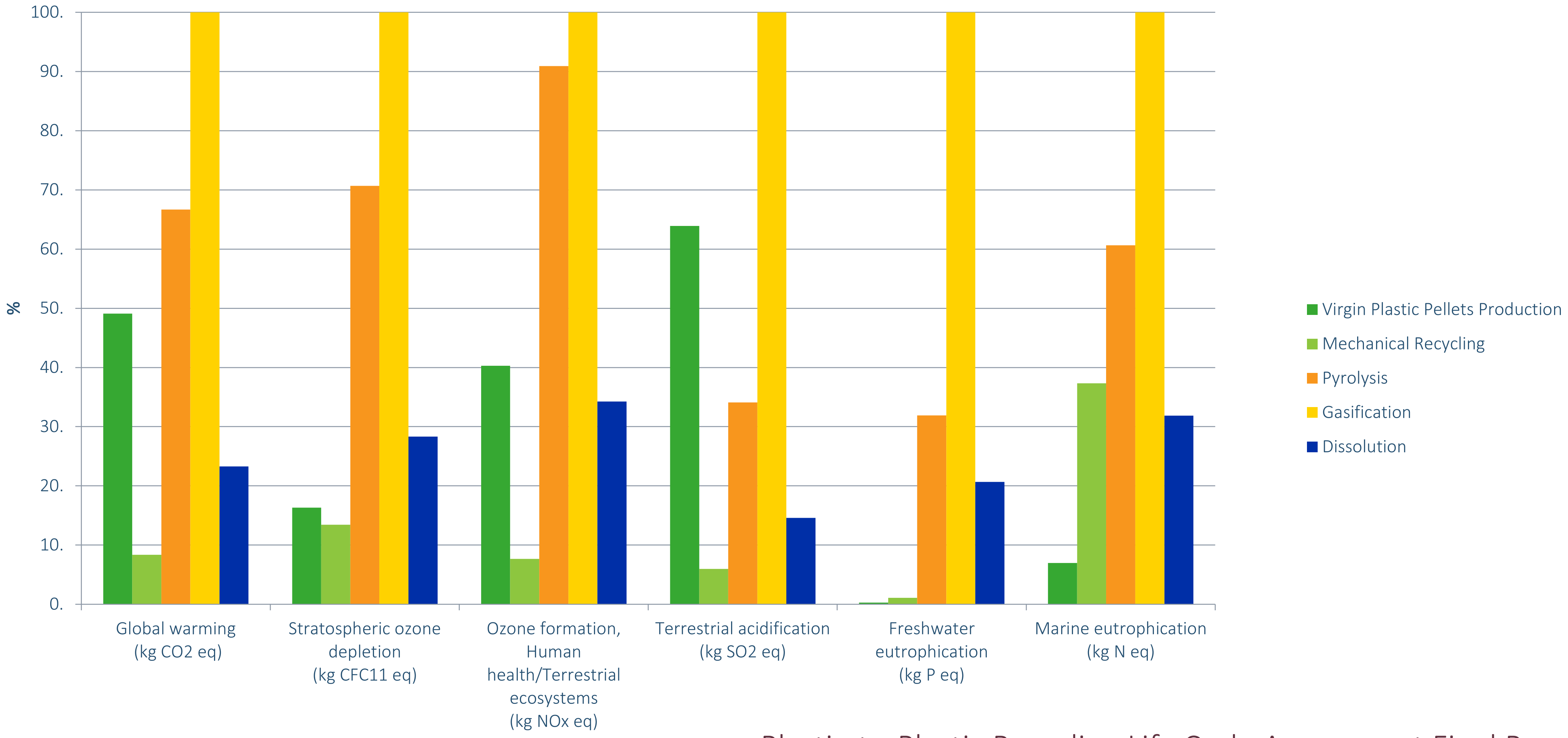
- A physical process where a polymer is dissolved in a solvent and then precipitated out by cooling, evaporation, or the addition of an antisolvent. Additives and traces of other polymers can be removed via filtration, adsorption, distillation, and other purification methods.
    - Dissolution requires complex solvent polymer interactions, design, recovery, and operating conditions more akin to other solvolysis, that is solvent based chemical recycling, reactions.

- Preferred Plastic Types: All conventional plastic types
- Conditions: Highly specific operating conditions by polymer and solvent. 75-100°C to 300 °C in supercritical conditions.
- Products: specific polymer
- Pros: recovers polymer, material quality
- Cons: energy consumption and solvent use associated with environmental and human health impact and risk, cost



Plastics Europe. (2024). Chemical Recycling. https://plasticseurope.org/sustainability/circularity/recycling/chemical-recycling/

Plastic to Plastic LCA: Polypropylene (PP) - Midpoints



Plastic-to-Plastic Recycling Life Cycle Assessment Final Report

Plastic-to-Plastic Recycling Life Cycle Assessment Report Factsheet

4.2.3 Polyethylene Terephthalate

Figure 4.10 shows the impact results of producing PET plastic.

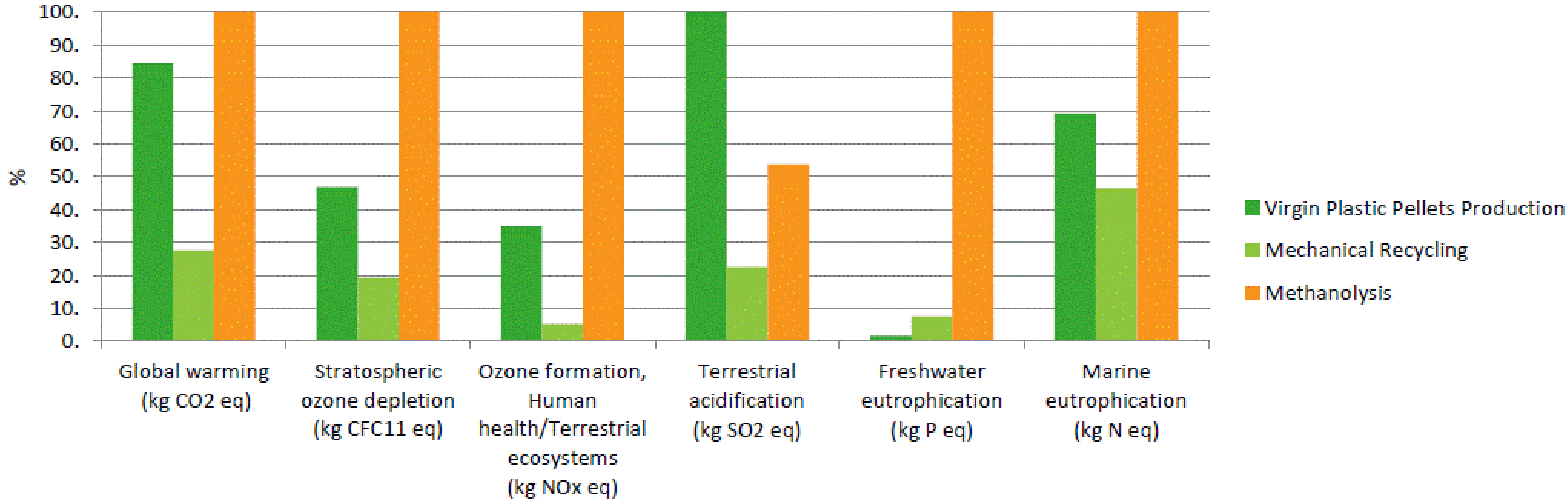


Figure 4.10 Comparison of Impacts From Three Methods of Producing Polyethylene Terephthalate

- **Methanolysis**: Methanolysis results in the highest impacts to produce PET plastic across most environmental categories. This is primarily due to the energy and chemical requirements of the methanolysis process, which includes depolymerization, purification, and repolymerization steps. The process is resource-intensive and generates emissions throughout multiple stages.
- **Virgin production:** Virgin PET leads terrestrial acidification, primarily from SO_2 and NO_x associated with upstream extraction/refining and petrochemical production/polymerization. It is also very high in global warming due to the energy intensity of upstream activities.
- **Mechanical recycling:** Mechanical recycling generally shows lower impacts compared to methanolysis and virgin production. Its environmental profile benefits from fewer process steps and reduced energy demand. However, the quality of recycled PET may decline over multiple cycles, which can limit the potential for repeated recycling.
- **Implication:** The choice of production method for PET significantly influences its environmental impact.

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Impacts of the Pyrolysis of Waste Plastic

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The makeup of waste plastic and the complex pyrolysis chemistry of the plastic components dictate what is in the pyrolysis product and the low efficiency of the process

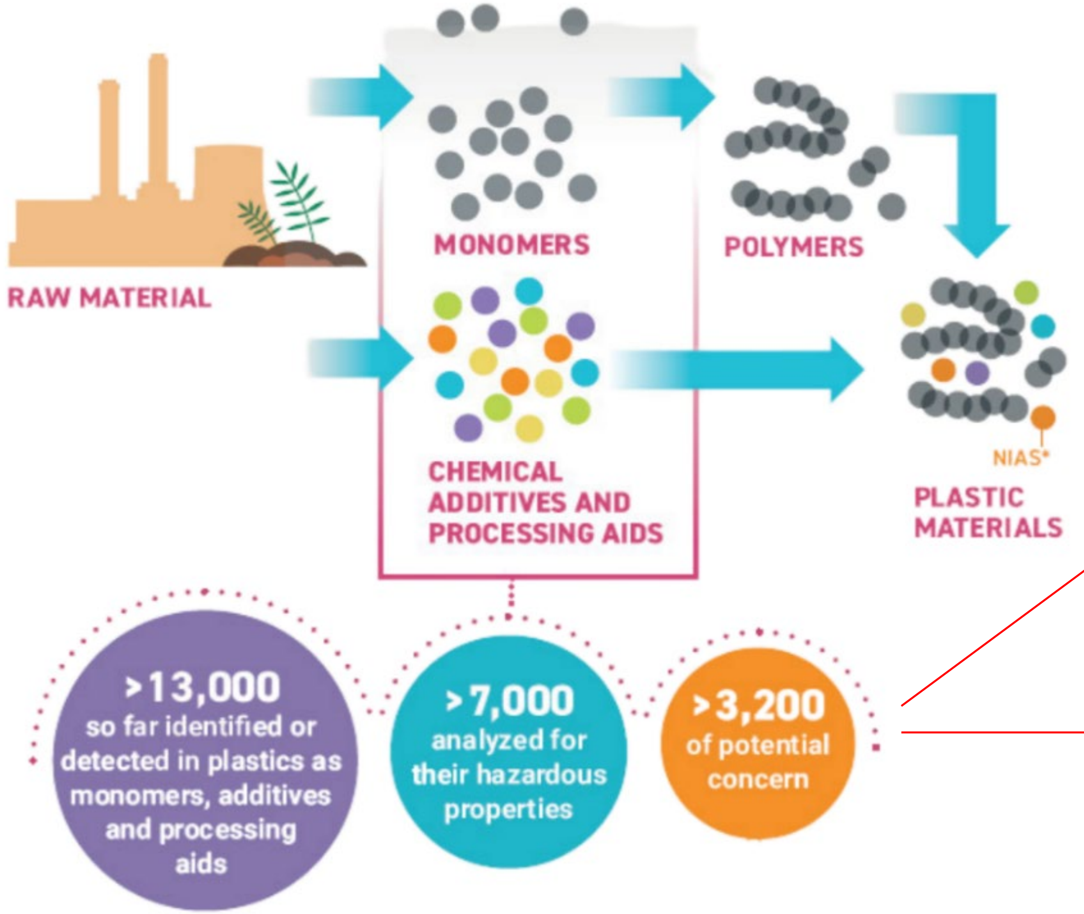
New plastic? **No**

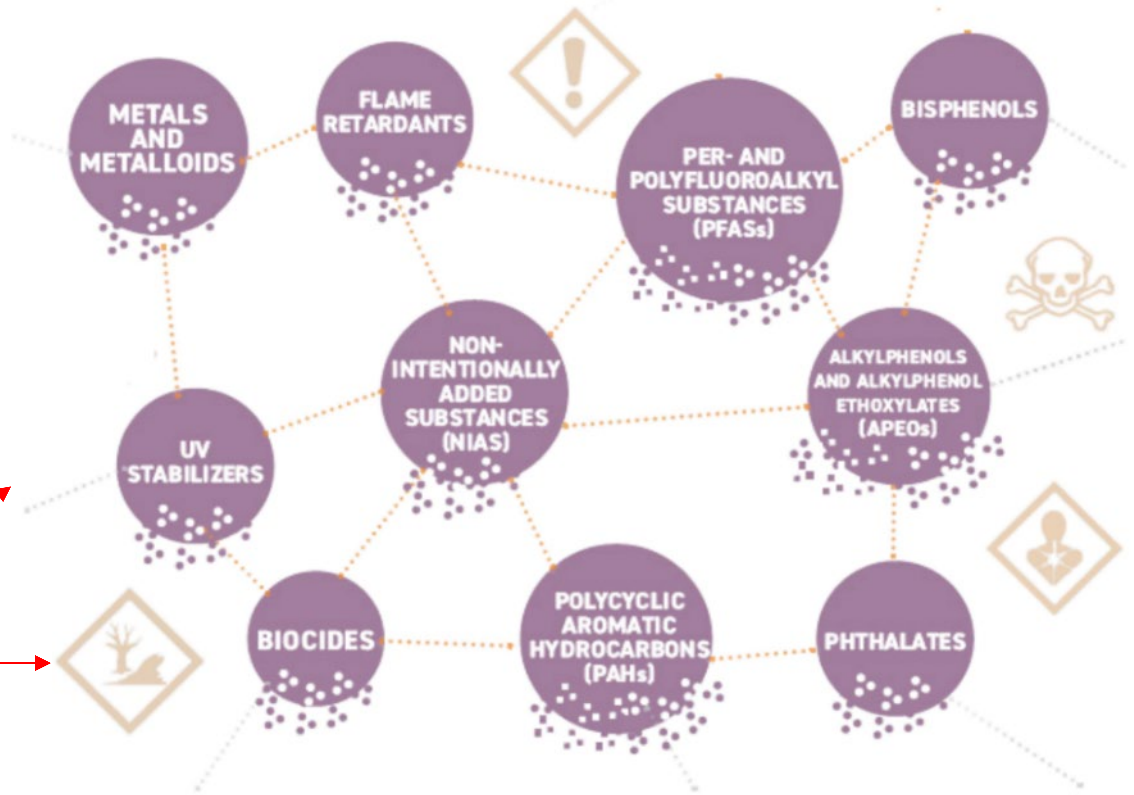
New polymer? **No**

New monomer? **No**

Naphtha equivalent to virgin naphtha? **No**

Components of plastic



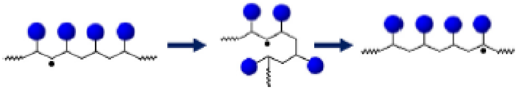
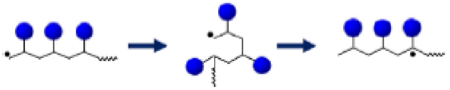
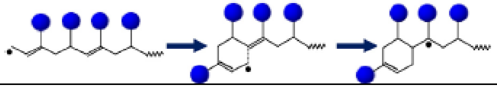


Source: UNEP. Chemicals in Plastic (2023)

Complex breakdown products – polymer backbone

Depolymerization reactions

Table 16
Reaction families in the depolymerization mechanism for a generic vinyl polymer. The blue circle represents H, CH_3, and C_6H_5 for PE, PP, and PS respectively.

Reaction families (depolymerization mechanism)		CRECK	Broadbelt	Mastral	Németh
Initiation reactions		X	X	X	X
Initiation from "weak links"		X	X		
Recombination		X	X	X	X
Specific scission (e.g. allylic position)		X	X	X	X
Disproportionation			X	X	
H-abstractions (end-chain radicals)		X	X	X	X
H-abstractions (mid-chain radicals)		X			X
H-abstractions (specific position, e.g. allylic)		X	X		X
β-scission		X	X	X	X
β-scission (unzipping)		X	X	X	X
Isomerization (backbiting, mid-chain radical, (1,4), (1,5), (1,6))		X	X	X	X
Isomerization (backbiting, end-chain radical, (1,4), (1,5), (1,6), (1,7))		X	X	X	X
Addition reactions			X		
Cyclization of allyl radicals			X	X	

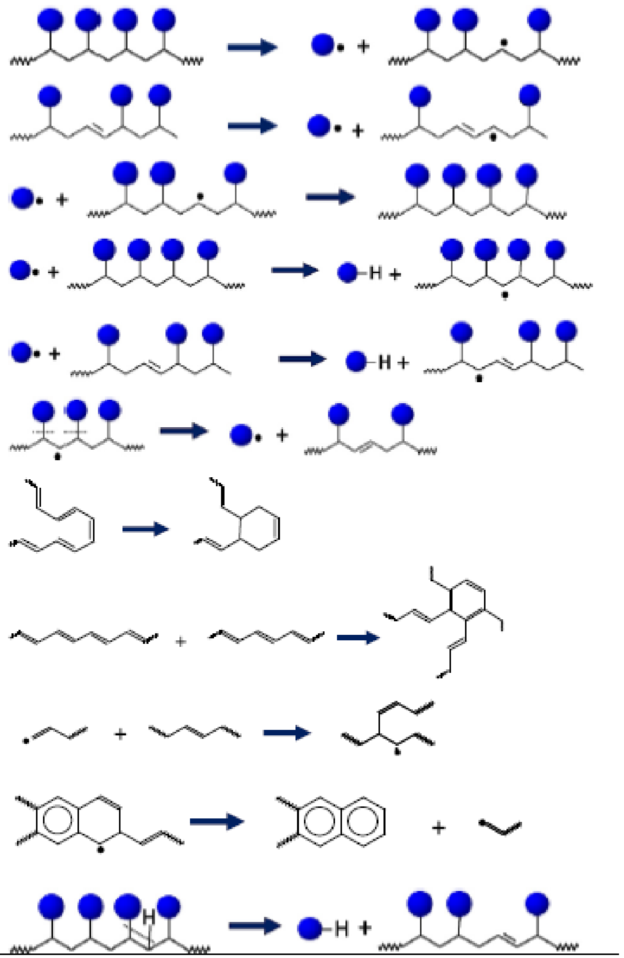
O. Dogu, M. Pelucchi, R. Van de Vijver et al. Progress in Energy and Combustion Science 84 (2021) 100901

Complex breakdown products – polymer backbone

Side reactions

Table 17
Reaction families of the side group mechanism for a generic vinyl polymer.

Reaction families ("side group" mechanism)
Initiation reactions
Specific scission(*e.g.* allylic position)
Recombination
H-abstractions
H-abstractions(specific position, *e.g.* allylic)
β-scission
Cyclization through intramolecular Diels-Alder
Cyclization through intermolecular Diels-Alder
Addition to polyenes
β-scission of unsaturated resonance stabilized radicals
Four-center molecular decomposition



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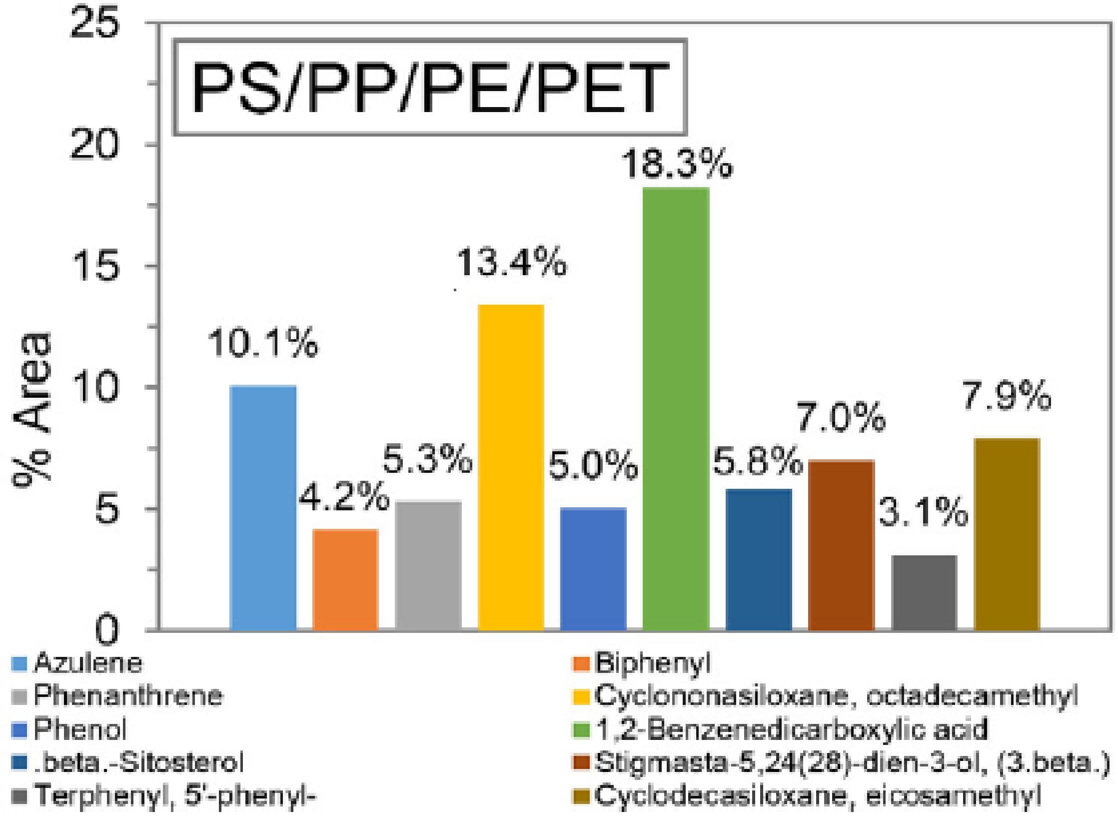
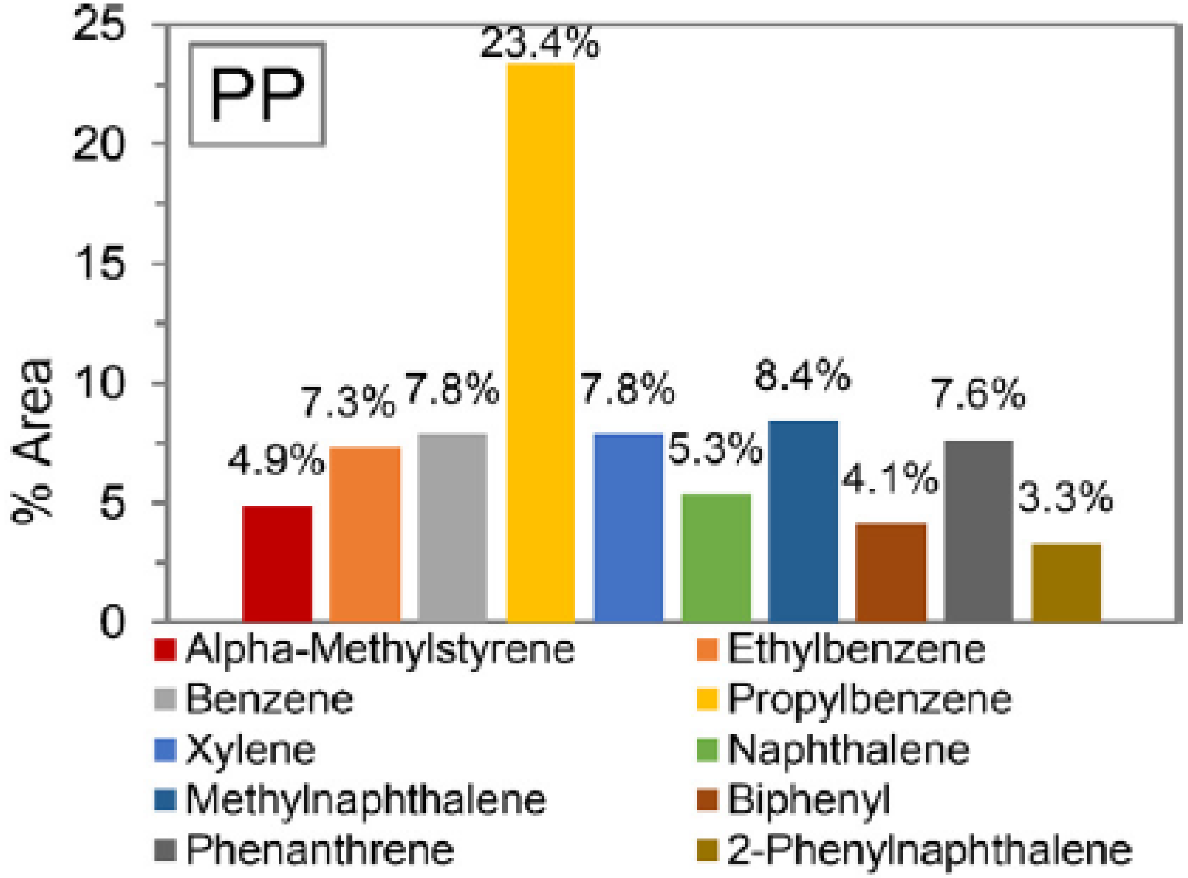
Pyrolysis of even single types of waste plastics have low efficiencies

Table 10
Yields of products (wt%) obtained from PE pyrolysis in a Pyroprobe 1000 (adopted from [363]).

	Polyethylene Type A					Polyethylene Type B				
Temp. (°C)	500	600	700	800	900	500	600	700	800	900
C1	0.09	0.87	3.10	1.67	3.57	0.03	0.69	2.54	1.97	3.03
C2	0.13	0.66	0.89	0.76	0.93	0.04	0.36	0.64	1.01	0.85
C2=	0.64	6.08	15.1	22.6	13.7	0.43	4.42	10.7	15.6	17.0
C3	0.19	0.35	0.31	0.46	0.54	0.03	0.22	0.29	0.61	0.24
C3=	0.37	2.65	3.75	2.59	2.80	0.21	1.73	1.09	2.41	4.72
C2≡	0.00	0.00	0.03	0.04	0.25	0.01	0.07	0.08	0.14	0.04
C4	0.04	0.28	3.98	2.57	9.04	0.01	0.19	0.17	0.38	1.54
C4=	0.35	1.53	1.77	1.58	1.50	0.14	0.83	4.19	3.87	1.28
C5	0.21	1.68	2.49	1.68	1.77	0.16	1.10	2.35	3.72	2.71
Benzene	0.09	0.29	1.88	2.34	1.18	0.50	0.72	1.30	2.15	2.16
Toluene	0.30	0.19	0.33	0.51	0.39	0.11	0.16	0.25	0.31	0.39
Xylenes + Styrene	0.00	0.04	0.21	0.39	0.10	0.06	0.03	0.00	0.00	0.00
Total gas	2.42	14.6	33.8	37.2	35.8	1.73	10.5	23.6	32.1	32.0
Total waxes and tars	97.5	85.3	66.1	62.7	64.1	98.2	89.4	76.3	67.8	67.9

Complex breakdown products – polymer backbone





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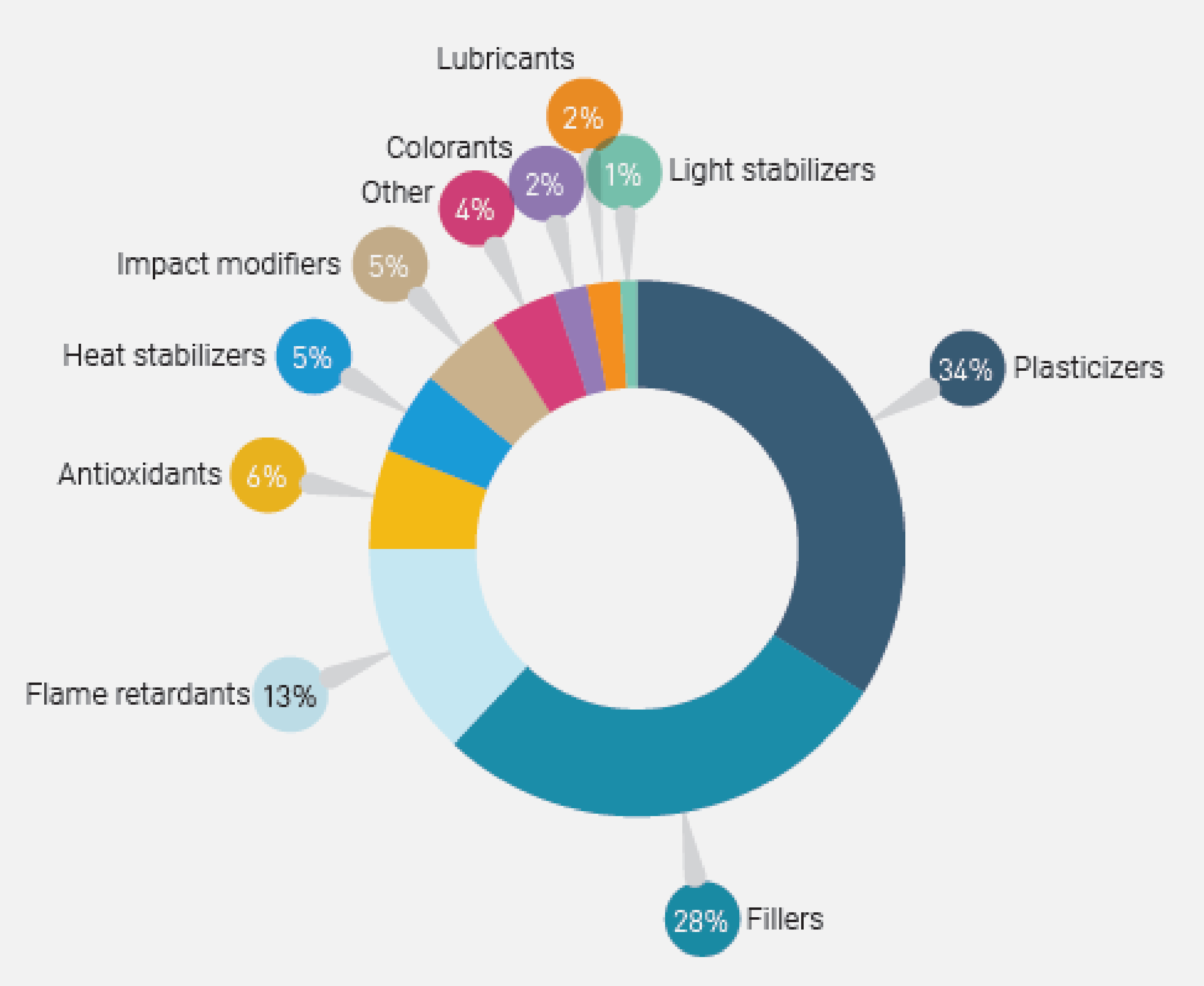
Additives increase reaction complexity, lower efficiency and contaminate outputs



- Brominated and chlorinated flame retardants
- Heat stabilizers
  - Cadmium and lead compounds
- Plasticizers
  - Phthalates
  - Chlorinated paraffins
- Pigments
  - Cadmium, chromium, and lead compounds
- PFAS
- Antistatic agents
  - Ethoxylated amines
- Additives typically not considered part of LCAs

Source: UNEP. Chemicals in Plastic (2023)

Contaminates in pyrolysis oil and air toxics

- Aside from the hydrocarbon complexity of the pyrolysis oils, they are heavily contaminated
  - Chlorinated and brominated compounds
  - Silicon
  - Heavy metals (lead, mercury, cadmium, chromium)
  - Nitrogen compounds
  - PFAS and other halogens
  - Dioxins
  - Phthalates
  - Complex aromatics
- Contamination damages catalysts, corrodes equipment and reduces oil quality

Use of waste-plastic pyrolysis oil with virgin feedstocks

- Blends of waste-plastic pyrolysis oils and virgin petroleum streams can be cracked to form hydrocarbon feedstocks for fuels and petrochemicals
- The percentage of the waste-plastic pyrolysis oil that can be blended in is generally low given contamination
- Varying the relative amounts of waste-plastic pyrolysis oil can increase aromatics, including complex aromatics, many of which are carcinogens
- The waste-plastic pyrolysis oil may instead be used to fuel the process rather than being blended with the petroleum feedstocks

Health impacts

- These pollutants have real world impacts on communities living near waste-plastic pyrolysis units
    - Harm to development
    - Harm to reproduction
    - Toxicity to the immune system
    - Liver, kidney toxicity
    - Cancer

This is not recycling, manufacturing, or a way to make new products

- Given the large range of plastic materials in the MSW – combinations of polymer types and large range of additives – pyrolysis facilities need to manage **up to 1,000 different chemicals** and highly complex chemical reactions
- It is no wonder that the process is **inefficient** and the limited amount of pyrolysis oil produced is highly **contaminated** and there **are air toxics** released into surrounding communities
- Economic and environmental impacts of pyrolysis estimated to be 10–100 times higher than virgin polymers due to low yields and high energy requirements
  - This does not include the impact of the additives

Key Takeaways

- Pyrolysis of waste plastic is not recycling
- Pyrolysis of waste plastic is inefficient and produces harmful toxic chemicals
- Pyrolysis methods are energy intensive
- Falsely advertised as a circular solution - but the chemistry and the numbers do not support that characterization

Environmental Defense Fund

Thank you!

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Environmental Defense Fund

CHEMICAL RECYCLING, TURNING SCIENCE INTO POLICY

Tom Metzner

POLICY ISSUES CONCERNING CHEMICAL RECYCLING

Are chemical recycling plants classified as waste or manufacturing?

How to increase recycled content for plastics

What are the human health and environmental impacts of chemical recycling?

What are our overarching environmental goals and how does chemical recycling fit into them?

WHO IS NERC?

Northeast Recycling Council

Mission

NERC is a multi-state 501(c)(3) non-profit dedicated to minimizing waste, conserving natural resources, and advancing a sustainable economy. We carry out this mission by bridging informational gaps between the public and private sectors - providing educational tools, policy research, and collaborative spaces like our committees and annual Rethink Resource Use Conference

CHEMICAL RECYCLING COMMITTEE

Made up of State environmental agency leads

Started the committee in 2022 and issued our position paper in May 2025

Received information from a variety of stakeholders

Met regularly to establish a policy.

Northeast Recycling Council – link to Chemical Recycling Policy Paper

NERC CHEMICAL RECYCLING COMMITTEE

Purpose:

The purpose of this policy statement is to articulate guiding principles for environmentally responsible chemical recycling of plastics.

Stated beliefs:

1. reduction of plastics where feasible alternatives exist
2. Design for recycling and responsibly recycled
3. A more circular and sustainable economy
4. Plastic to fuel or energy is not recycling
5. Mechanical recycling is currently preferred

CHEMICAL RECYCLING CAN BE CONSIDERED

For plastics that can’t be feasibly eliminated, replaced, redesigned, or mechanically recycled.

When there is an equal or net benefit to human health and the environment with chemical recycling compared to other waste management processes.

If it is less environmentally harmful and less energy intensive than virgin production of plastics.

Recycling process must be verifiable through third party certification and mass balance accounting through the chain of custody that reflects the source material and true composition of the product.

OTHER ORGANIZATIONS WITH CHEMICAL RECYCLING POLICY POSITIONS

US Plastics Pact

Physical and Chemical Recycling Position Paper

Standardization of terminology

Robust standards and safeguards

Third party verified LCA for claims on carbon emissions compared to virgin

Chemical recycling processes that create fuel are not recycling

Must compliment, not replace mechanical recycling and reuse/reduction strategies

RECYCLING PARTNERSHIP

Lower overall environmental impacts than producing brand new plastics

True circularity

Transparent science and metrics

Enhance, not replace mechanical recycling, source reduction and reuse

IN SUMMARY

Chemical recycling

Needs to be better than virgin plastic production in terms of environmental outcomes

Should supplement, not replace mechanical recycling, reuse and source reduction

Should be transparent in terms of metrics and claims should be independently verified

Fuel production is not recycling