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Catalysis Made Plastics. Can Catalysis Unmake Them Too?

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Catalysis Made Plastics. Can Catalysis Unmake Them Too?

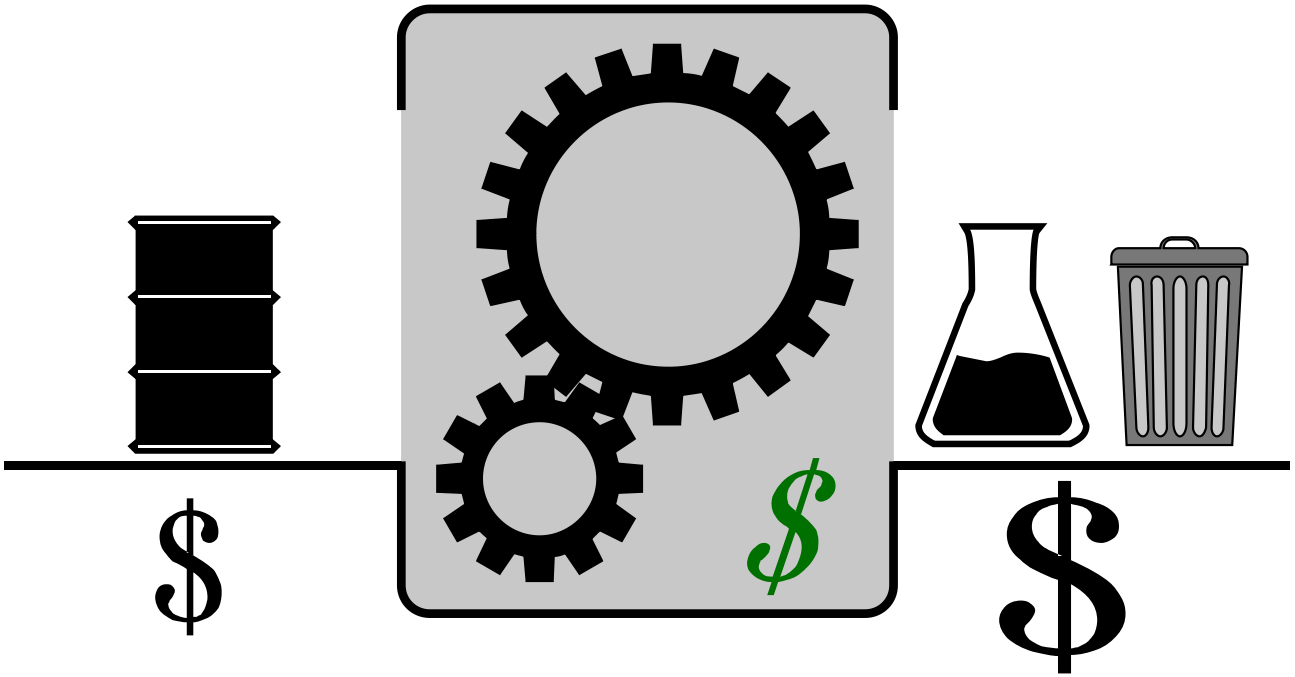
Production of industrial polymers is impossible without catalysis. In many cases, catalysts exert exquisite control over formation of molecular architecture and composition, yielding polymers with remarkable properties. Some applications release polymers into the environment both through unintended loss and through use profiles that create release. We must find solutions that eliminate persistent plastic in the environment. Desire to make plastics reusable faces many challenges. Polymers tend to degrade in processing, have the potential to carry contaminants through physical recycling, and improved physical properties of virgin polymers loom large, making infinite recycling of polymer problematic. “Chemical recycling” even wrinkles faces with confusion at an ACS meeting. “Monomerization” is actually already a word describing what we want to do; controlled decomposition of polymers to form monomers. Returning polymer to monomers is appealing, but technically difficult. Catalysis will surely be part of the solution as we are asked to use less, recycle more and to make those polymers that are released to the environment more degradable. We are entering a new era where catalysis is being asked to undo, to disassemble what it assembled. Creative solutions and new approaches are needed, turning waste into opportunity.

Challenges facing the chemical industry (which is really the plastics industry).

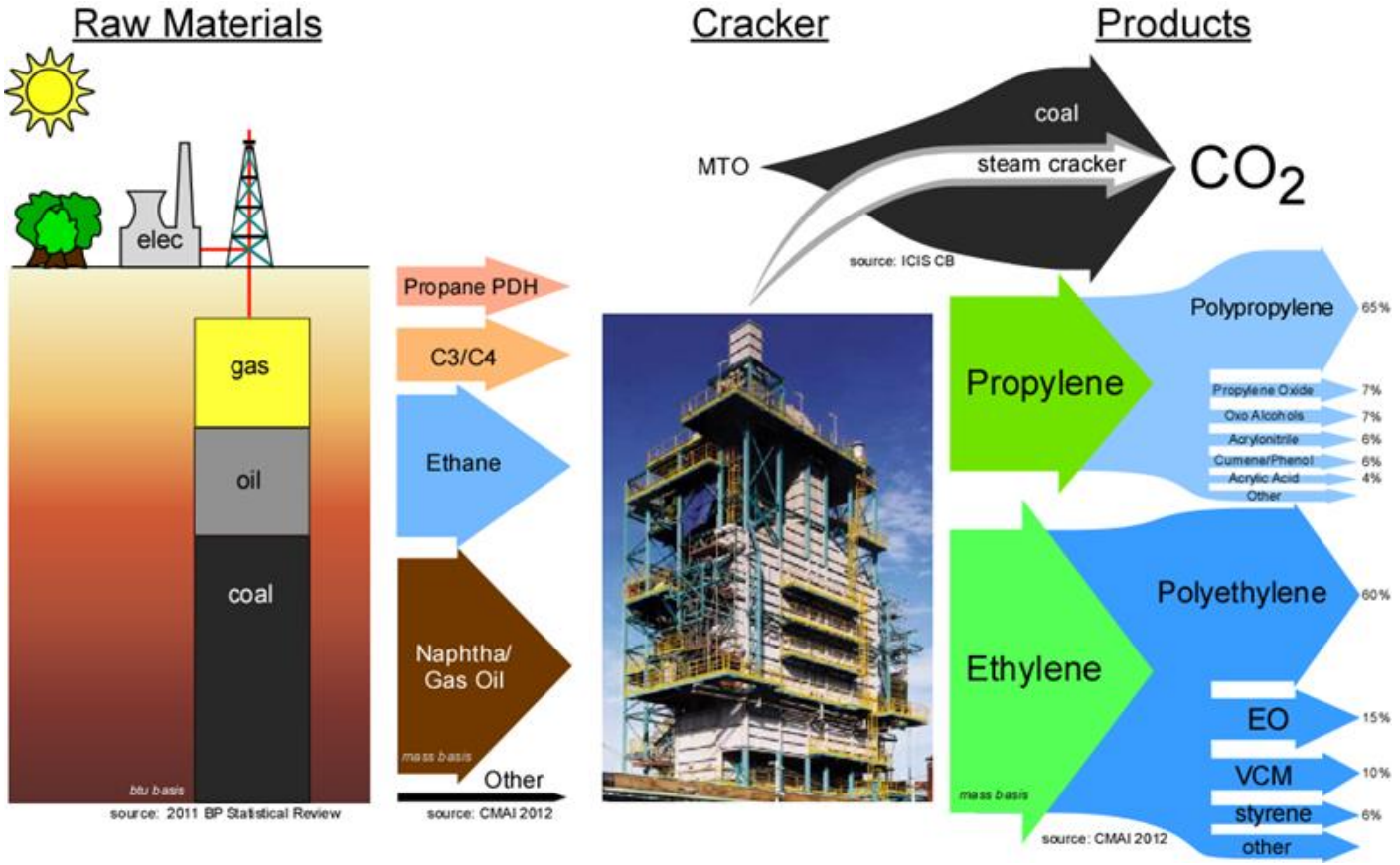
Incumbency is a hurdle.

Creative solutions are needed.

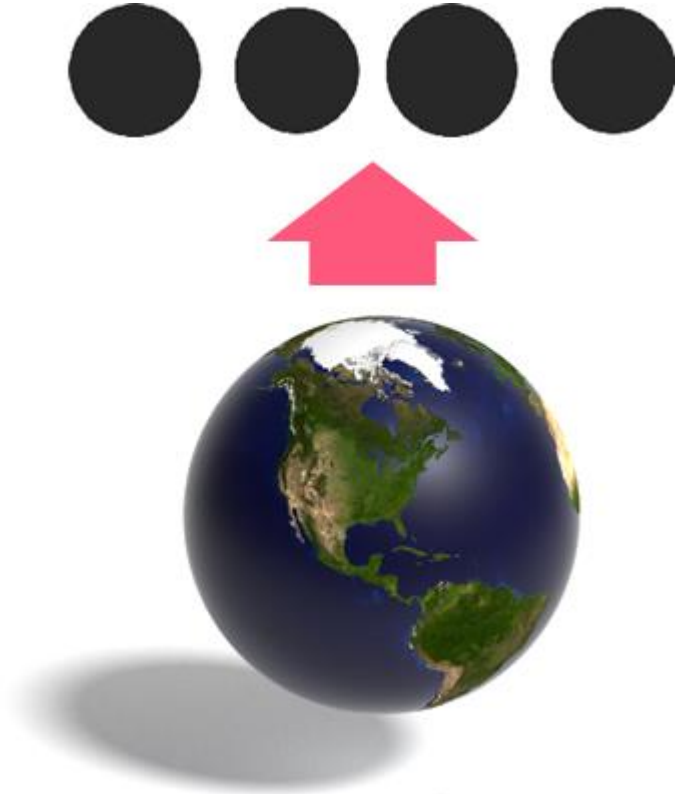
Simplified Chemical Industry



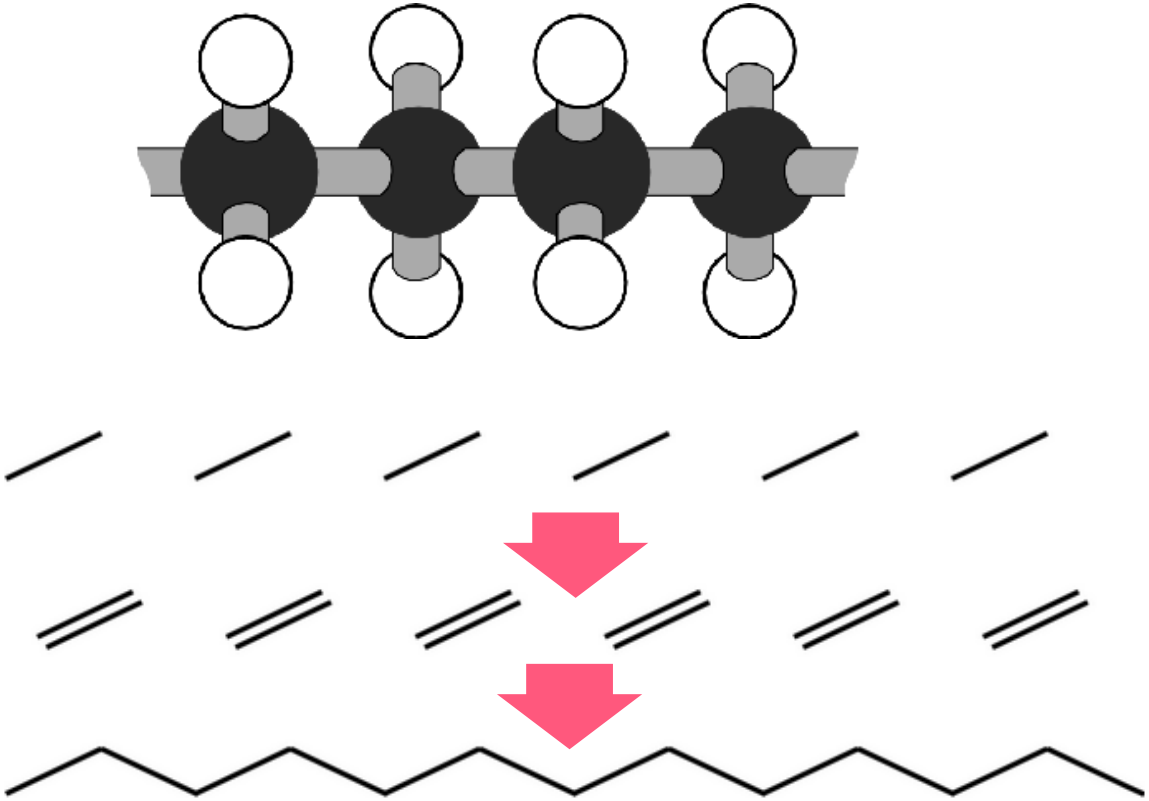
Modern Chemical Industry



Rough Industry Mass Balance

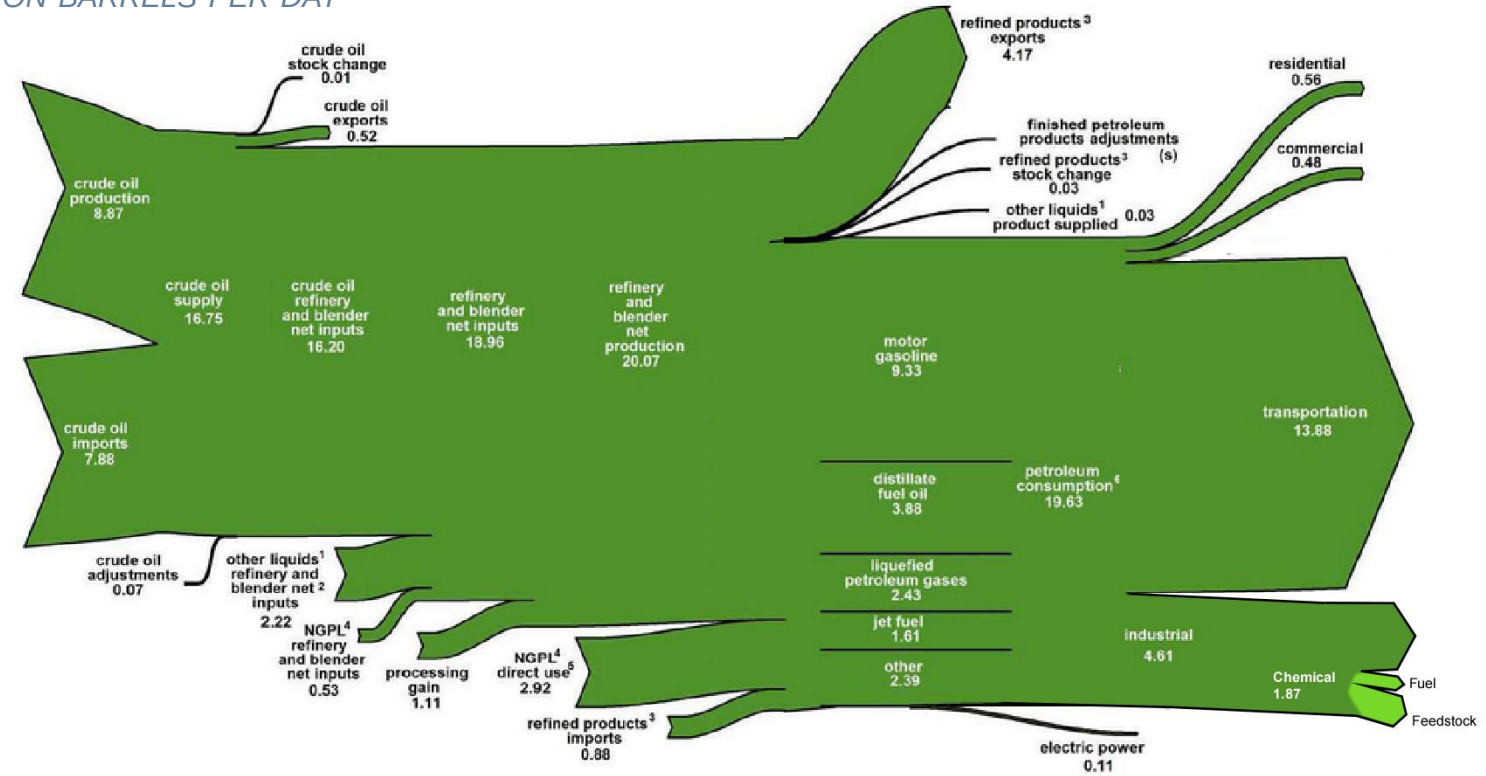


Chemical Transformation



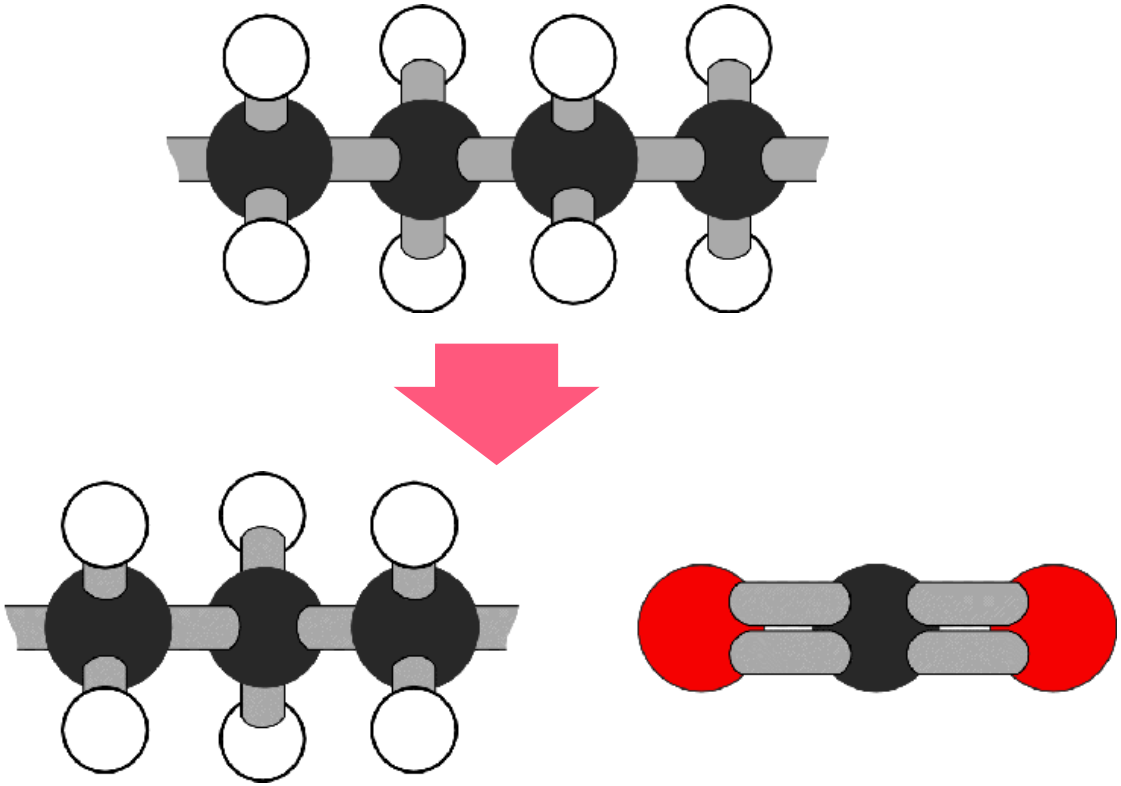
US Petroleum Flow, 2016

IN MILLION BARRELS PER DAY



EIA Monthly Energy Review, September 2017 (Release Date: September 28, 2017)
Lippe, Dan; *Oil & Gas Journal*, 4 Sept 2017, pg 82.

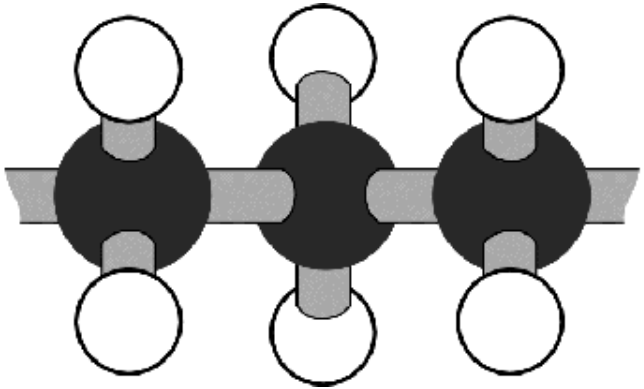
Rough Mass Balance

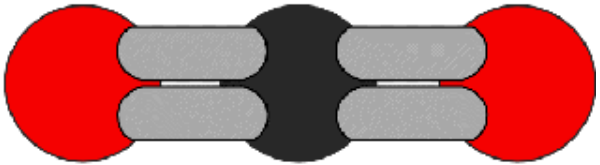


IMPLICATIONS

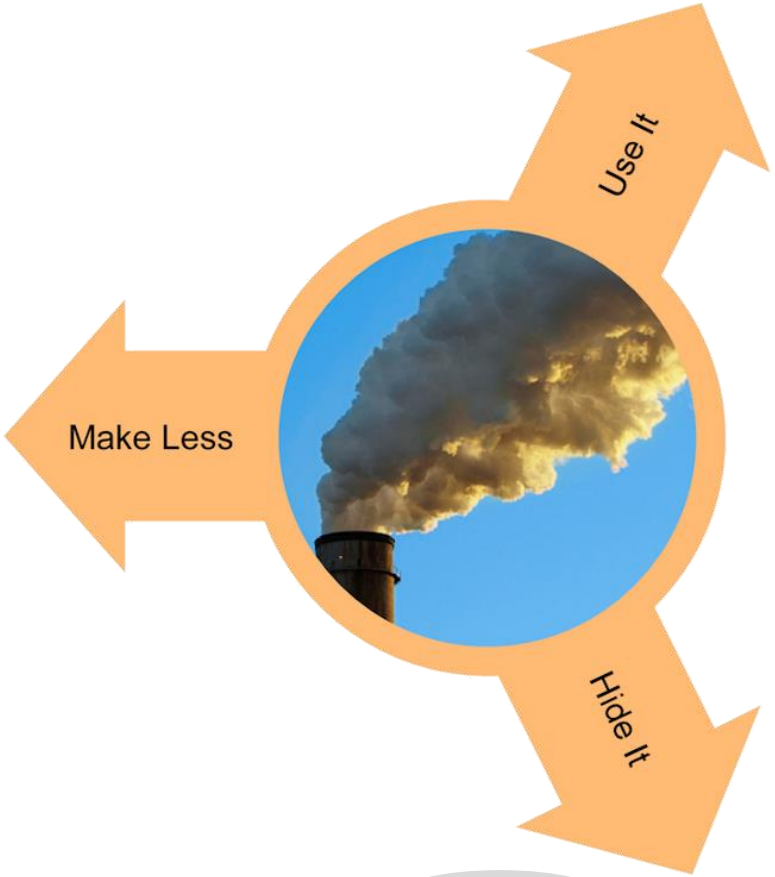
EPA 2.59 lb CO2/lb black

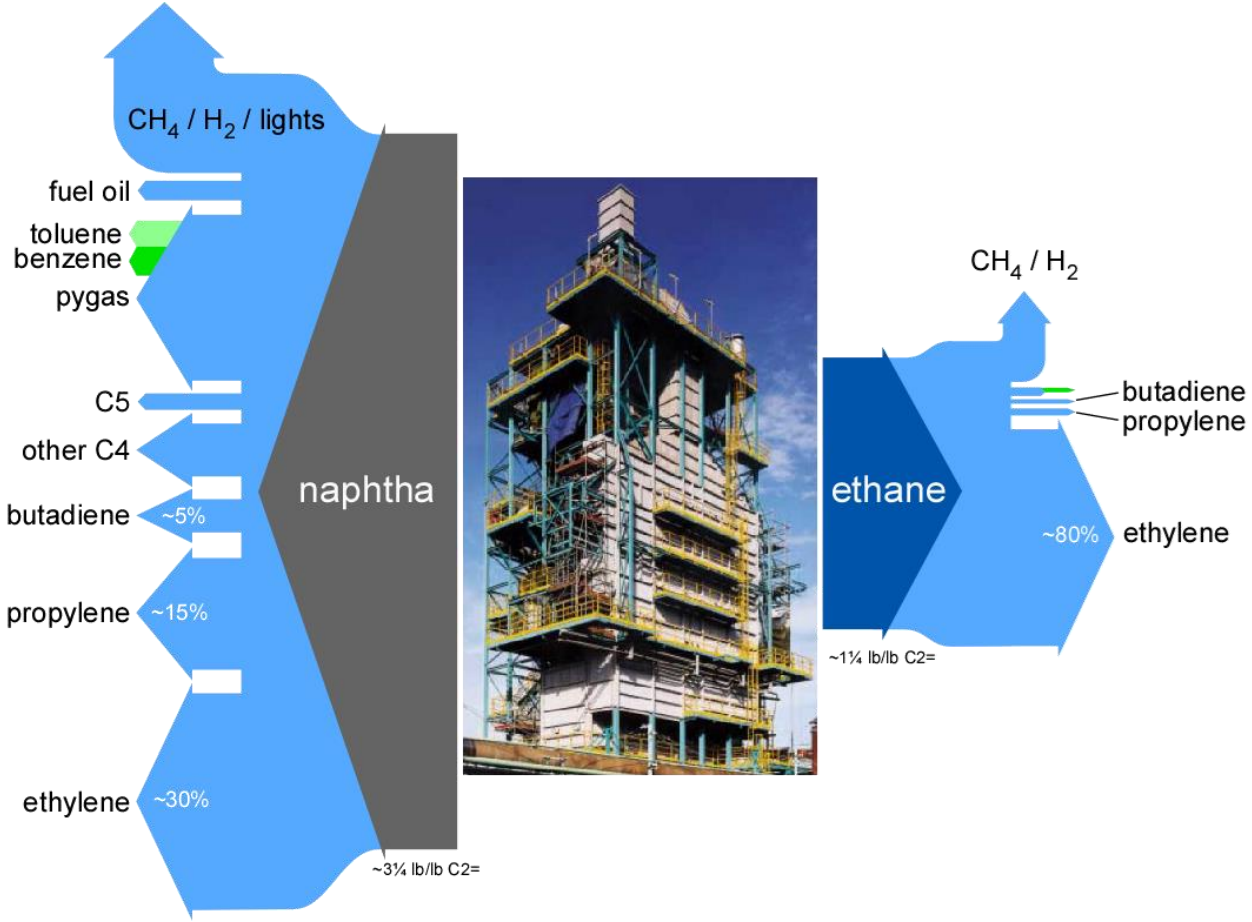
~5 carbons out of ground
2 go to CO2
3 go to CB
(12 out, 5 burned, 7 product is closer)

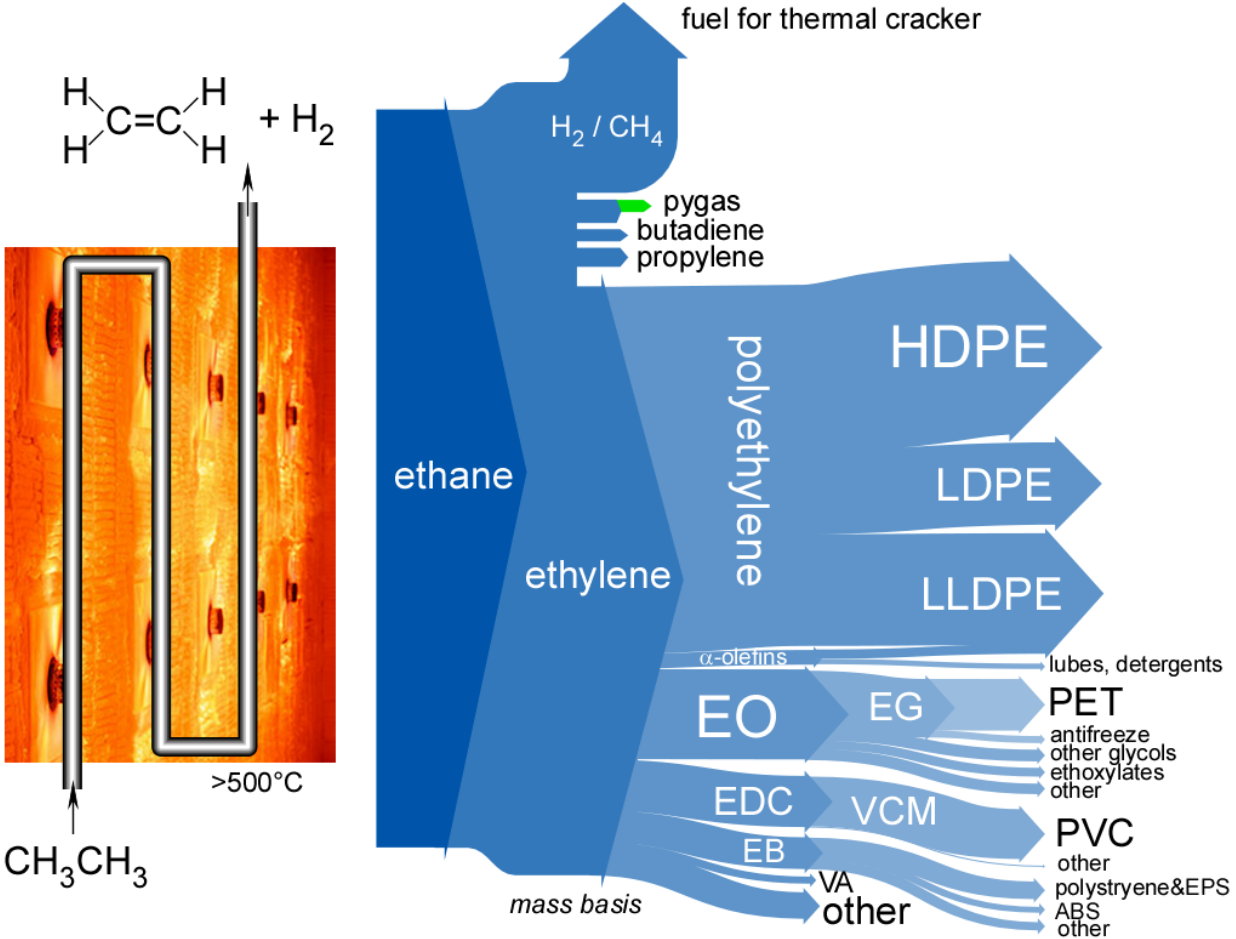




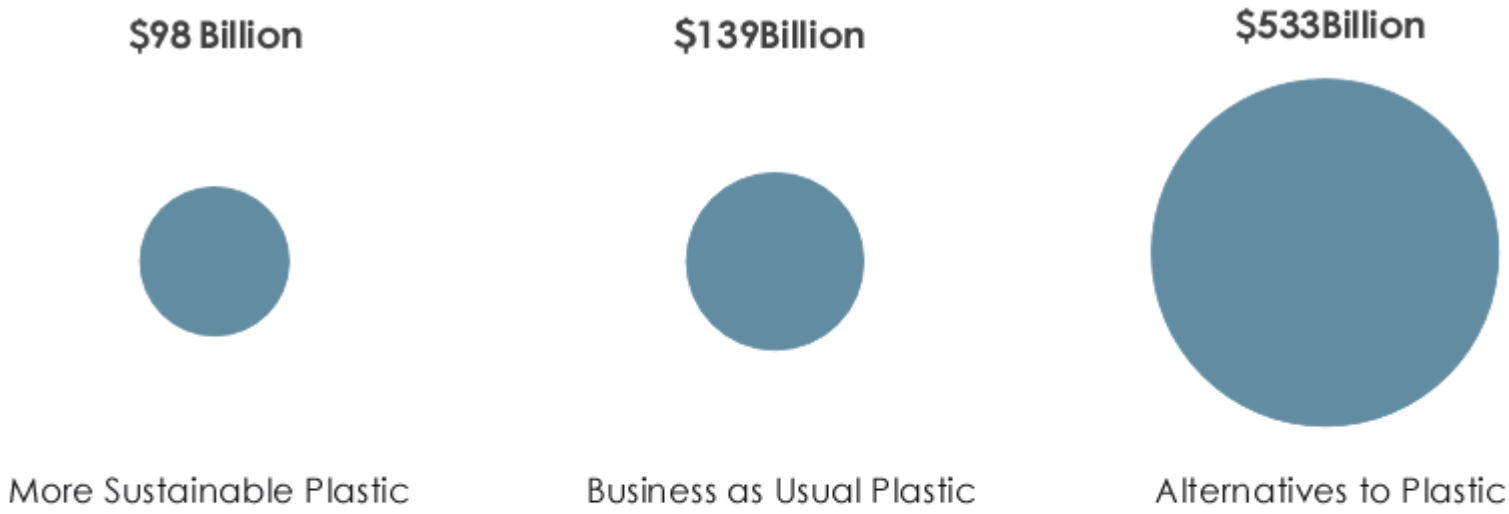
Options For CO_2




CH_4 / H_2 / lights
fuel oil
toluene
benzene
pygas
C5
other C4
butadiene
~5%
propylene
~15%
ethylene
~30%
naphtha
~3¼ lb/lb C2=
CH_4 / H_2
butadiene
propylene
ethane
~80%
ethylene
~1¼ lb/lb C2=


+ H_2
>500°C
CH_3CH_3
fuel for thermal cracker
H_2 / CH_4
pygas
butadiene
propylene
ethane
ethylene
polyethylene
HDPE
LDPE
LLDPE
α-olefins
lubes, detergents
EO
EG
PET
antifreeze
other glycols
ethoxylates
other
EDC
VCM
PVC
EB
other
VA
polystryene&EPS
other
ABS
other
mass basis

Alternatives Cost More



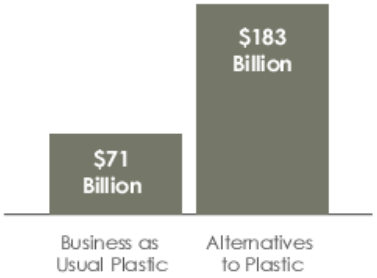
The cost of using alternative materials is approximately four times that of using plastic (in a business as usual scenario). We're producing more and more consumer goods, so choosing the material that creates the least impact is important.

Source: Trucost

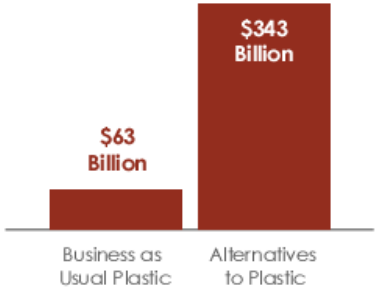
Source: American Chemistry Council TRUCOST report

Alternatives Have Higher Environmental Costs

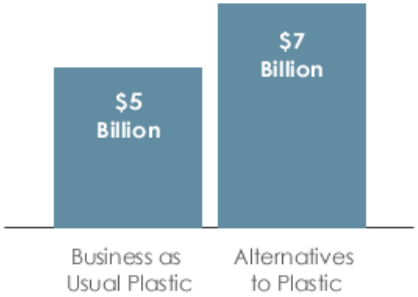
Climate change



Damage to the health of humans and ecosystems



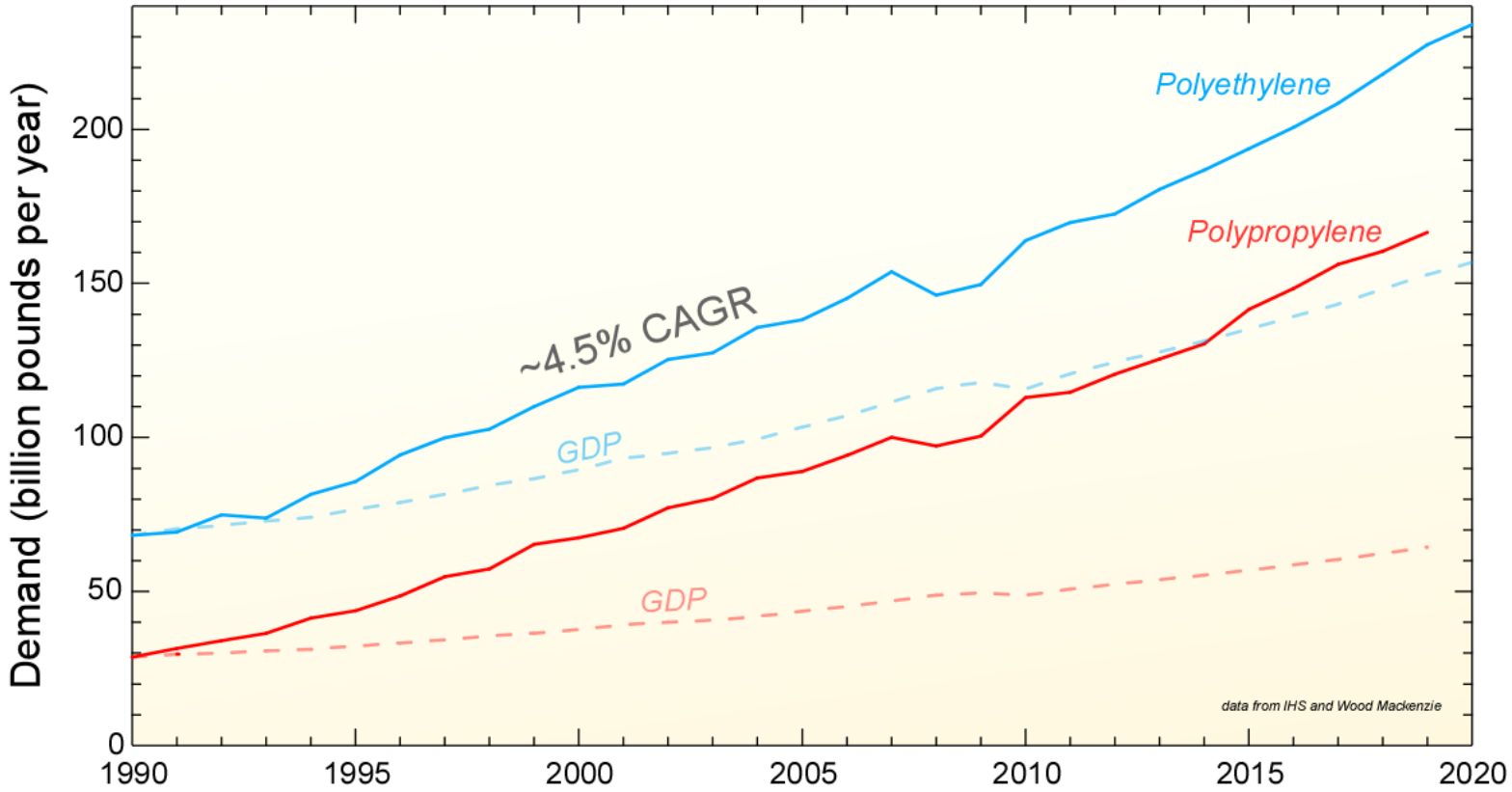
Damage to the oceans



All dollar values are in USD
Source: Trucost

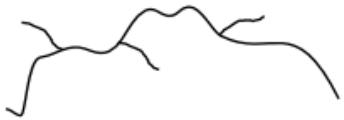
Source: American Chemistry Council TRUCOST report

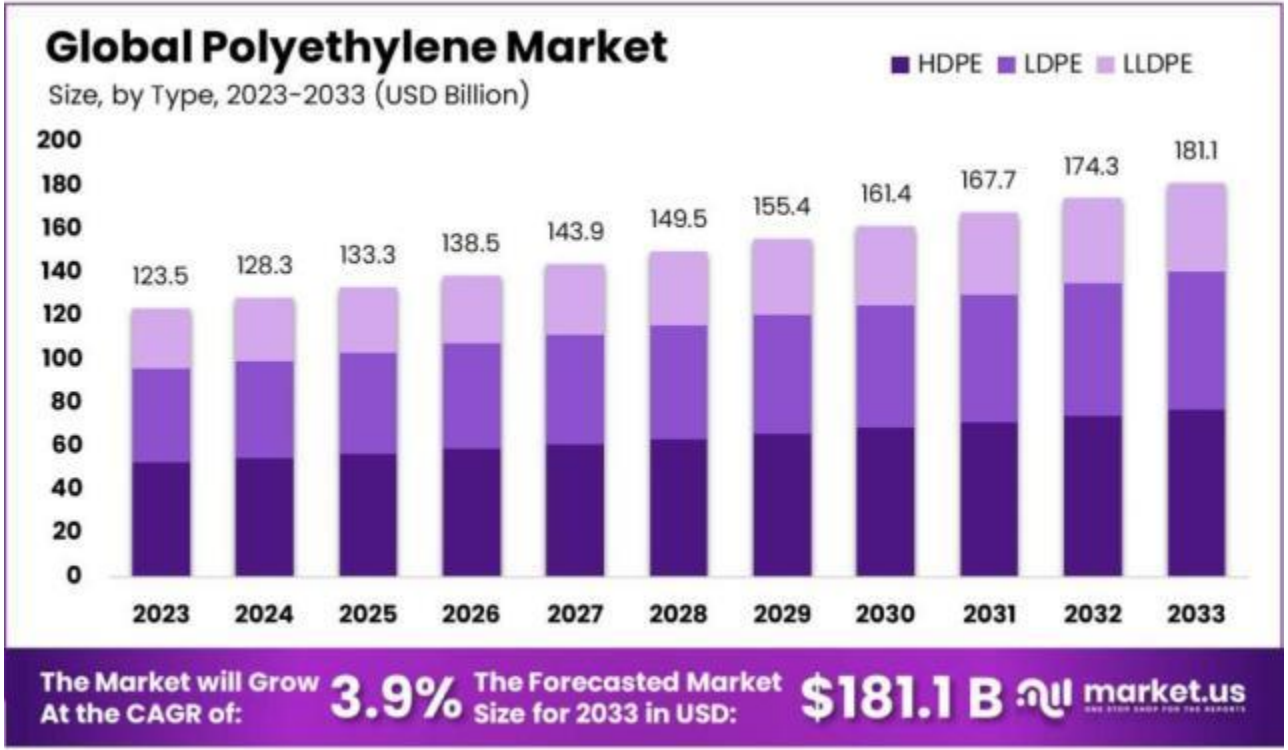
GROWING >GDP

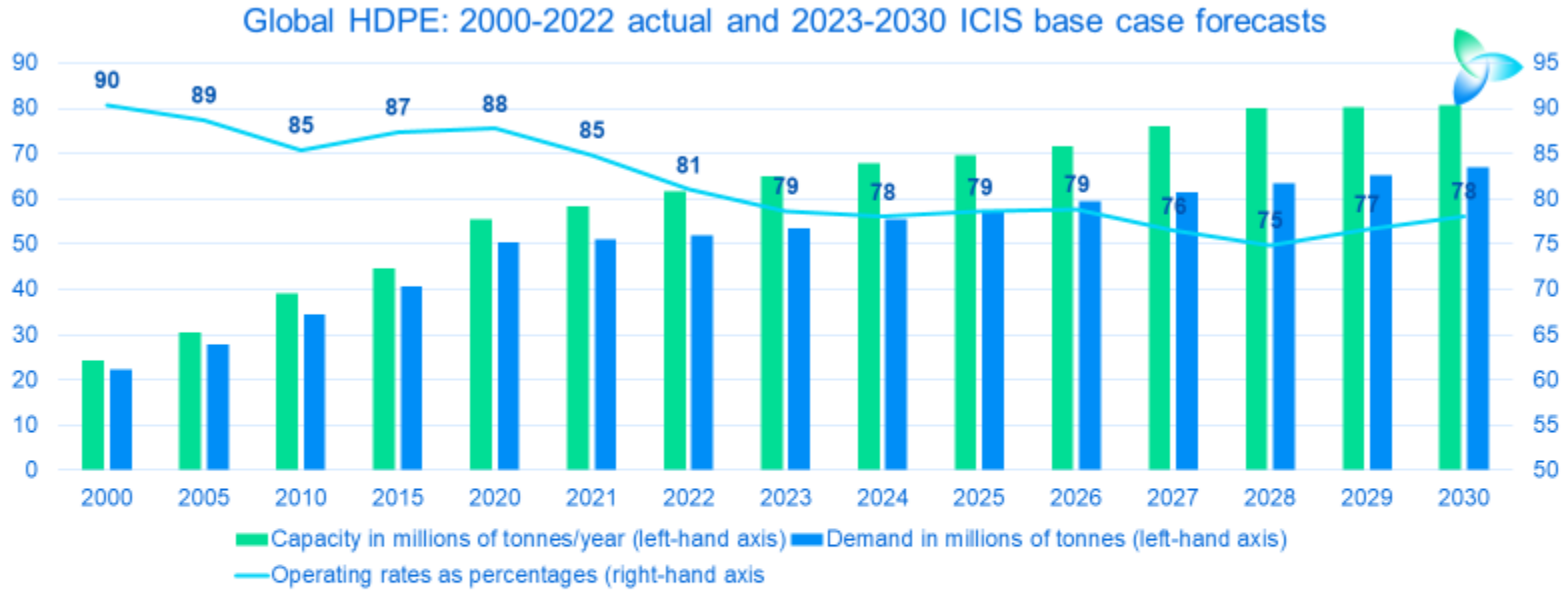

Demand (billion pounds per year)
0
50
100
150
200
1990
1995
2000
2005
2010
2015
2020
Polyethylene
Polypropylene
~4.5% CAGR
GDP
GDP
data from IHS and Wood Mackenzie

Three Kinds of Polyethylene

Polyethylene

LDPE	**LLDPE**	**HDPE**
		
high-pressure radical polymerization	catalytic co-polymerization of ethylene and α-olefin	organometallic catalysis
lots of branching	controlled branching	limited branching
low density polyethylene	*linear low density polyethylene*	*high density polyethylene*

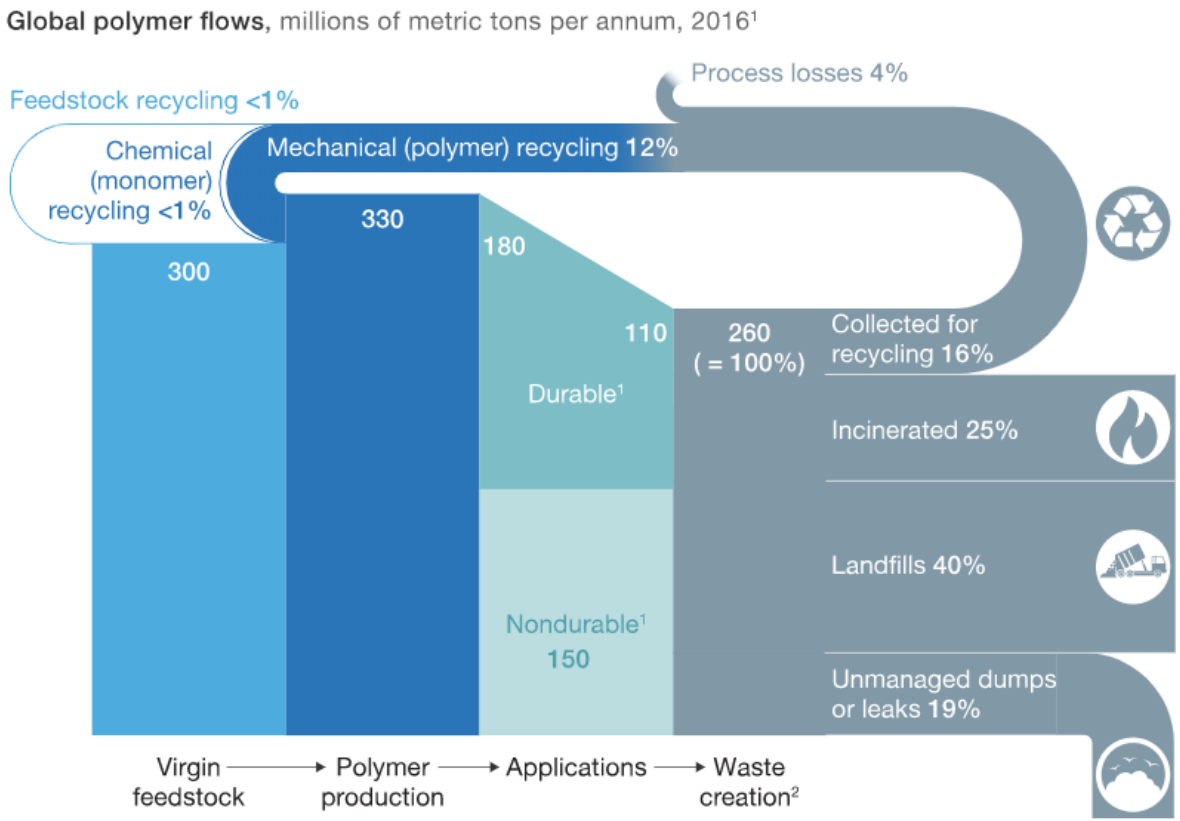

Global Polyethylene Market
Size, by Type, 2023-2033 (USD Billion)
HDPE
LDPE
LLDPE
200
180
160
140
120
100
80
60
40
20
0
123.5
128.3
133.3
138.5
143.9
149.5
155.4
161.4
167.7
174.3
181.1
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
The Market will Grow At the CAGR of:
3.9%
The Forecasted Market Size for 2033 in USD:
$181.1 B
market.us



Average annual capacity exceeding demand was 4m tonnes in 2000-2019 with the operating rate at 88%. But annual average annual capacity exceeding demand is forecast to be 12m tonnes in 2020-2030 with the operating rate at 79%.

ICIS Supply & Demand Database

Where Does Plastic Go?



U.S. TRASH

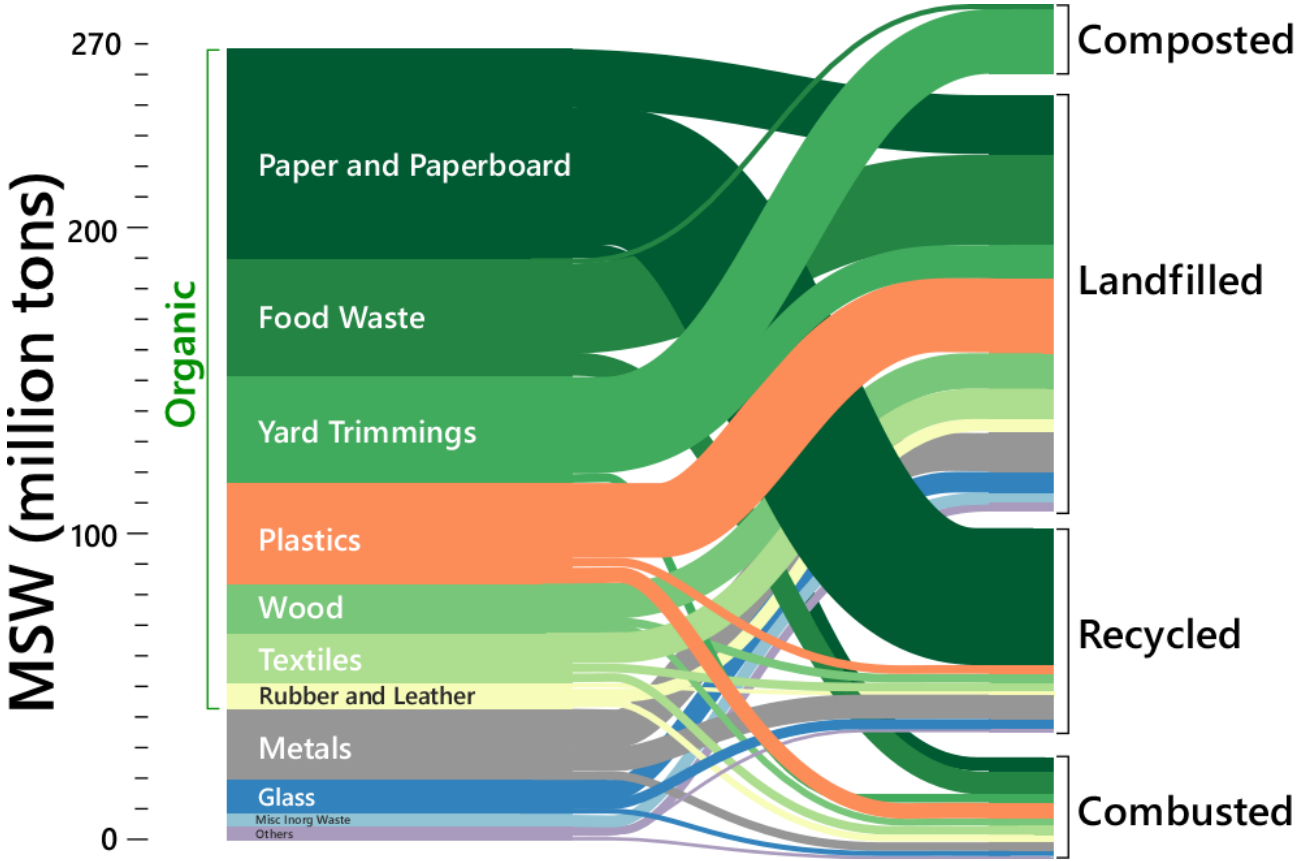
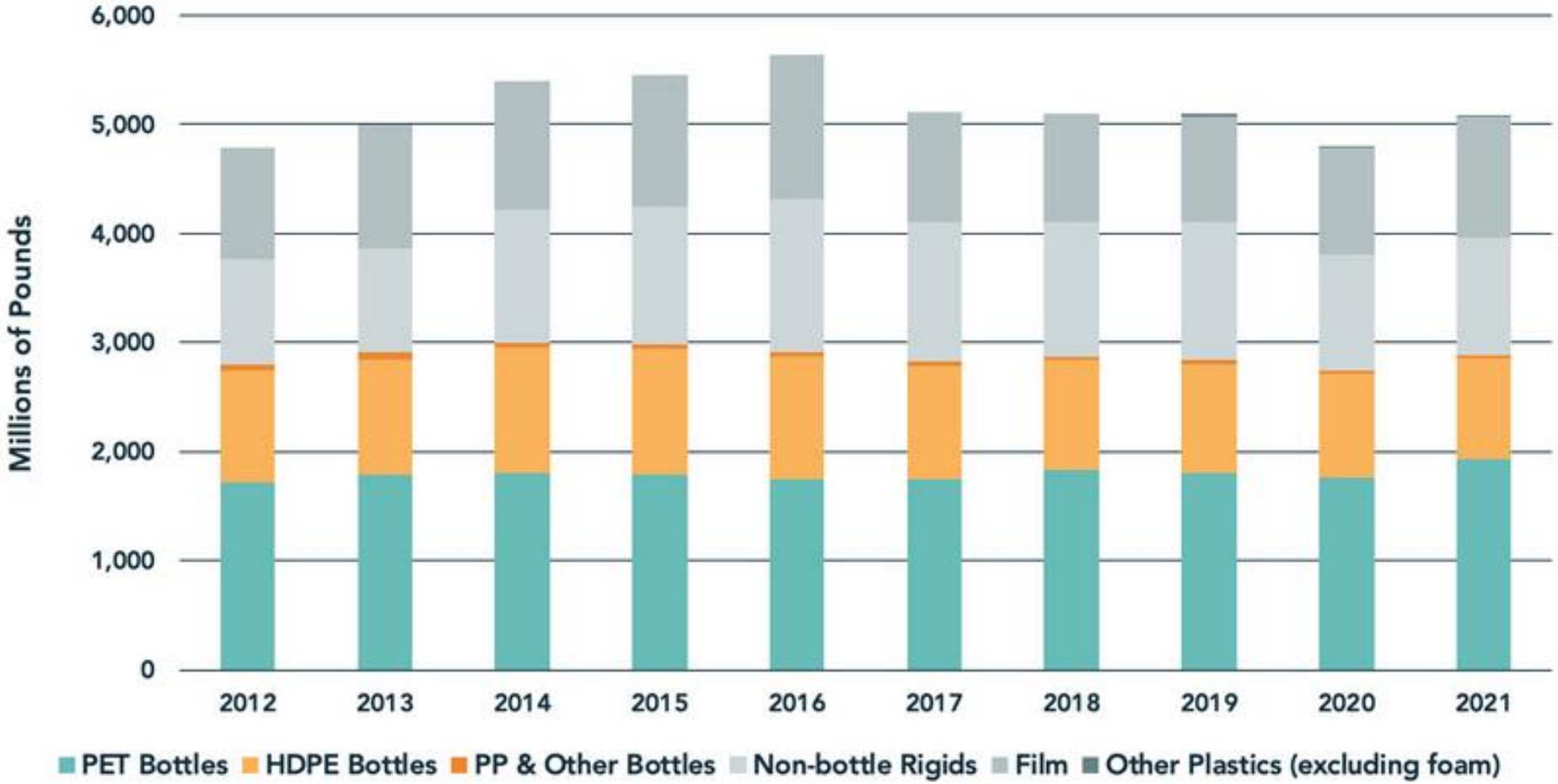

MSW (million tons)
270
200
100
0
Organic
Paper and Paperboard
Food Waste
Yard Trimmings
Plastics
Wood
Textiles
Rubber and Leather
Metals
Glass
Misc Inorg Waste
Others
Composted
Landfilled
Recycled
Combusted

Figure 1. U.S. Sourced Post-consumer Plastic Recovered for Recycling by Category



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https://circularityinaction.com/2021PlasticRecyclingData

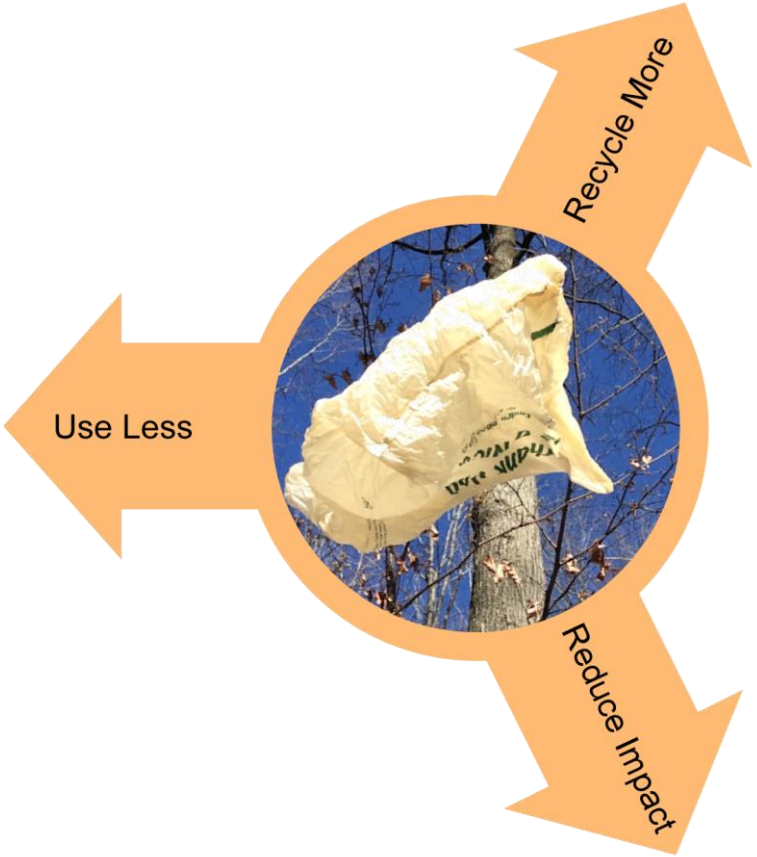
Table 1. U.S. Sourced Post-consumer Plastic Recovered for Recycling by Category

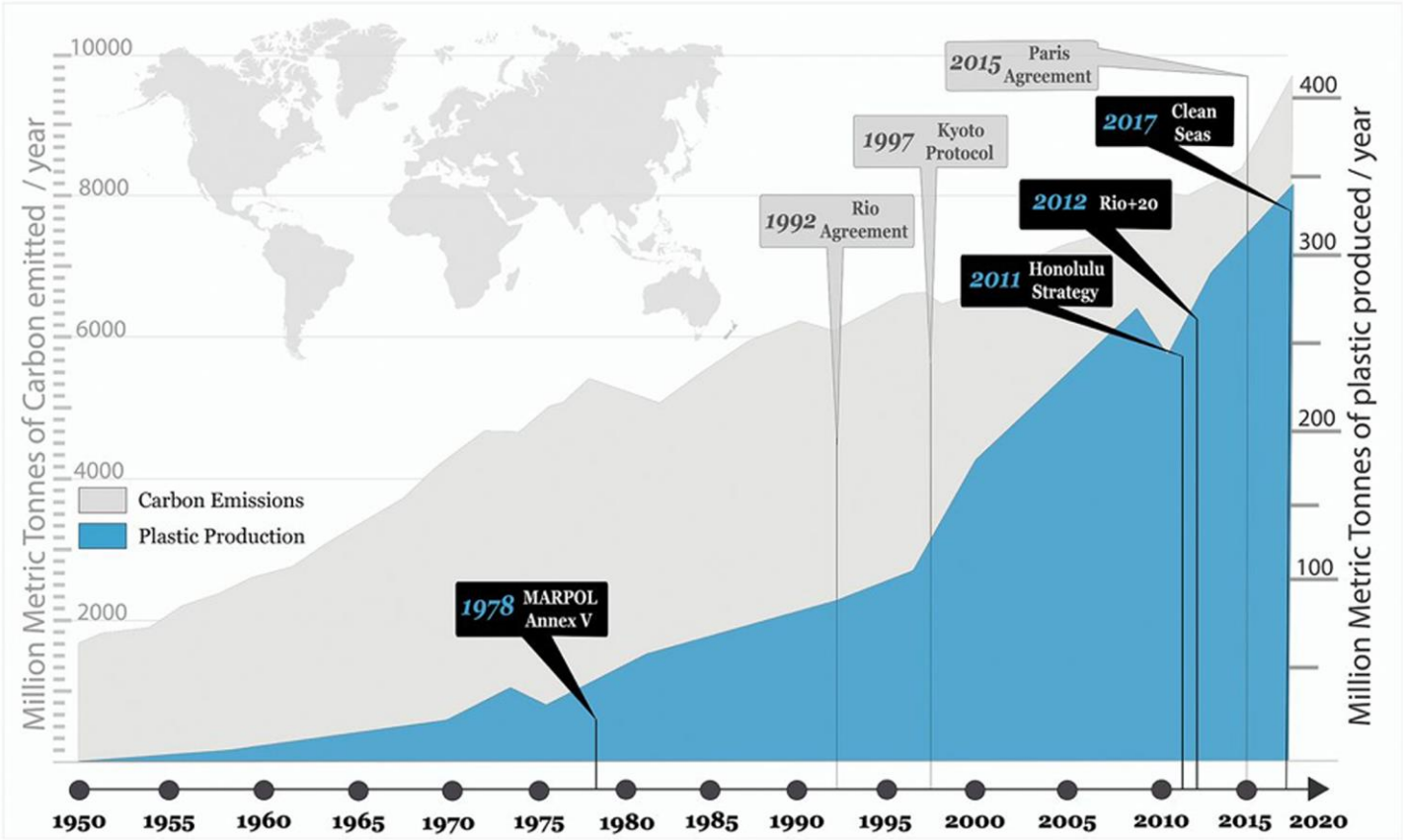
Plastic Category	Total Recovered for Recycling in 2021 (Millions of Pounds)	Total Percent Change Since 2020	% Acquired by North American Reclaimers
PET Bottles	1,931.5	9.3%	96.9%
HDPE Bottles	927.2	-1.7%	99.2%
PP & Other Bottles	28.1	-15.8%	96.9%
Non-bottle Rigids	1,071.0	1.3%	88.5%
Film	1,106.2	12.2%	83.1%
Other Plastics (excluding foam)	20.2	22.4%	37.2%
Total	**5,084.1**	5.8%	**92.3%**

Total Recovered for Recycling in 2021 includes all destinations, including North America as well as Export Overseas.
Due to rounding, some totals may not correspond with the sum of the separate figures.

https://circularityinaction.com/2021PlasticRecyclingData

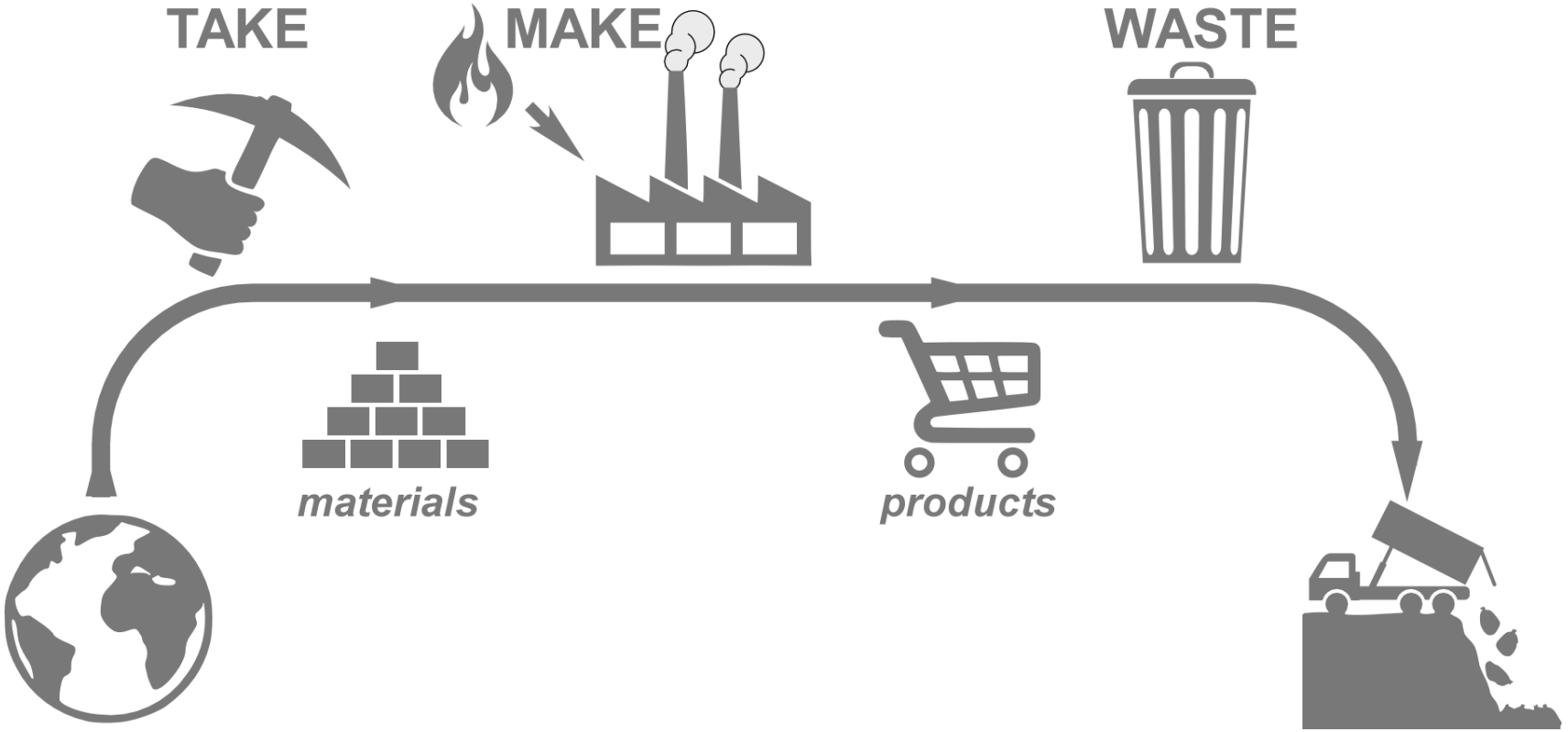
Possible Solutions



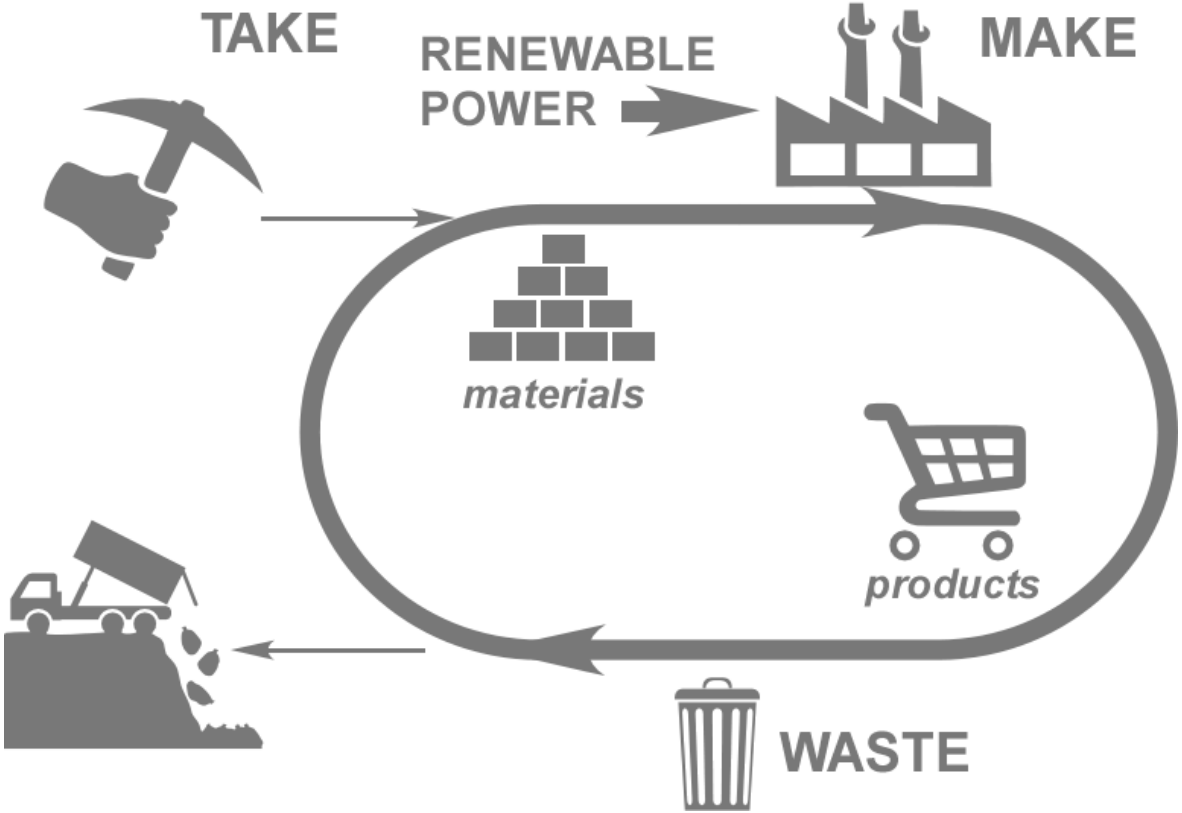


from Borrelle, PNAS September 19, 2017; doi.org/10.1073/pnas.1714450114

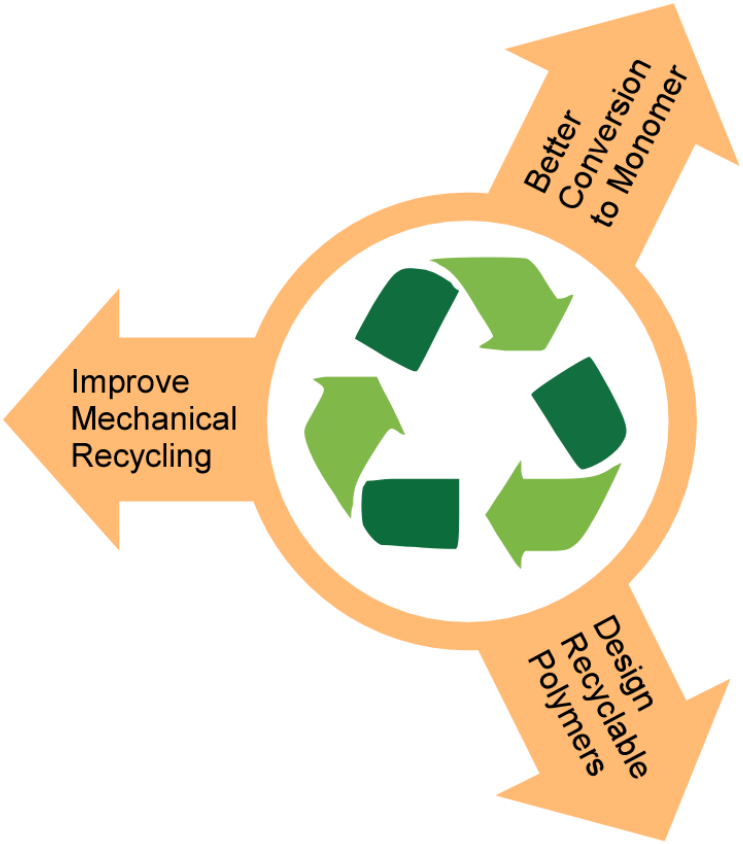
Linear Economy



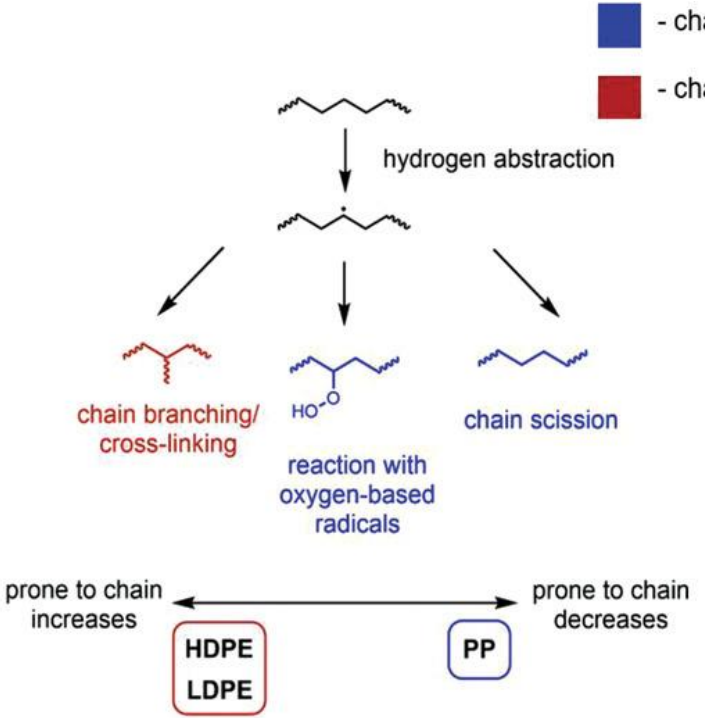
CIRCULAR ECONOMY

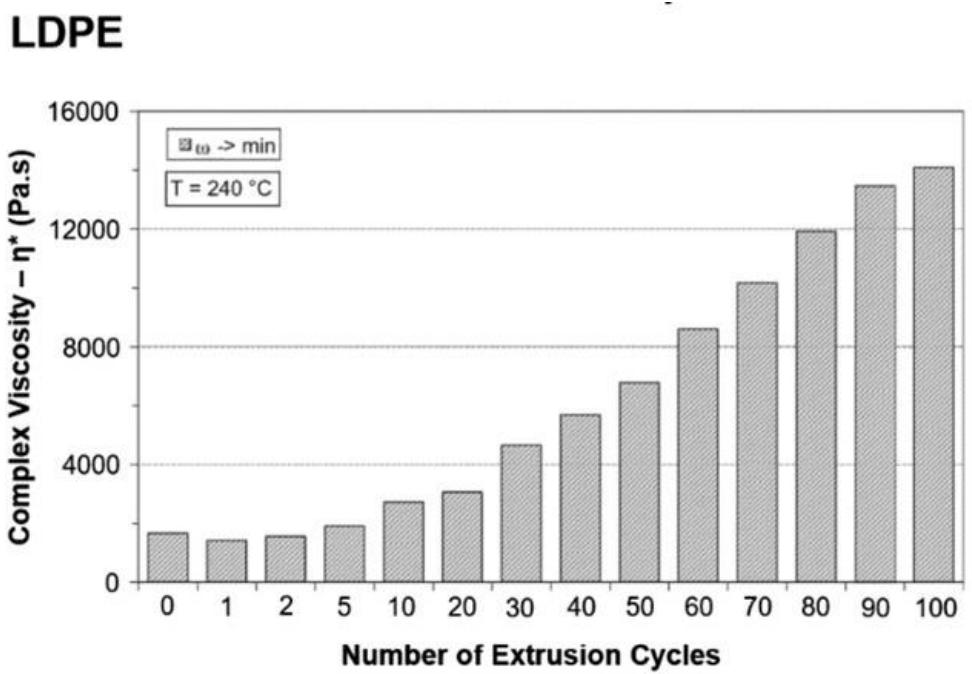


RECYCLING


Better Conversion to Monomer
Improve Mechanical Recycling
Design Recyclable Polymers

Degradation During Mechanical Recycling





https://onlinelibrary.wiley.com/doi/full/10.1002/marc.202000415

Waste Reduction Hierarchy

DOWNCYCLED PET

More Downcycled Content

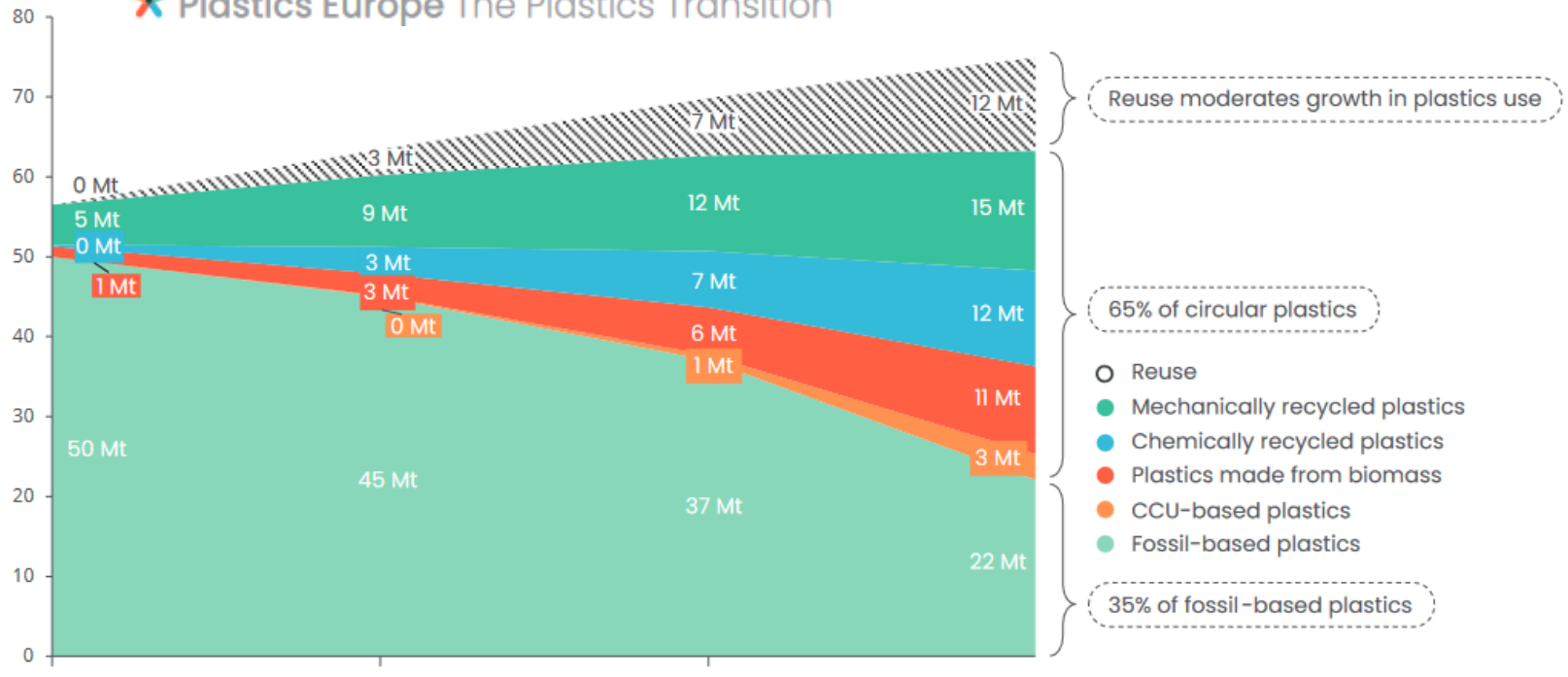

This road contains
recycled plastic
made possible by
DOW
Midland County
Road Commission

RECOVER


ENERGYBAG
THE PLACE FOR YOUR PLASTIC LEFTOVERS
IF YOU DON'T BIN IT, BAG IT
3-MONTH PILOT PROGRAM TO RECOVER NON-RECYCLED PLASTICS
ENERGYBAG
THE PLACE FOR YOUR PLASTIC LEFTOVERS


Hefty
ENERGYBAG
NON-RECYCLED PLASTICS
COLLECTION PROGRAM
20

Plastics Europe The Plastics Transition

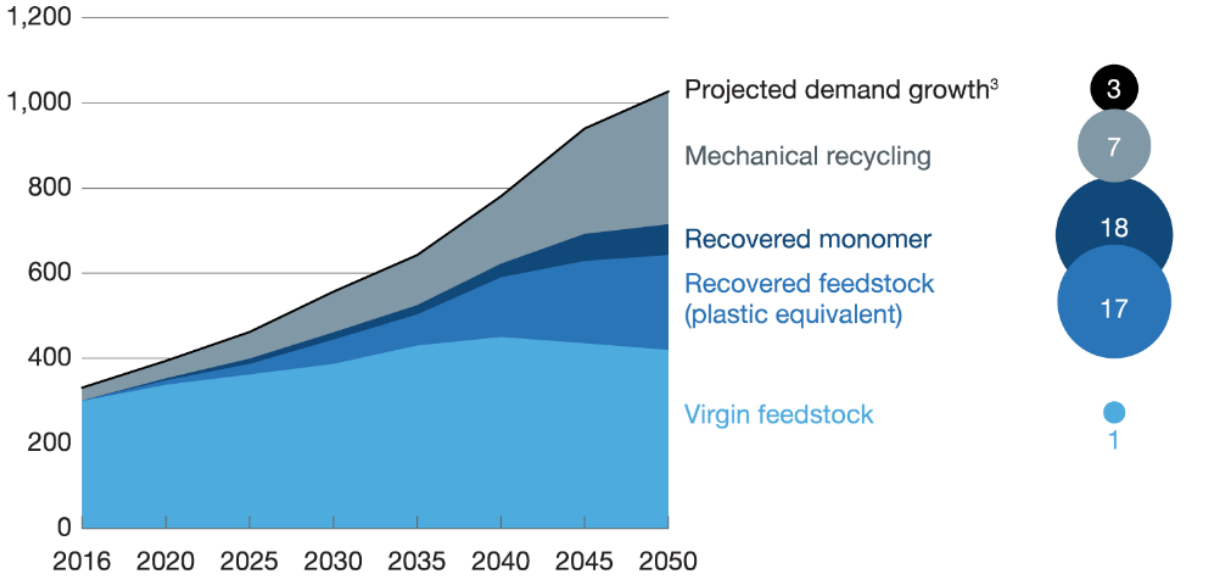


2021	2030	2040	2050	
57 Mt	60 Mt	62 Mt	65 Mt	Converter's use (in Mt)
12%	25%	40%	65%	% of circular plastics compared to total converter's use

https://plasticseurope.org/wp-content/uploads/2023/10/PlasticsEurope_Report_24.10.pdf

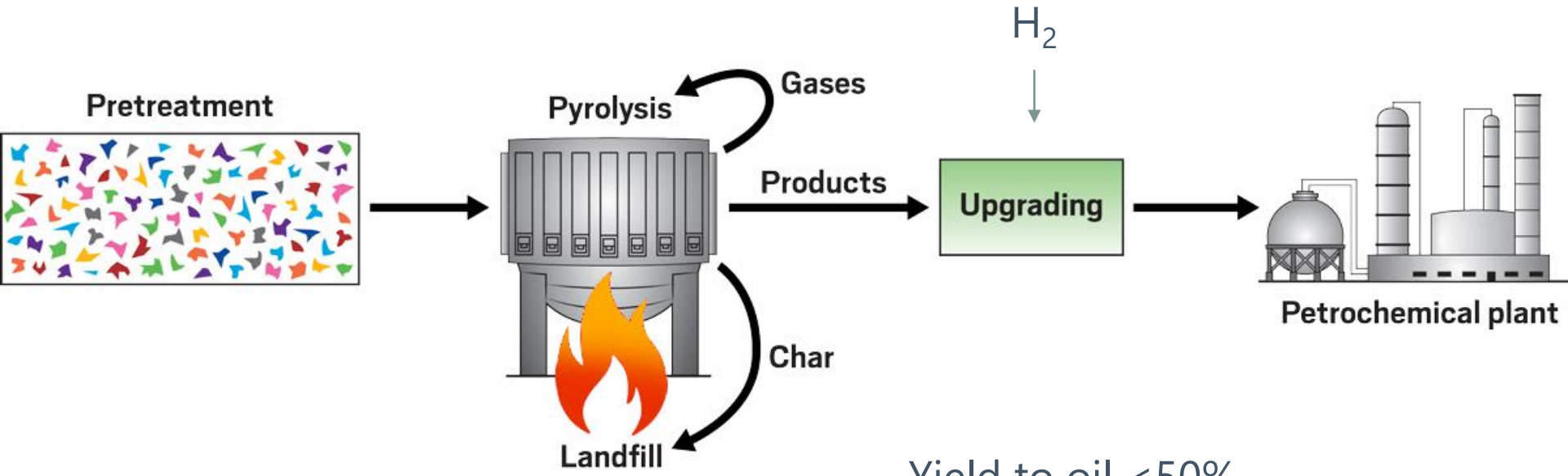
By 2050, nearly 60 percent of plastics production could be based on plastics reuse and recycling.

Global polymer demand 2016–50 and how it could be covered, millions of metric tons[1]

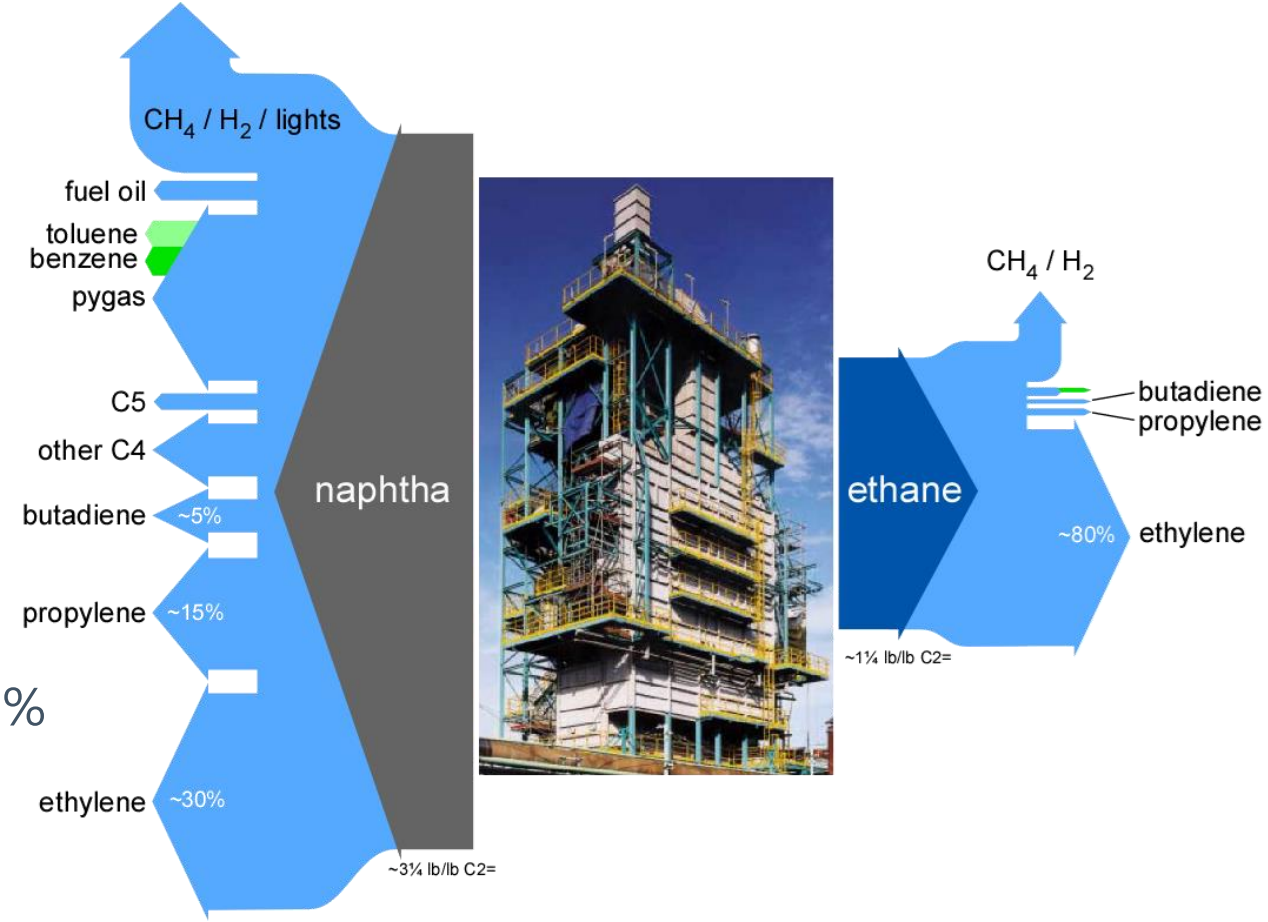


[1]Scenario based on a multi-stakeholder push to boost recycling, regulatory measures to encourage recycling, consistent progress on technologies, and $75-per-barrel oil price.
[2]Compound annual growth rate. Mechanical recycling limited by downcycling and applicable materials, monomerization limited by applicability to condensation polymers only, pyrolysis limited by likely rise in input costs.
[3]After demand reduction, assuming annual global GDP growth of 3.1%.

PYROLYSIS



Yield to oil <50%

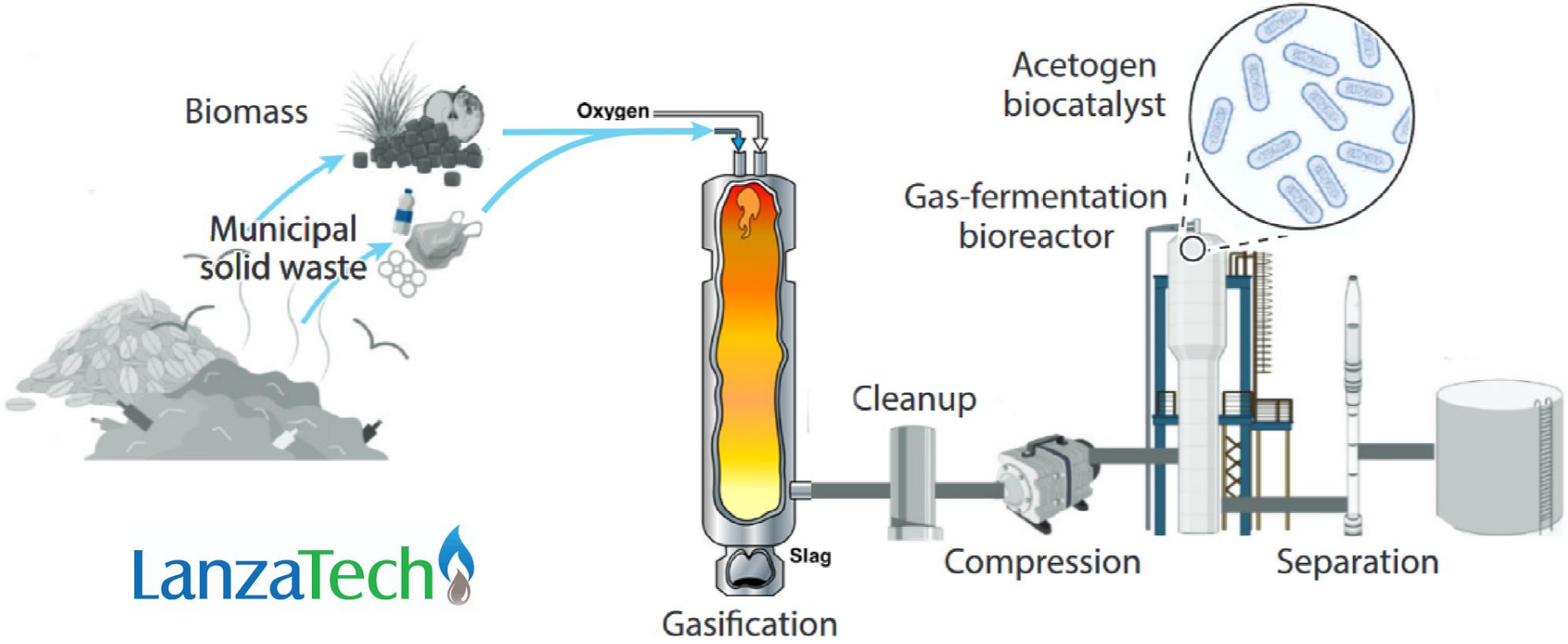


Yield to oil <45%

Pyrolysis Problems

- Yield
  - only ~50% to pyrolysis oil
  - yield to prime olefins is <25%
  - yield to ethylene from PE <15%
- Oil unsuitable without treatment
  - formation of aromatics and olefins
- Cost
- Emissions
  - NGOs use “incineration”

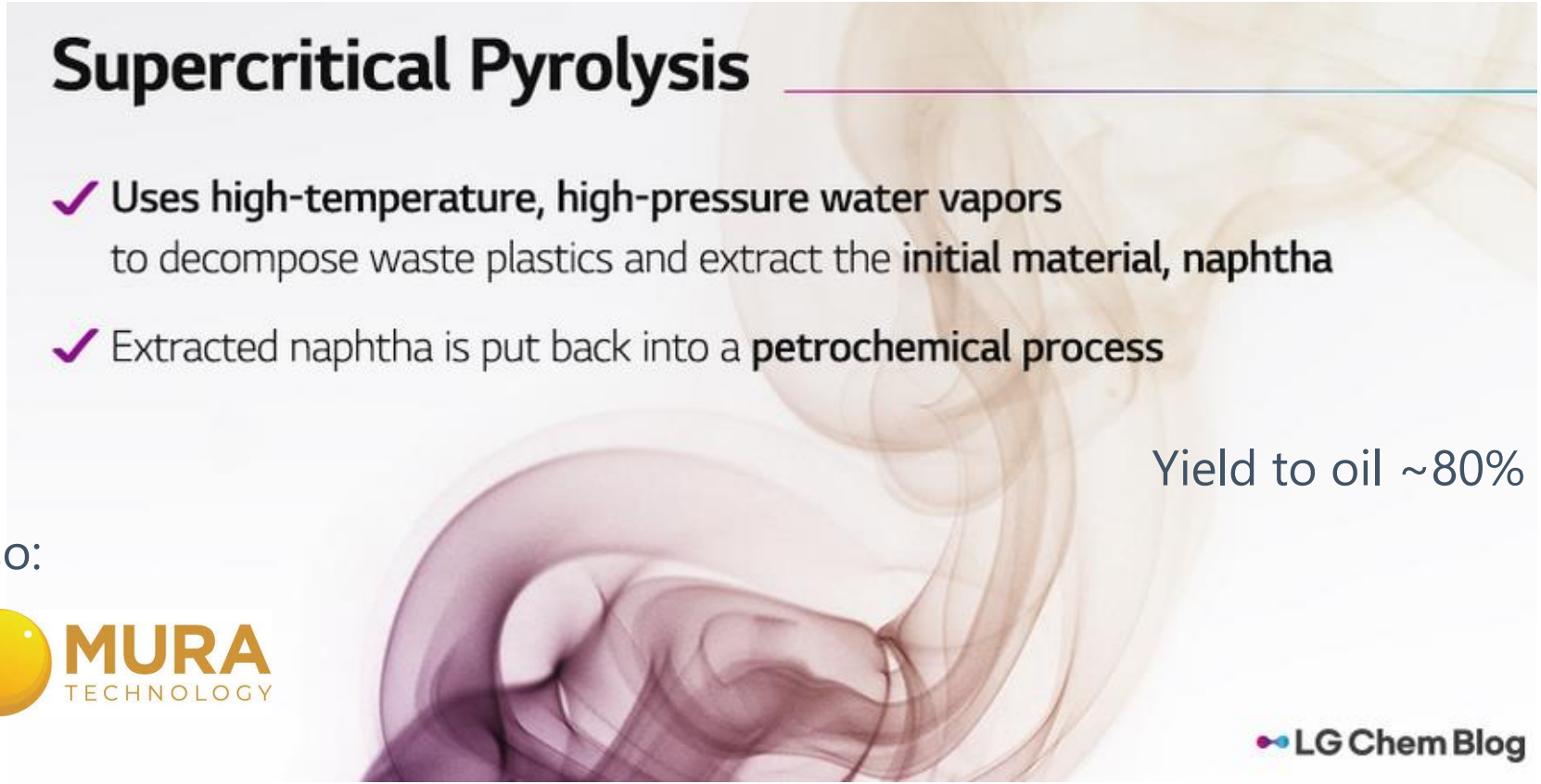
Syngas Fermentation



Syngas Fermentation Improvements/Problems

- Yield
  - ~75% to ethanol (molar)
  - near 75% to ethylene (ethanol near 100% to ethylene)
- Flexible for C2= and C3=
- Cost
  - gasification capital is high
- Emissions
  - still high
- Scales down well

Supercritical Pyrolysis



Also:

MURA TECHNOLOGY

ground broken on 20,000 tonnes per year in 2023

MAKING POLYPROPYLENE

LIKE NEW AGAIN

TODAY:
Traditional Life Cycle of Polypropylene (PP):

High-quality PP waste packaging goes to a recycling facility.

PP is downcycled into a gray, low-value resin.

Low-value resin is only fit for utilitarian applications.

1 2 3

TOMORROW:
With PURECYCLE

High-quality PP waste packaging goes to the PureCycle facility.

The PureCycle process removes dyes, odors and contaminants from PP, transforming it into virgin-like resin.

PureCycle resin completes the cycle and is ready to make product packaging again and again.

PURECYCLE

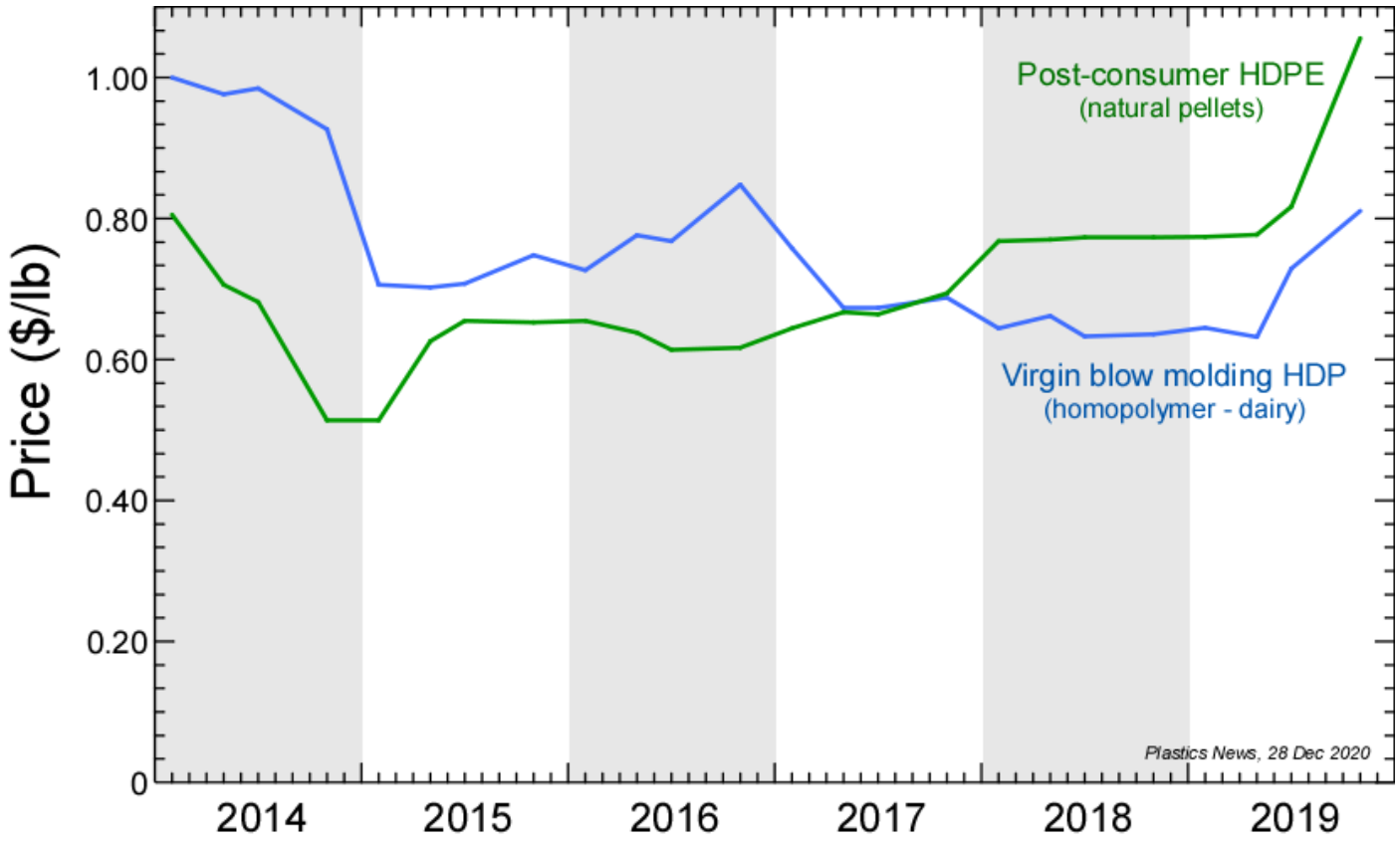
The PureCycle process:

1. Melting & Filtering
2. Extraction
3. Mixing & Settling
4. Filtering
5. Purification
6. Separation
7. Extruding & Pelletizing

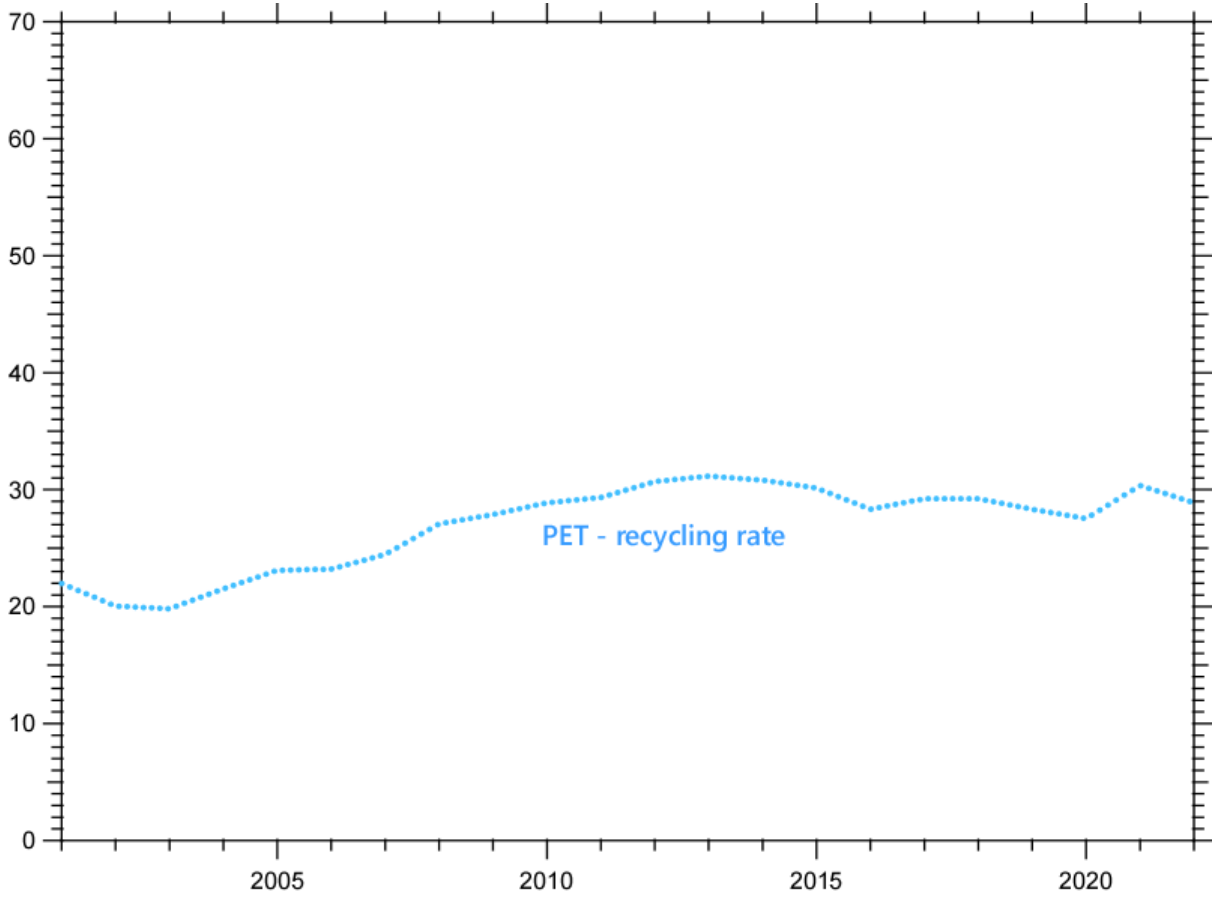
Good News

Bad News

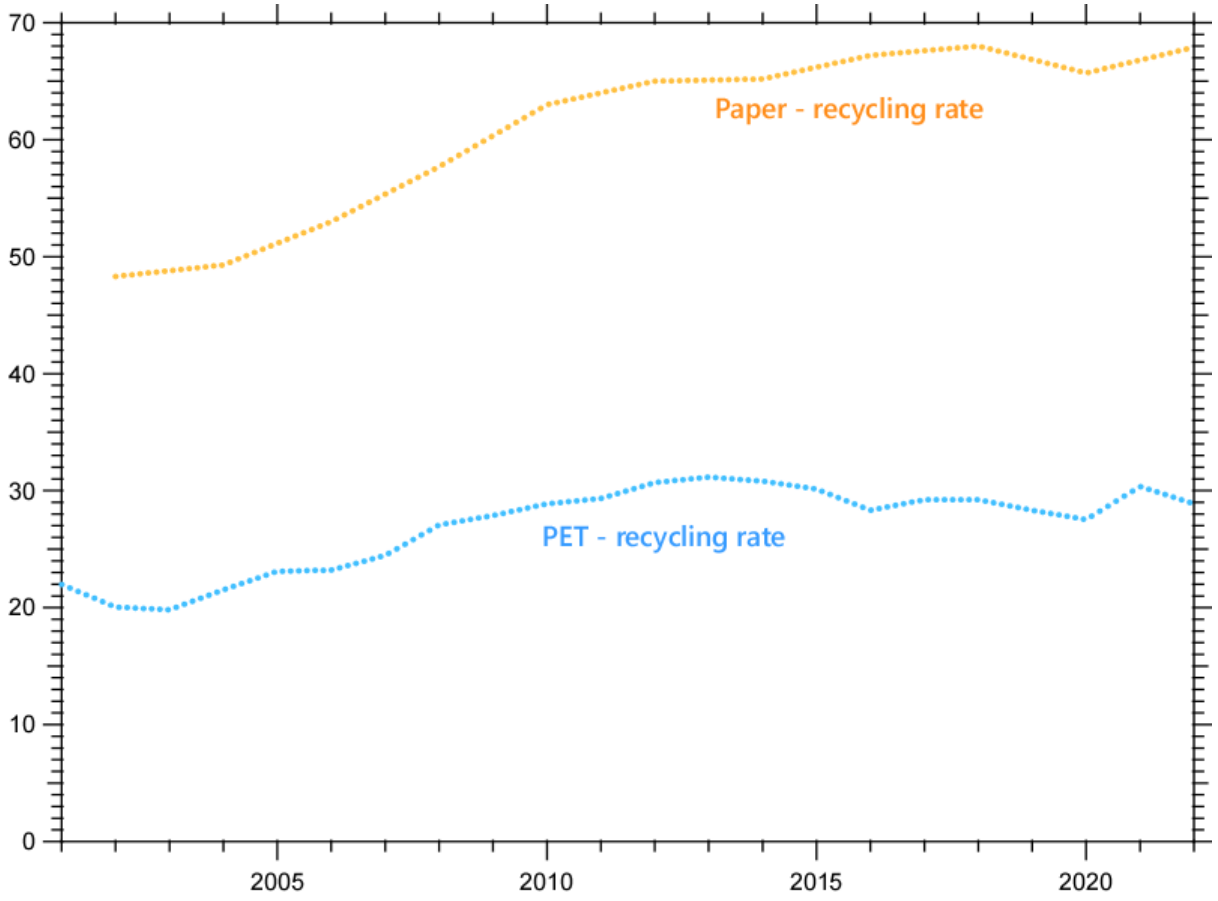
Good News


Post-consumer HDPE
(natural pellets)
Virgin blow molding HDP
(homopolymer - dairy)
Price ($/lb)
1.00
0.80
0.60
0.40
0.20
0
2014
2015
2016
2017
2018
2019
Plastics News, 28 Dec 2020

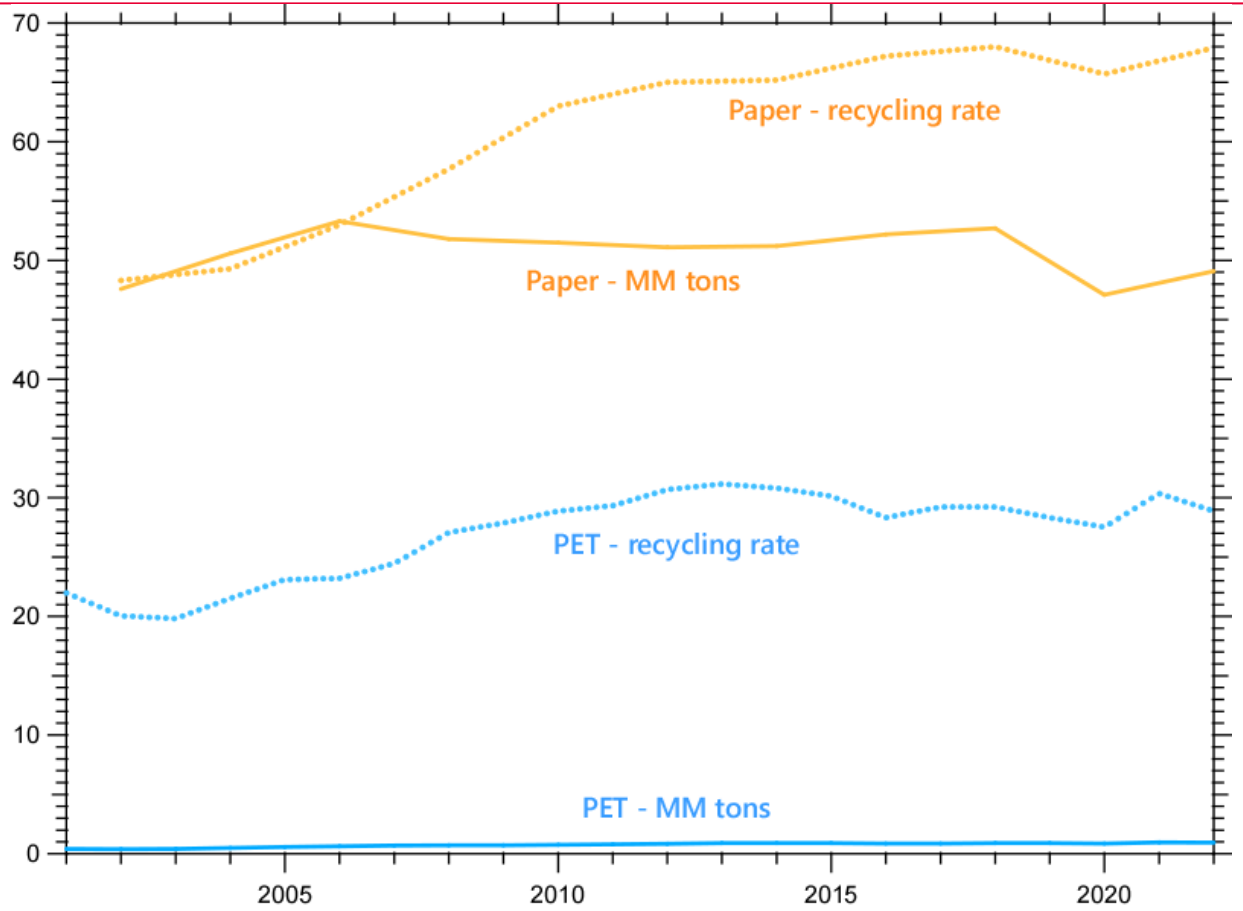
PET Recycling



PET Recycling



PET Recycling

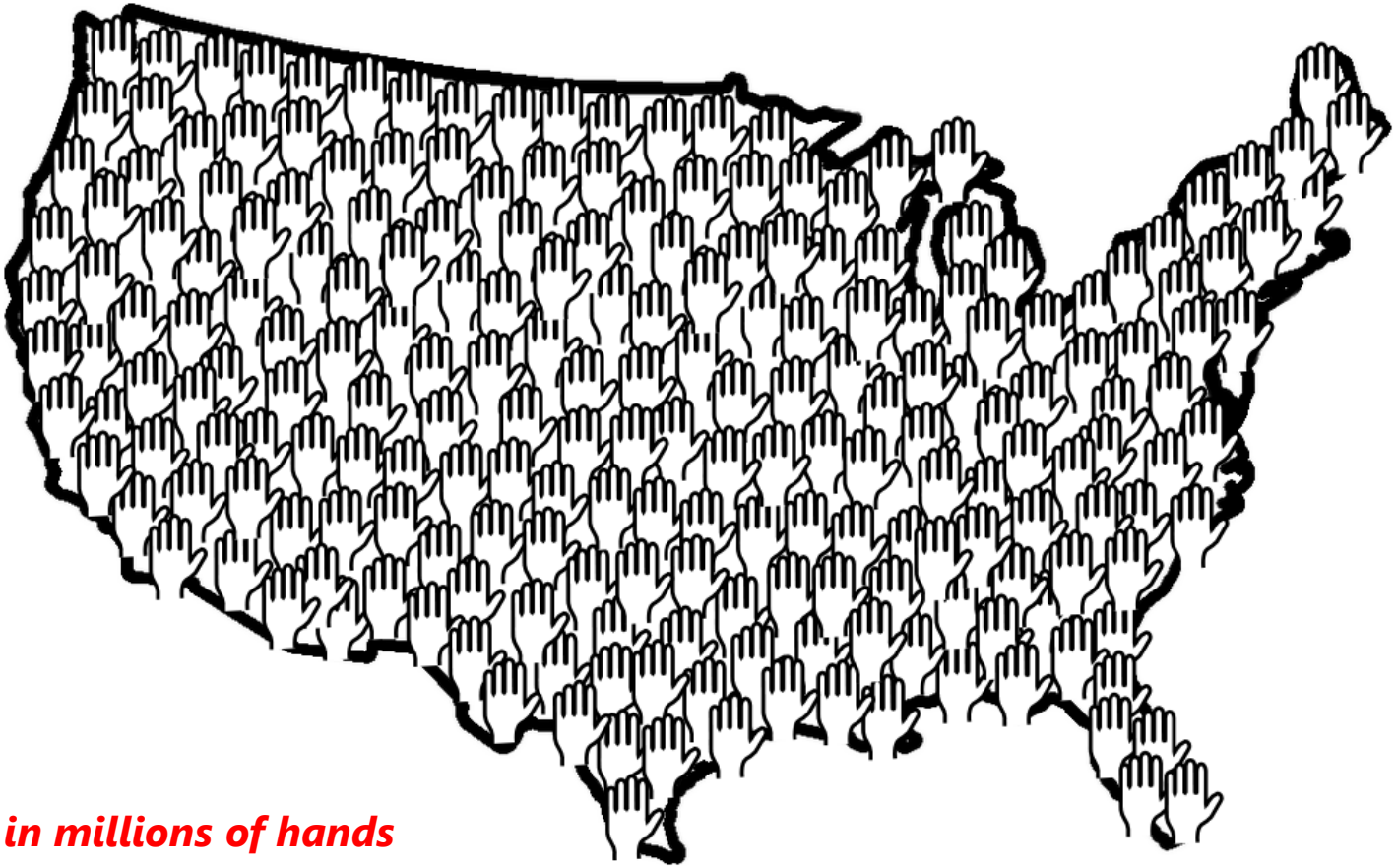


Bad News

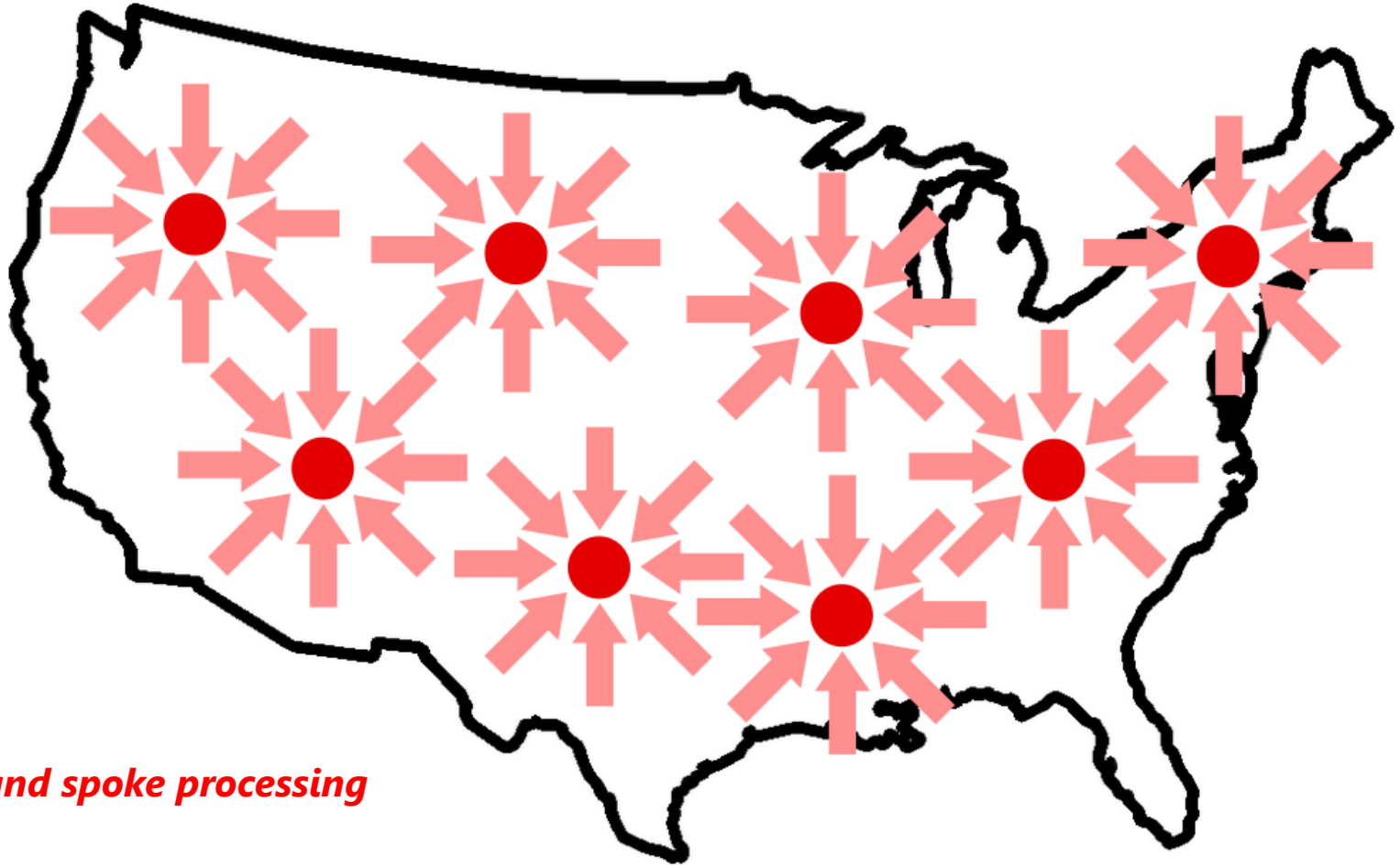
over 20% of recycle bin material is rejected


just a handful of crackers and polymer plants

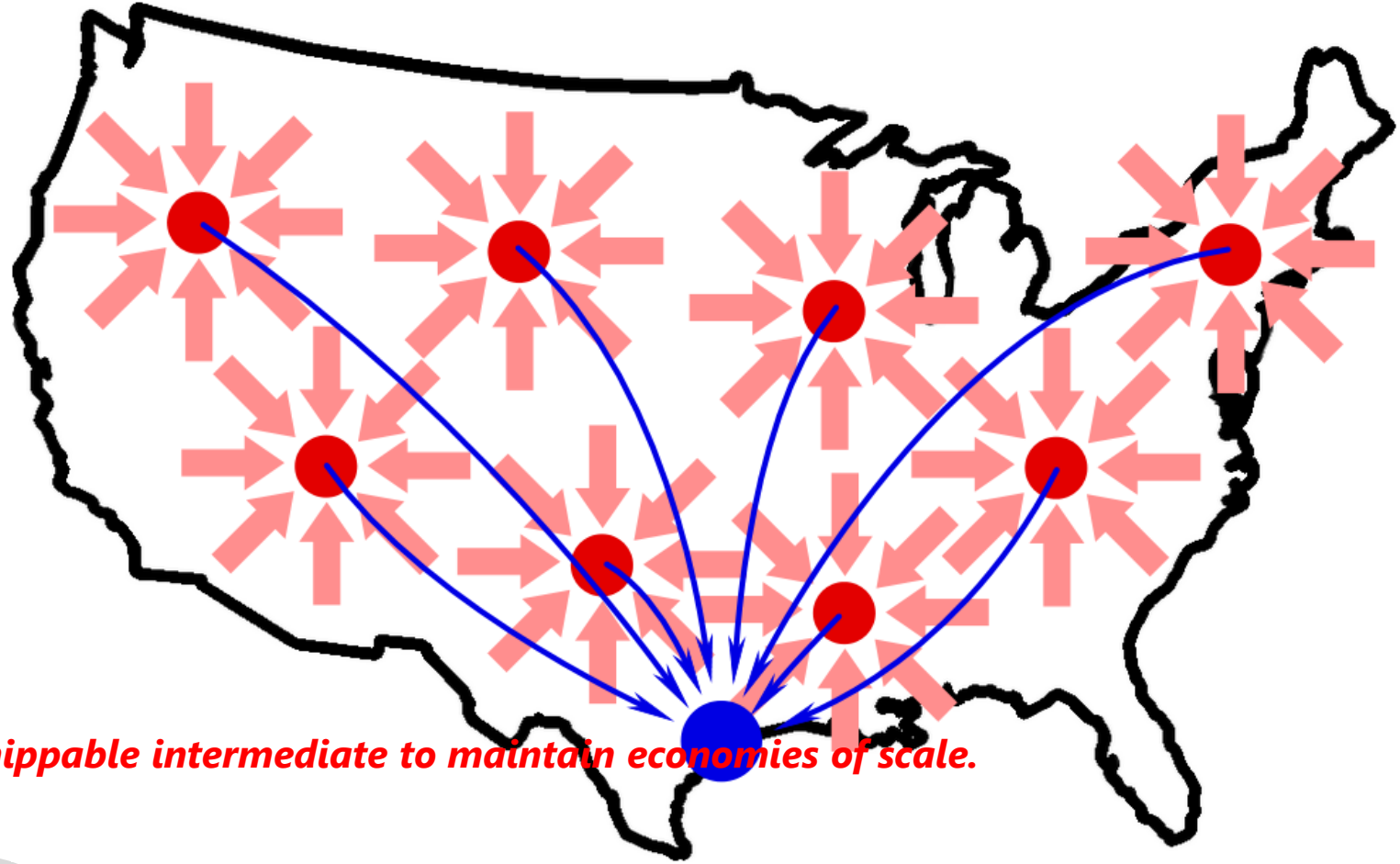
hundreds to thousands of converters



placed in millions of hands



hub and spoke processing



shippable intermediate to maintain economies of scale.

Challenges facing the chemical industry (which is really the plastics industry).

Incumbency is a hurdle.

Creative solutions are needed.

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