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Sustainable Packaging and PET: U.S. Flows, Material Recovery Facilities, and Recycling Processes

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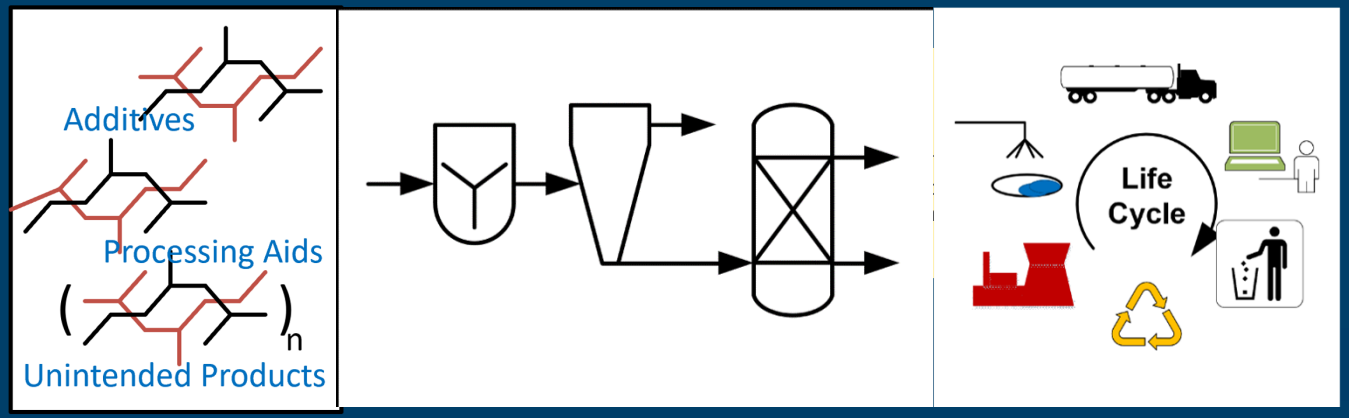

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The views expressed in this presentation are those of the author and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency.

Generation of Plastics

Inflation adjusted growth[1] for 2011-2021:

- Annual U.S. Manufacturing: (0.5%)
- Annual U.S. Plastics Manufacturing: 0.7%

Since 1950s, 8,300 Mt of plastic produced, 6,300 Mt of plastic waste generated

- Plastic demand in 1950s, about 2 Mt/year,[2] in 2019, 368 Mt/year.[3]
- Plastic demand expected to quadruple by 2050.[4]

Mt = Million metric (Mega) tons

1 – Plastics Industry Assn. 2022 Size and Impact Report, Exec. Summary; 2 – Geyer et al., 2017. https://doi.org/10.1126/sciadv.1700782; 3 – Plastics Europe, 2020. Plastics – The Facts; 4 – Ellen MacArthur Foundation, 2017. The New Plastics Economy: Rethinking the Future of Plastics & Catalysing Action

Some Effects of Plastic Pollution

- Marine Litter is estimated to cost the world $264 billion annually.
- Ohio's Lake Erie beaches have 2.8 million visitor days, $88 million in recreational value, $217 million in tourist spending, and 3,700 jobs. Increased pollution could cut these activities.

U.S. Federal Strategy for Addressing the Global Issue of Marine Litter (2020)

Recycling Opportunities

Metric[1]	Total	Plastics
Jobs	757,325	75,000
Wages	$36.6 billion	$3.2 billion
Tax Revenue	$6.8 billion	$0.3 billion

1 – 2016 Recycling Economic Information Report Estimates of Contributions of Recycling to U.S. Economic Activity/Quantity and Value Contribution, EPA530-R-17-002

Ecological Effects of Plastic Pollution[1]

Effects are seen in entanglements, smothering, rafting of species and pathogens, and ingestion of fragments.

Plastics are found in various fauna: fish, shellfish, marine turtles, seabirds, and marine mammals. Sea turtles are particularly vulnerable as they can't regurgitate.

Effects seen for algae and zooplankton as well.

Microplastics damage corals, and disease incidence rises from 4% to 89% with plastic effects on corals.

Microfibers are denser than sea water and are expected to remain at the bottom of water bodies for many decades.

Microplastics defined by most people as particles that are less than 5mm in size.

1 – UNEP, From Pollution to Solution: A Global Assessment of Marine Litter and Plastic Pollution (2021).

Microplastics

Inhaled microplastics: 39,000 – 121,000 particles per year.[1]

Drinking bottled water: 90,000 microplastic particles per year; 4,000 if tap water.[1]

Mice were fed 5μm and 20μm polystyrene microplastics for four weeks.[2]

- Livers, kidneys, and guts accumulated about 1 mg/g of microplastics.
- Liver weights decreased, while food intake increased over control mice.
- Energy and lipid metabolism were impaired.
- Inflammation and oxidative stress.

Smaller particles generally accumulated more in tissues.[2]

1 – UNEP, From Pollution to Solution: A Global Assessment of Marine Litter and Plastic Pollution (2021). 2 – Deng et al., "Tissue Accumulation of Microplastics in Mice and Biomarker Responses Suggest Widespread Health Risks of Exposure", Scientific Reports, 7, 46687 (2017).

Chemicals in Plastics

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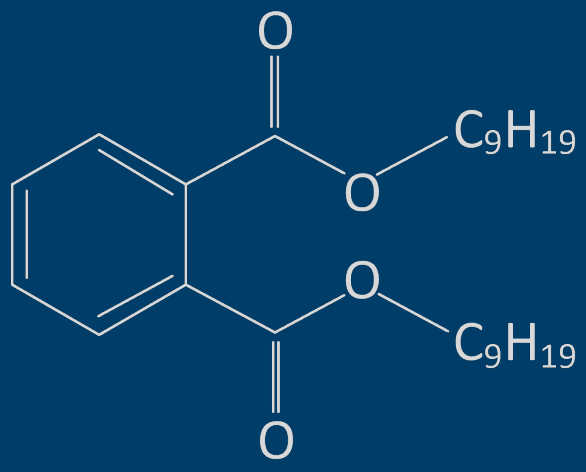
An online search for PVC bottles, finds many entries. Phthalates are used in PVC.

FDA was petitioned by NGOs to prohibit food contact of eight phthalates: diisobutyl phthalate (DIBP), di-n-butyl phthalate (DBP), butyl benzyl phthalate (BBP), dicyclohexyl phthalate (DCHP), di-n-hexyl phthalate (DHEXP), diisooctyl phthalate (DIOP), di(2-ethylhexyl) phthalate (DEHP), and diisononyl phthalate (DINP).[1]



EPA has added Diisononyl Phthalate (DINP) category to TRI listing.[2,3]

1 – EDF et al, Petition for Reconsideration, Docket No. FDA-2016-P-1171 (6/21/22). 2 - Addition of DINP Category, 88 FR 45089 (2023). 3 – ACC's High Phthalates Panel on Misleading Claims Regarding Food Contact Materials and Phthalates (1/18/24).

More Chemicals in Plastics

"use of PFOS, PFOA, and related substances (precursors) was in the manufacturing of side-chain fluorinated polymers… These polymers are used as linings for food containers and wrappers"[1]

Fast Food Contact Paperboard[2]
20% Contain Fluorine

Fast Food Contact Papers[2]
46% Contain Fluorine

"These [toxic] chemicals are not labelled on *textile* products, rendering it virtually impossible for consumers to make informed purchasing decisions and for recyclers to recycle these products safely."[1] – the same goes for packaging.

1 – UNEP, Chemicals in Plastics: A Technical Report (2023) 2 – Schaider et al., Fluorinated Compounds in U.S. Fast Food Packaging, Env. Sci. & Tech. Letters, 4, 105-111 (2017).

National Recycling Strategy (DRAFT, 2020)

EPA's strategy has three objectives to strengthen the U.S. recycling system:

1. Reduce Contamination
2. Increase Processing Efficiency
3. Improve Markets

→ Approach for Plastics:

a. Understand system flows and barriers to increased recycling
b. Profile processes and impacts
c. Polyethylene terephthalate (PET) as first plastic / system to study

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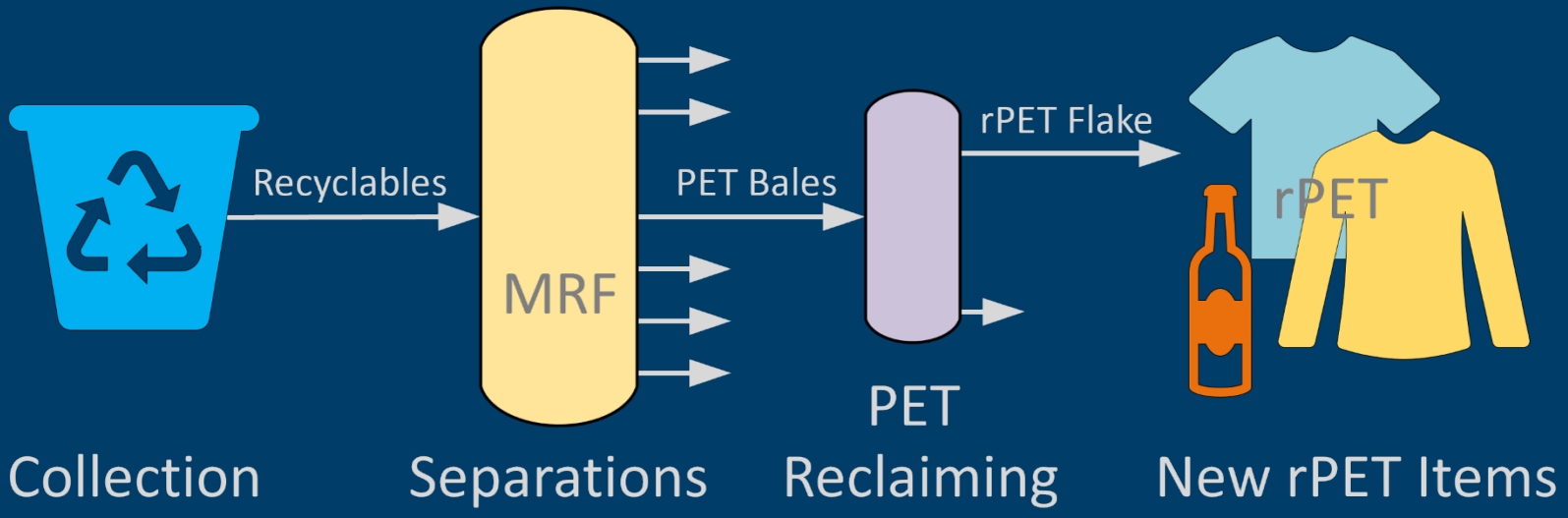
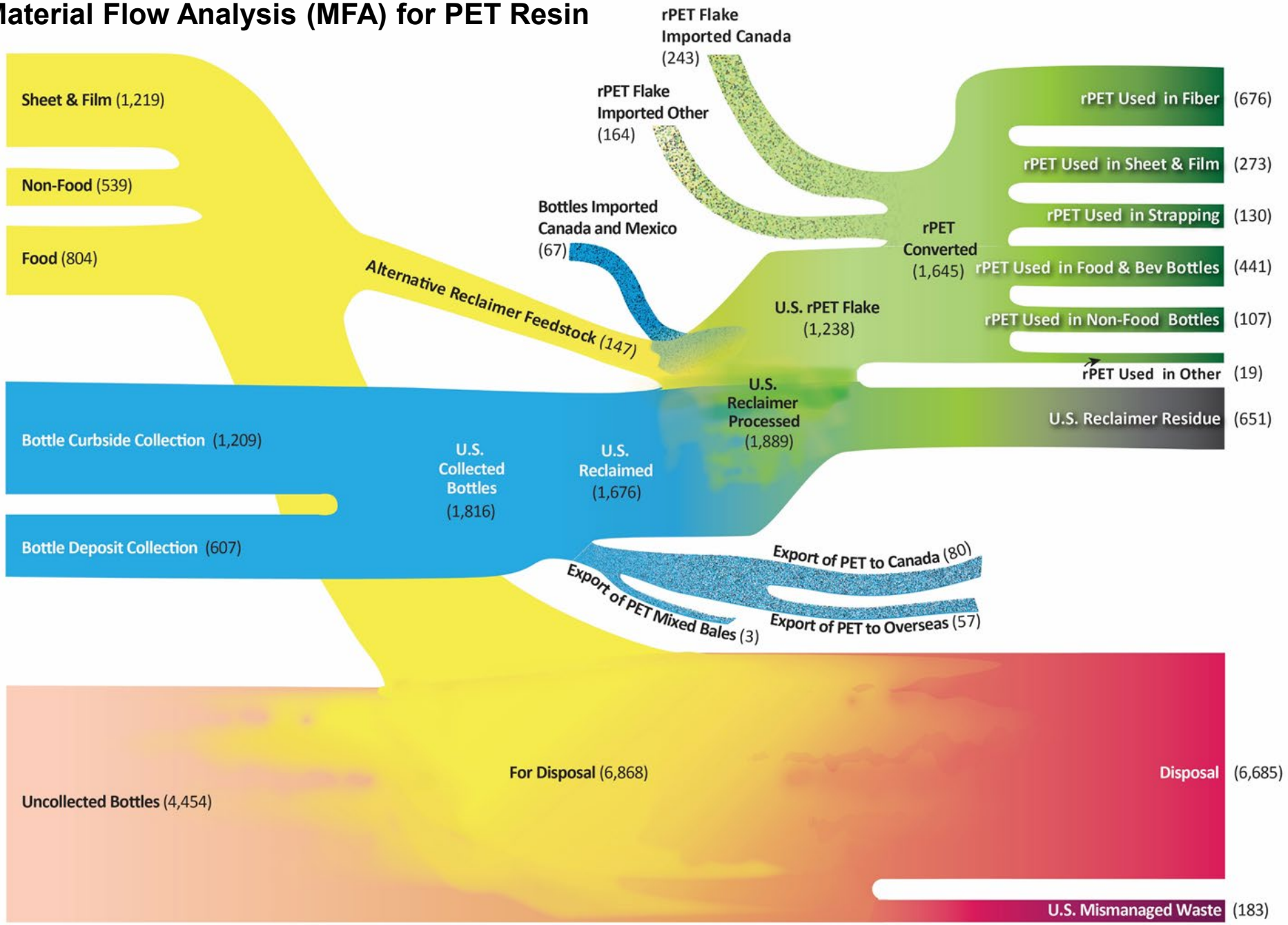
Recycling in the U.S.



Material Flow Analysis (MFA) for PET Resin



Adapted from NAPCOR (2019) *Postconsumer PET Recycling Activity in 2018*. Flows of PET resin in MMlb.

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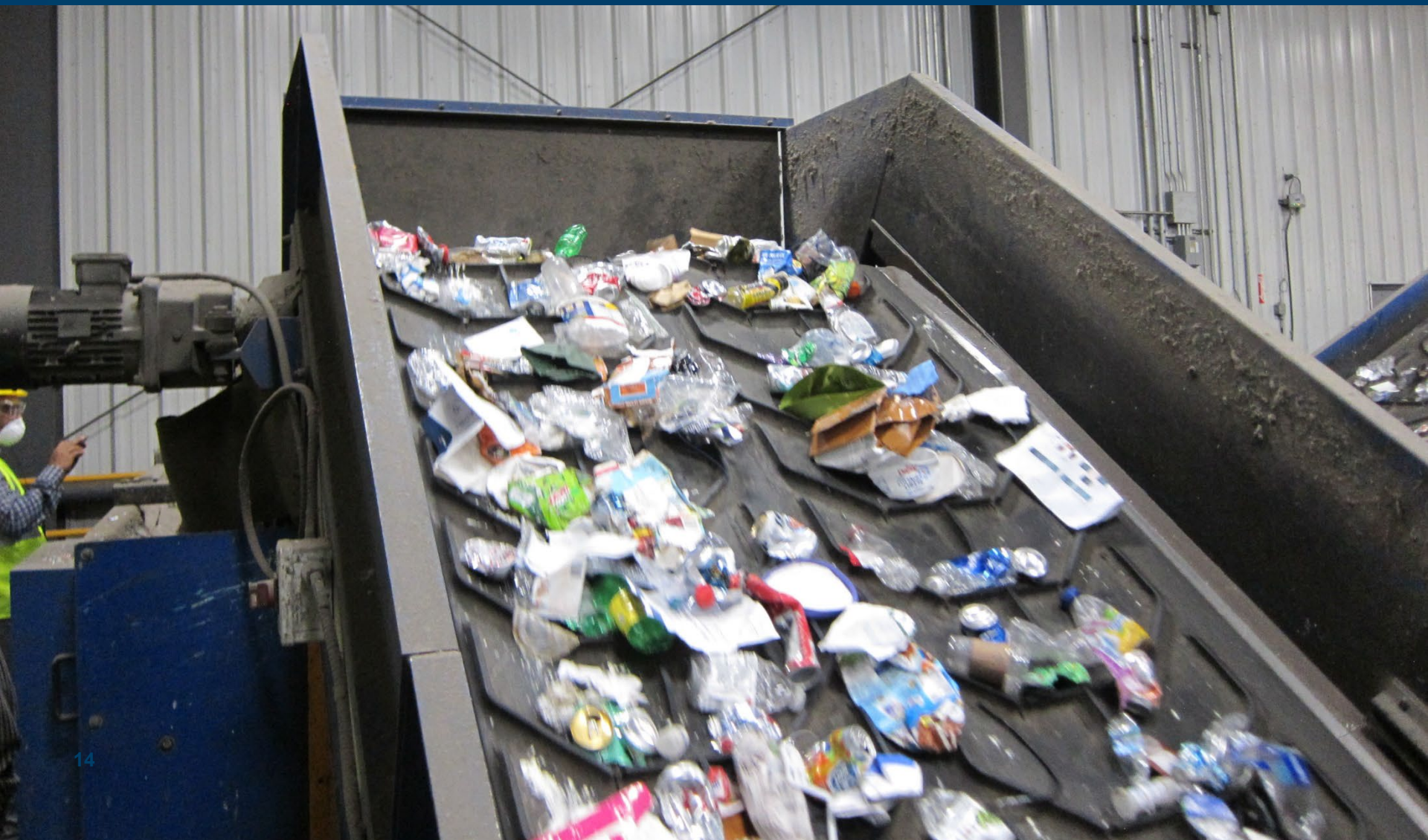
Material Recovery Facilities

Material Recovery Facility Separations

Separations: Nonsharp (or Sloppy) Splits



Material Recovery Facility (MRF) Separation Rates

% of Incoming Streams Leaving in Each Output Material

Process	Pre-sort for Bulk Plastics	Pre-Sort for Rejects	Disc Screen 1	Fiber Rejects Bunker	Disc Screen 2
Output Materials	Bulk Plastics	Rejects	OCC	Fiber Rejects	Mixed Paper
Newspaper (ONP)	0.03%	3.64%	0.13%	0.69%	94.91%
Bagged Newspaper	0.17%	37.36%	0.00%	22.96%	36.39%
Corrugated Cardboard (OCC)	0.06%	3.42%	43.88%	1.01%	50.56%

ONP = old newspapers
OCC = old corrugated containers

Augmented H. Damgacioglu et al. (2020) *Waste Management*, 102, 804–814; Separation Rate Table

PET-Item MRF-Sorted Output Material

Example Items are 1. Bottles with Caps and Labels, 2. Clamshells with Labels

PET Bale output material is
95.8% PET items.
6.1% of PET items are dirt and water residue.
11.7% of PET items are other materials (HDPE, adhesive).

Therefore, the PET Bale is 78.0% PET, so even for this "great" example of recycling plastics, there are barriers to increased recycling.

	PET Optical Sorter PET Bale
PET Bottles	89.0%
Natural HDPE Bottles	0.1%
Colored HDPE Bottles	0.3%
Non-Bottle PET	6.8%

Part of Separation Rate Table for PET Bale Output Material

Reclaiming PET – Removing Unwanted Impurities

Actual and Theoretical Performance

Reclaiming involves

1. Opening Bales
2. Sorting Out Unwanted Materials
3. Grinding the Plastics
4. Washing
5. Density Separation
6. Air Drying
7. Air Sifting

Yield is 97% of PET during reclaiming, resulting in 75.7% PET from original PET Bale.

This compares to 65.5% of PET flake reclaimed from collected bottles according to the Material Flow Analysis (MFA) diagram. Theoretical model appears to present an opportunity for better performance.

Process Profiles: Resource Use and Emissions per Metric Ton of MRF and Reclaimer Feed

Resource Use or Release	Units	MRF	Reclaimers
Electricity	kWh / ton of feed	13.7	251.7
Diesel Use	L / ton of feed	0.75	0.75
Baling Wire	kg / ton of feed	1.559	--
Natural Gas	scm / ton of feed	0.516	0.051
Sodium Hydroxide	ton / ton of feed	--	0.0047
Water Use	ton / ton of feed	--	0.188
Wastewater	L / ton of feed	0.631	188
Diesel Storage Emissions	kg / ton of feed	2.3×10^{-6}	2.5×10^{-6}
Greenhouse Gases	kg CO2 equiv. / ton of feed	8.58	103.7
Additional Emissions	Detailed in Supporting Info of Journal Article*	-	-

R.L. Smith et al. (2022). *ACS Sustainable Chemistry & Engineering*, 10, 2084-2096.

Paper vs Plastic

Generalizations about Differences in Recycling Systems for Two Materials

Category	Paper	Plastic
Who	Businesses	Households
Where	Commercial	Single-Family Homes
When	On Own Schedule	Community Schedule
How	Sorted to Reclaim	Single Stream to MRF
Why	Policy	Good Thing to Do
What	Cardboard, Office Paper (i.e., all are the same material, wood fiber)	#1 PET #2 HDPE #3 PVC #4 LDPE #5 PP #6 PS #7 Other

Plastics in Flux

Changing Systems, Many Unknowns, and Research Opportunities

EPA's Office of Resource Conservation and Recovery

EPA's U.S. Environmentally-Extended Input-Output (USEEIO)

China National Sword

Basel Convention

COVID-19

Pressure from Ellen MacArthur Foundation

Brand Commitments

State and Local Actions

Chemical Recycling

Plastics #3-7 MFA and Process Profiles

Textiles

Microplastics

Additives and Processing Aids

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Other Current Project

Releases for occupational exposures