انجمن ملی صنایع پلیمر ایران

چهارمین همایش ملی

اقتصاد صنایع پلاستیک در ایران ۱۴۰۲

۳۱ خرداد الی ۱ تیر ۱۴۰۲

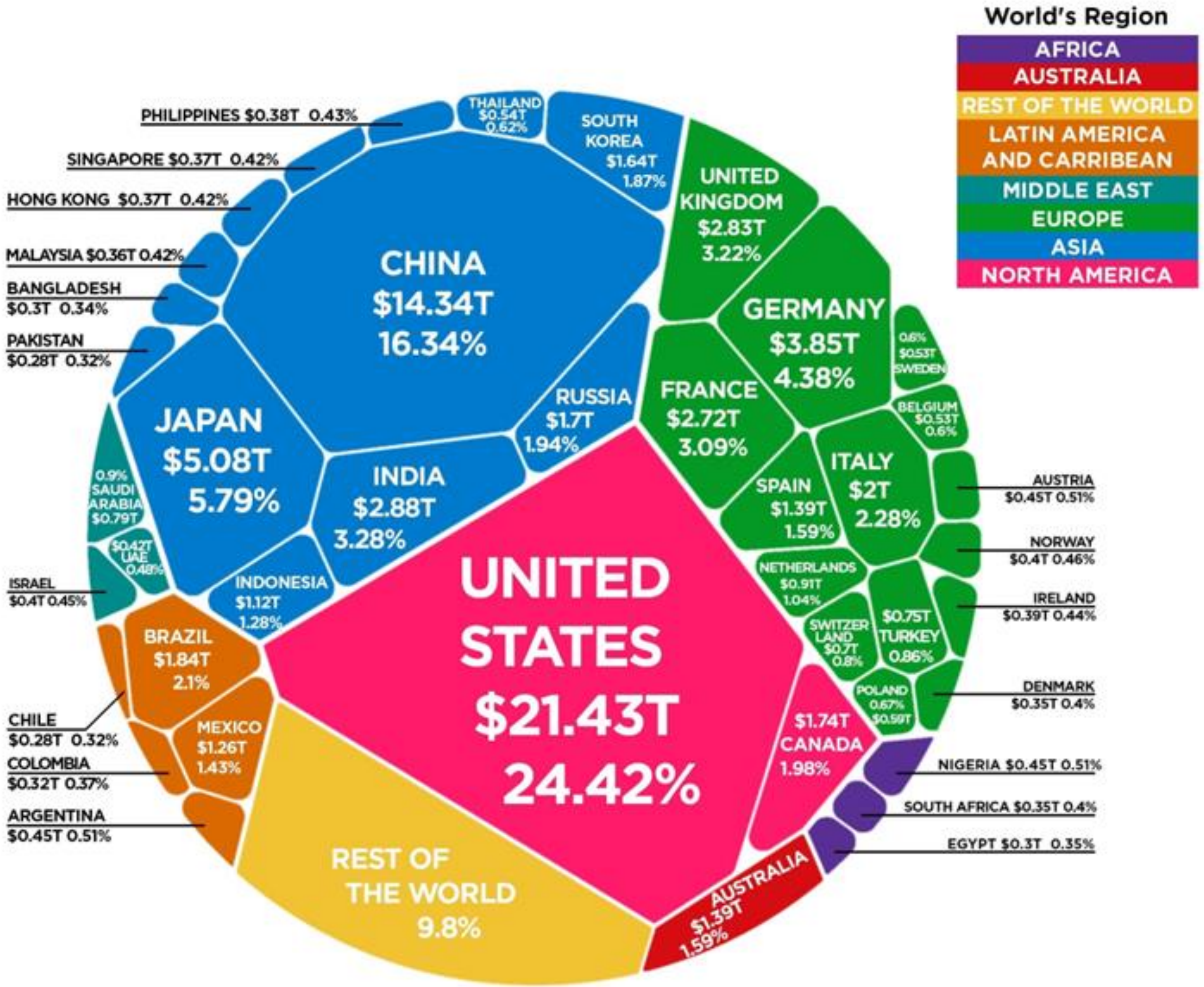
موضوع:

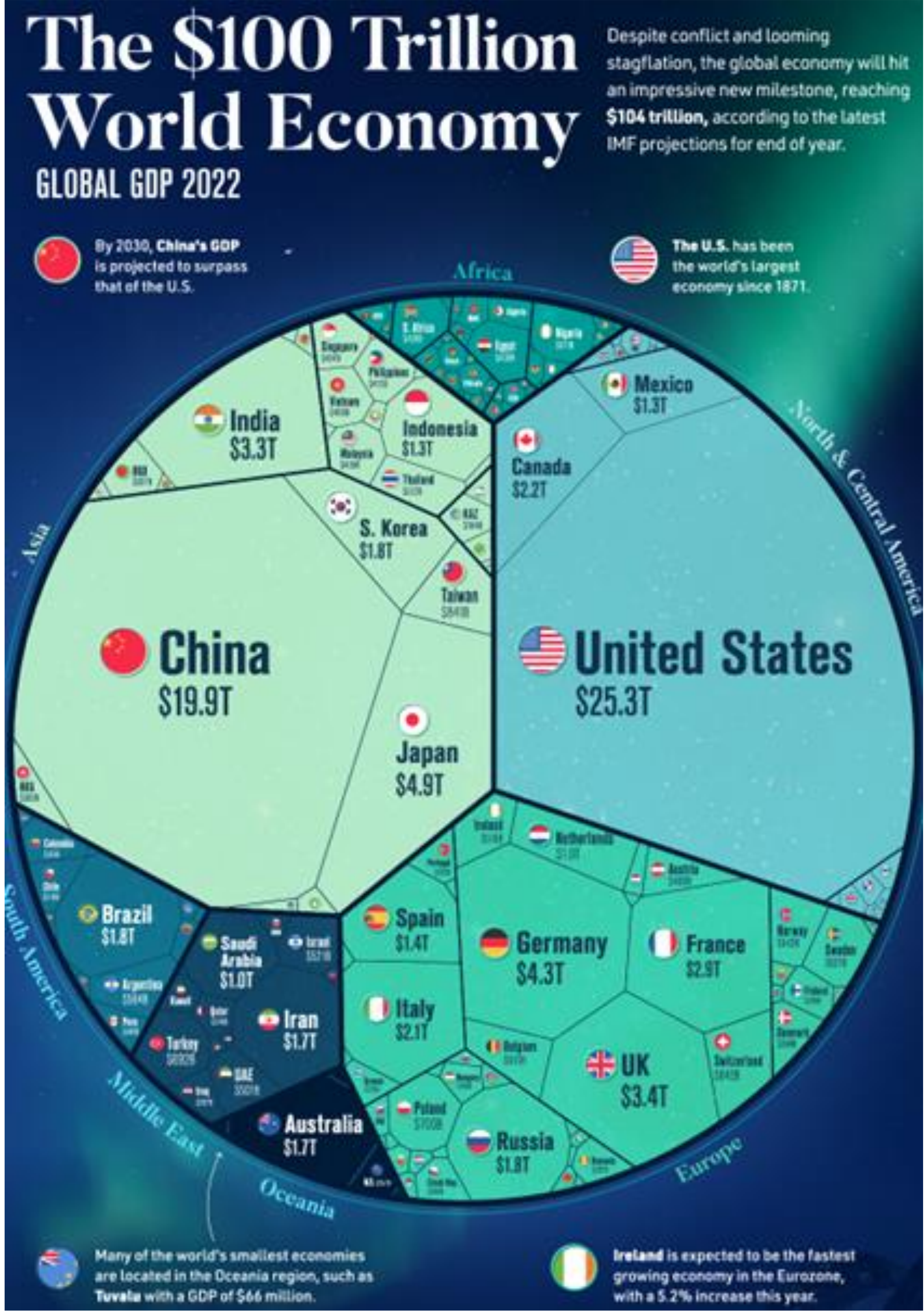
عنوان سخنرانی: بررسی اقتصادی، قوانین روز آمد زیست محیطی و تکنولوژی های نوین بازیافت شیمیایی و مکانیکی پلیمرها

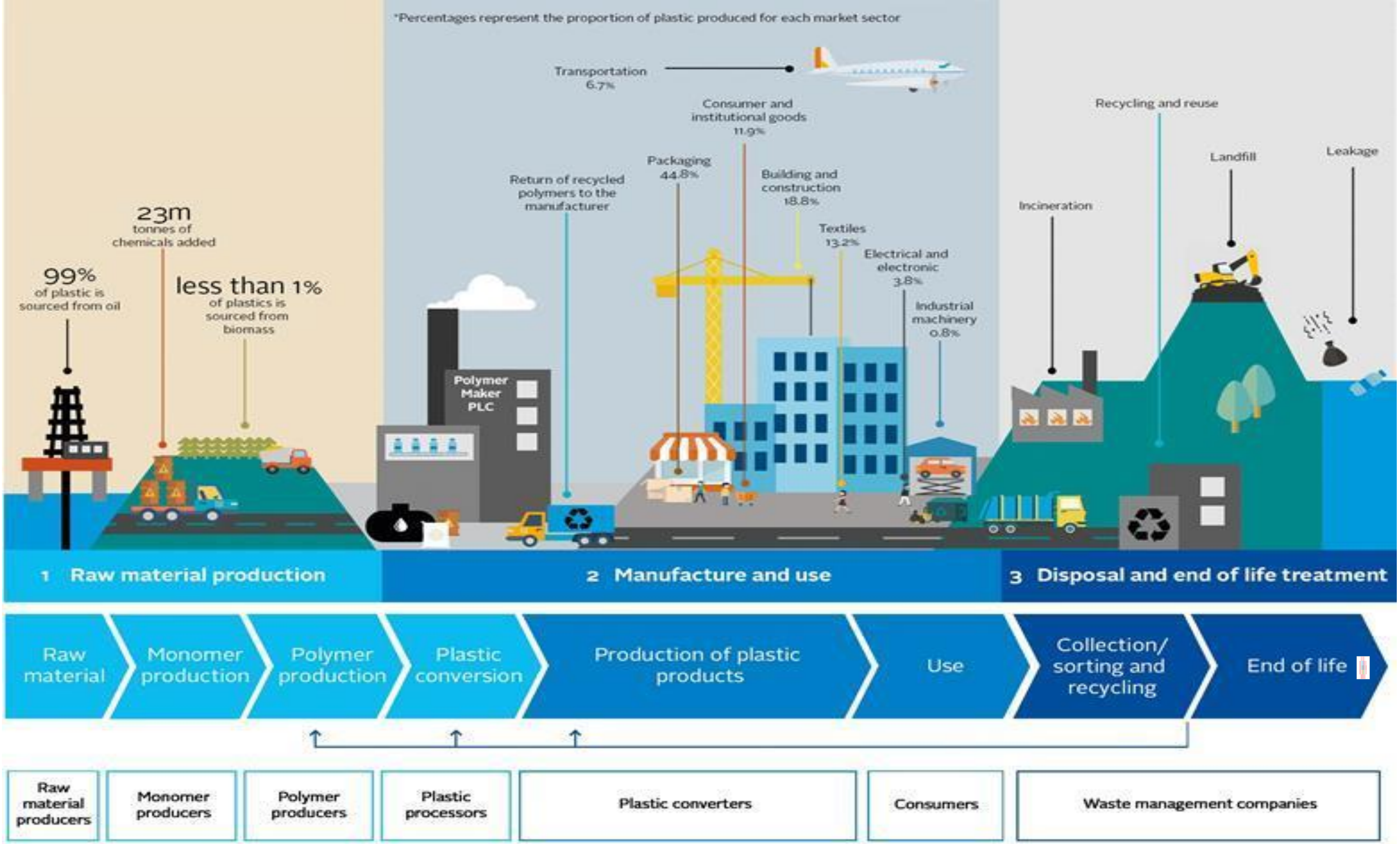
نام سخنران: شروین احمدی

۳۱ خرداد الی ۱ تیر ۱۴۰۲

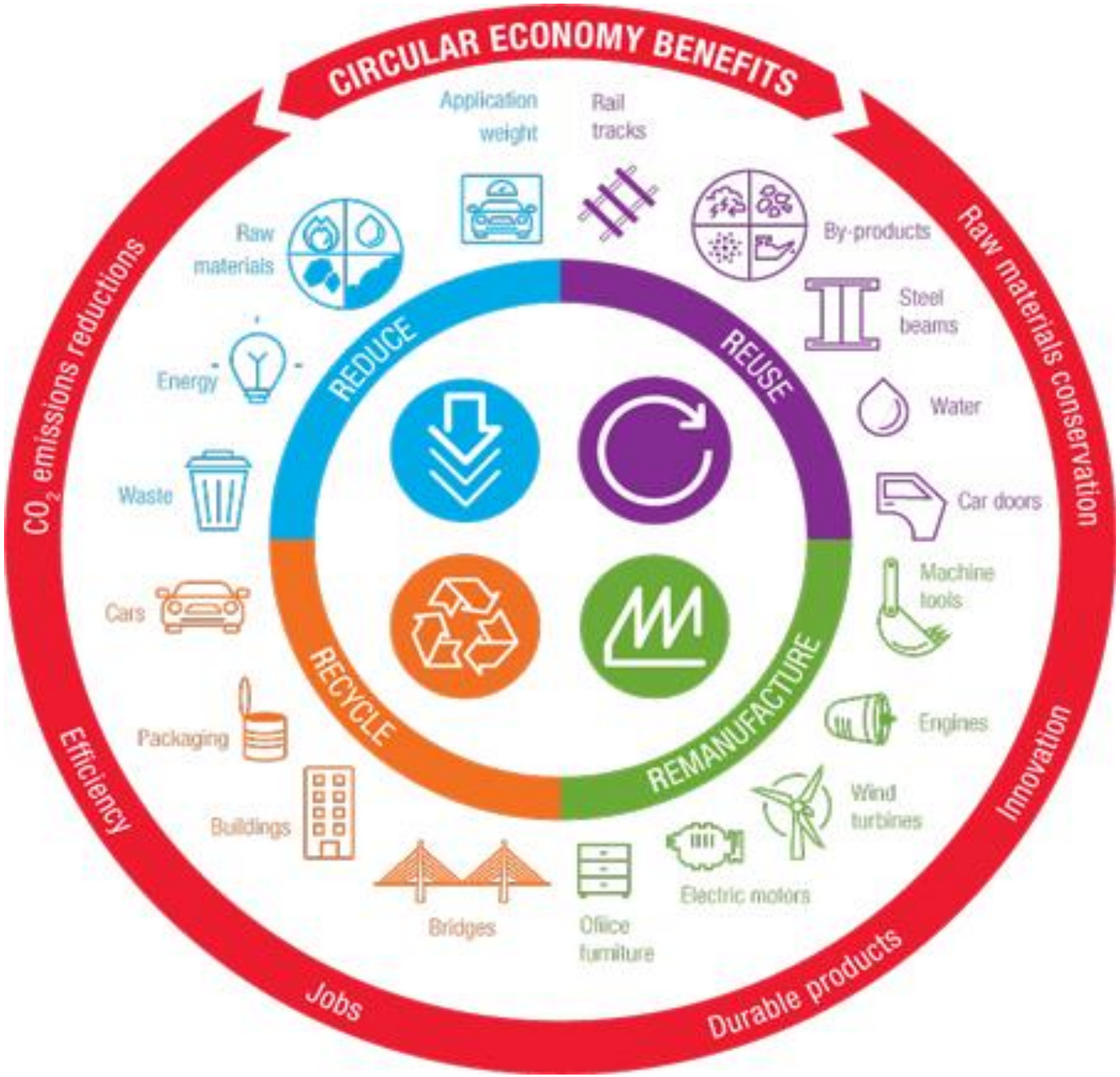
POPULATION	**87.920.000**
GDP (2021)	**531 B USD**
Petrochemical products	**57 MT/Y**


World's Region
AFRICA
AUSTRALIA
REST OF THE WORLD
LATIN AMERICA AND CARRIBEAN
MIDDLE EAST
EUROPE
ASIA
NORTH AMERICA
PHILIPPINES $0.38T 0.43%
SINGAPORE $0.37T 0.42%
HONG KONG $0.37T 0.42%
MALAYSIA $0.36T 0.42%
BANGLADESH $0.3T 0.34%
PAKISTAN $0.28T 0.32%
THAILAND $0.54T 0.62%
SOUTH KOREA $1.64T 1.87%
CHINA $14.34T 16.34%
JAPAN $5.08T 5.79%
RUSSIA $1.7T 1.94%
INDIA $2.88T 3.28%
INDONESIA $1.12T 1.28%
0.9% SAUDI ARABIA $0.79T
$0.42T UAE 0.48%
ISRAEL $0.4T 0.45%
UNITED KINGDOM $2.83T 3.22%
GERMANY $3.85T 4.38%
FRANCE $2.72T 3.09%
0.6% $0.53T SWEDEN
BELGIUM $0.53T 0.6%
ITALY $2T 2.28%
SPAIN $1.39T 1.59%
NETHERLANDS $0.91T 1.04%
SWITZERLAND $0.7T 0.8%
$0.75T TURKEY 0.86%
POLAND 0.67% $0.59T
AUSTRIA $0.45T 0.51%
NORWAY $0.4T 0.46%
IRELAND $0.39T 0.44%
DENMARK $0.35T 0.4%
UNITED STATES $21.43T 24.42%
$1.74T CANADA 1.98%
BRAZIL $1.84T 2.1%
MEXICO $1.26T 1.43%
CHILE $0.28T 0.32%
COLOMBIA $0.32T 0.37%
ARGENTINA $0.45T 0.51%
REST OF THE WORLD 9.8%
AUSTRALIA $1.39T 1.59%
NIGERIA $0.45T 0.51%
SOUTH AFRICA $0.35T 0.4%
EGYPT $0.3T 0.35%


The $100 Trillion World Economy
GLOBAL GDP 2022
Despite conflict and looming stagflation, the global economy will hit an impressive new milestone, reaching $104 trillion, according to the latest IMF projections for end of year.
By 2030, China's GDP is projected to surpass that of the U.S.
The U.S. has been the world's largest economy since 1871.
Africa
Asia
North & Central America
South America
Middle East
Oceania
Europe
India $3.3T
Indonesia $1.3T
S. Korea $1.8T
Taiwan
China $19.9T
Japan $4.9T
Mexico $1.3T
Canada $2.2T
United States $25.3T
Brazil $1.8T
Saudi Arabia $1.0T
Iran $1.7T
Turkey
UAE
Australia $1.7T
Spain $1.4T
Italy $2.1T
Germany $4.3T
France $2.9T
UK $3.4T
Netherlands
Poland
Russia $1.8T
Many of the world's smallest economies are located in the Oceania region, such as Tuvalu with a GDP of $66 million.
Ireland is expected to be the fastest growing economy in the Eurozone, with a 5.2% increase this year.

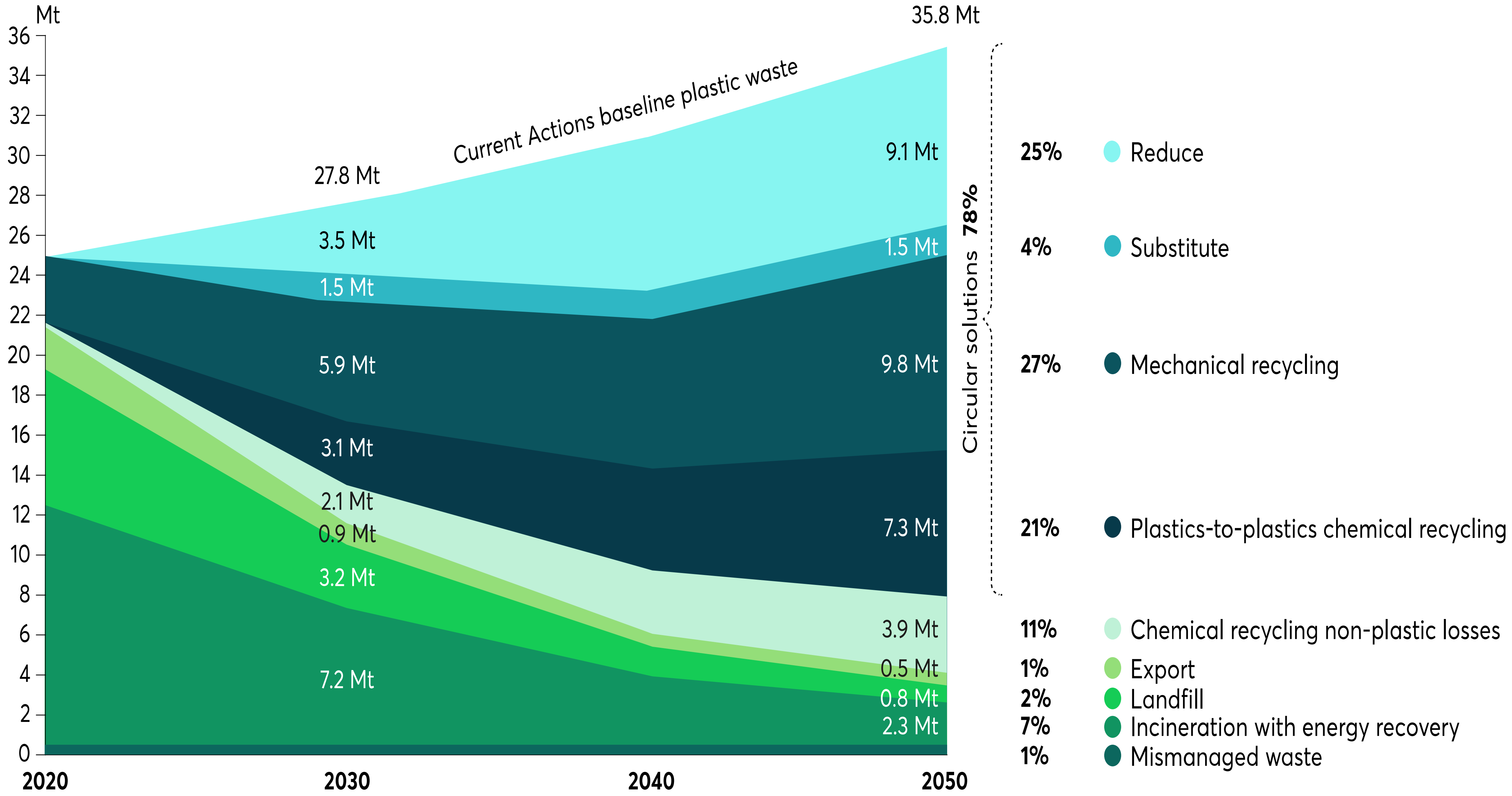


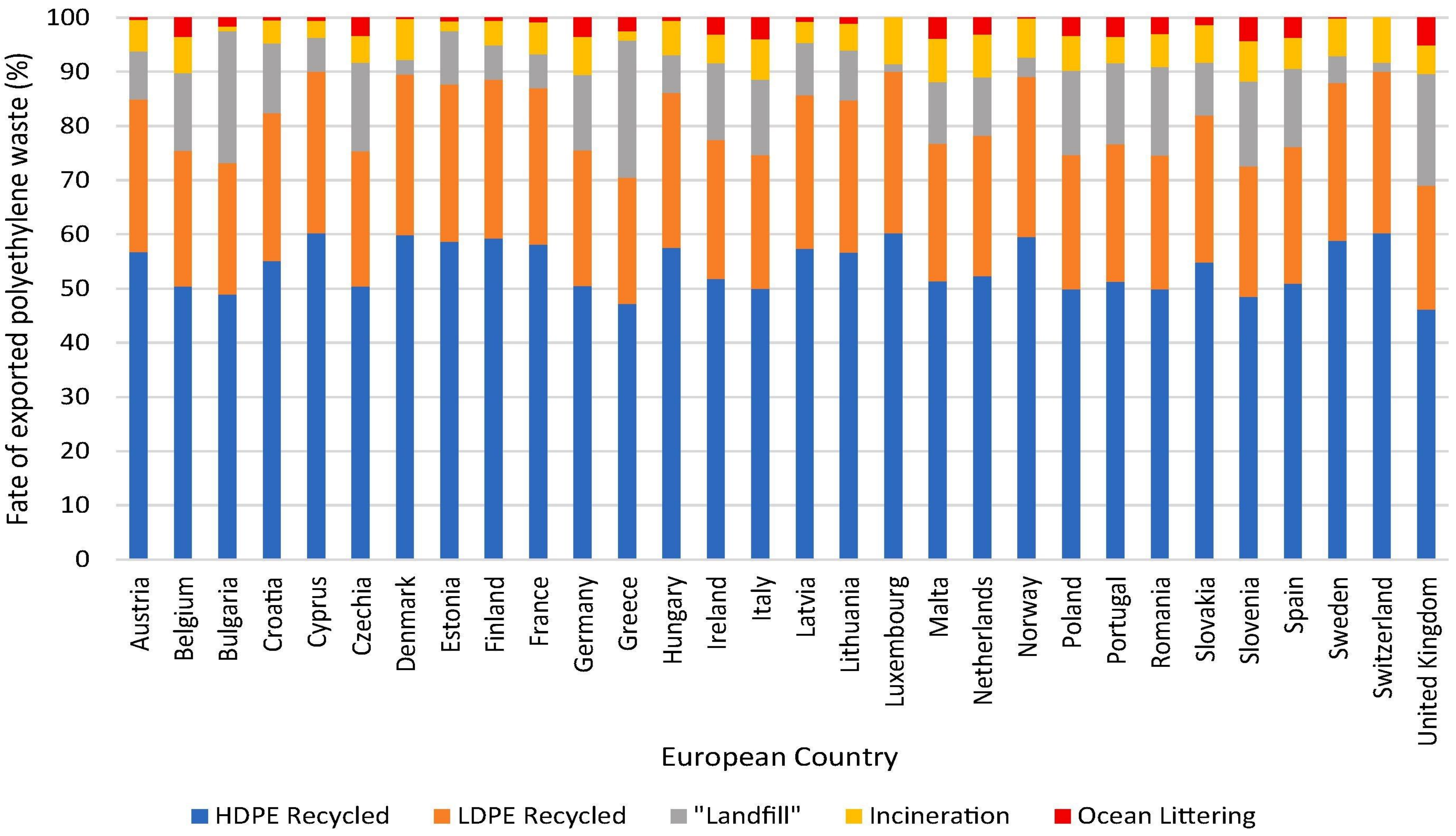
*Percentages represent the proportion of plastic produced for each market sector
Transportation 6.7%
Consumer and institutional goods 11.9%
Packaging 44.8%
Building and construction 18.8%
Textiles 13.2%
Electrical and electronic 3.8%
Industrial machinery 0.8%
Return of recycled polymers to the manufacturer
Polymer Maker PLC
23m tonnes of chemicals added
99% of plastic is sourced from oil
less than 1% of plastics is sourced from biomass
Recycling and reuse
Landfill
Leakage
Incineration
1 Raw material production
2 Manufacture and use
3 Disposal and end of life treatment
Raw material
Monomer production
Polymer production
Plastic conversion
Production of plastic products
Use
Collection/ sorting and recycling
End of life
Raw material producers
Monomer producers
Polymer producers
Plastic processors
Plastic converters
Consumers
Waste management companies


CIRCULAR ECONOMY BENEFITS
Raw materials conservation
Innovation
Durable products
Jobs
Efficiency
CO_2 emissions reductions
REDUCE
REUSE
REMANUFACTURE
RECYCLE
Application weight
Rail tracks
By-products
Steel beams
Water
Car doors
Machine tools
Engines
Wind turbines
Electric motors
Office furniture
Bridges
Buildings
Packaging
Cars
Waste
Energy
Raw materials

Sustainability

Circular strategies, technologies, and transition companies are looking beyond traditional economic models.


Mt
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
2020
2030
2040
2050
Current Actions baseline plastic waste
27.8 Mt
35.8 Mt
3.5 Mt
1.5 Mt
5.9 Mt
3.1 Mt
2.1 Mt
0.9 Mt
3.2 Mt
7.2 Mt
9.1 Mt
1.5 Mt
9.8 Mt
7.3 Mt
3.9 Mt
0.5 Mt
0.8 Mt
2.3 Mt
Circular solutions 78%
25% Reduce
4% Substitute
27% Mechanical recycling
21% Plastics-to-plastics chemical recycling
11% Chemical recycling non-plastic losses
1% Export
2% Landfill
7% Incineration with energy recovery
1% Mismanaged waste



Fate of exported polyethylene waste (%)
100
90
80
70
60
50
40
30
20
10
0
Austria
Belgium
Bulgaria
Croatia
Cyprus
Czechia
Denmark
Estonia
Finland
France
Germany
Greece
Hungary
Ireland
Italy
Latvia
Lithuania
Luxembourg
Malta
Netherlands
Norway
Poland
Portugal
Romania
Slovakia
Slovenia
Spain
Sweden
Switzerland
United Kingdom
European Country
HDPE Recycled
LDPE Recycled
"Landfill"
Incineration
Ocean Littering

Plastics waste rules and regulations

HS code 3915

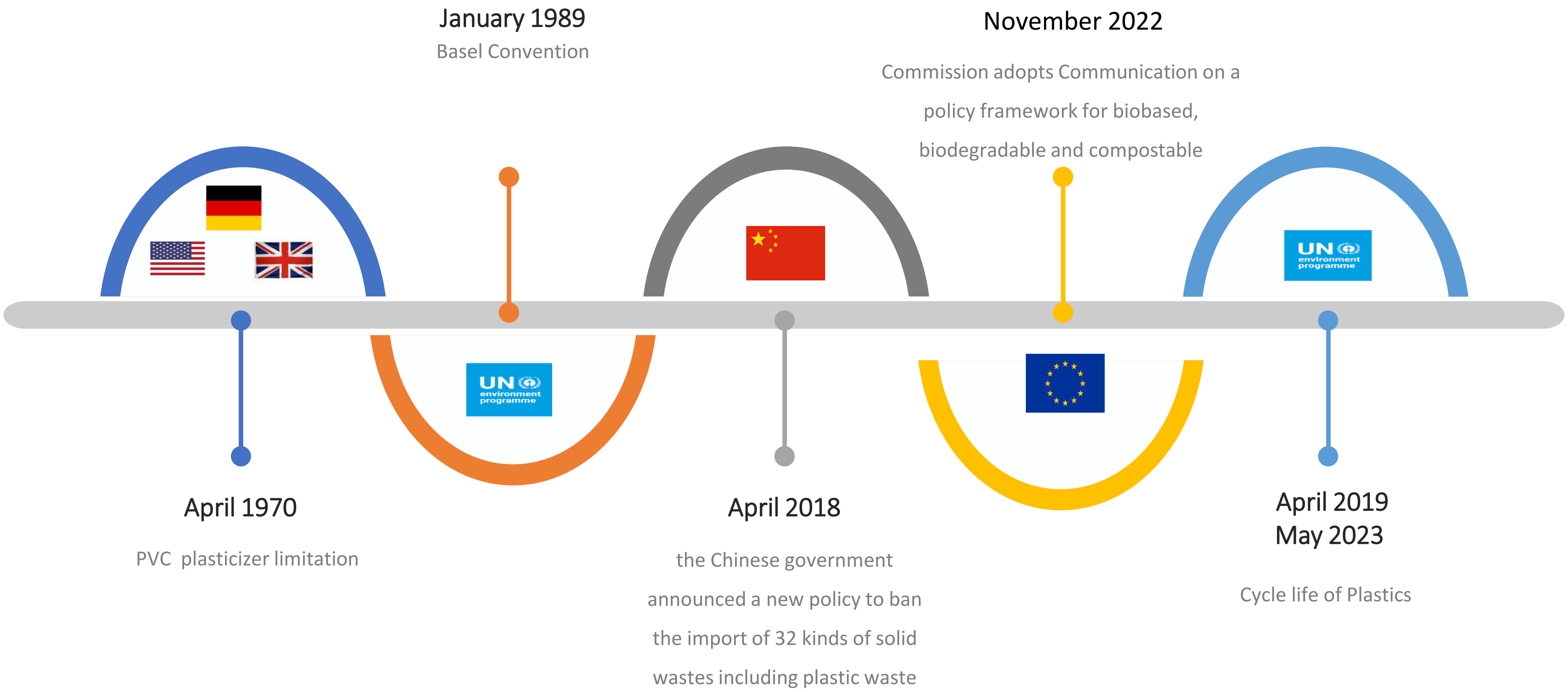
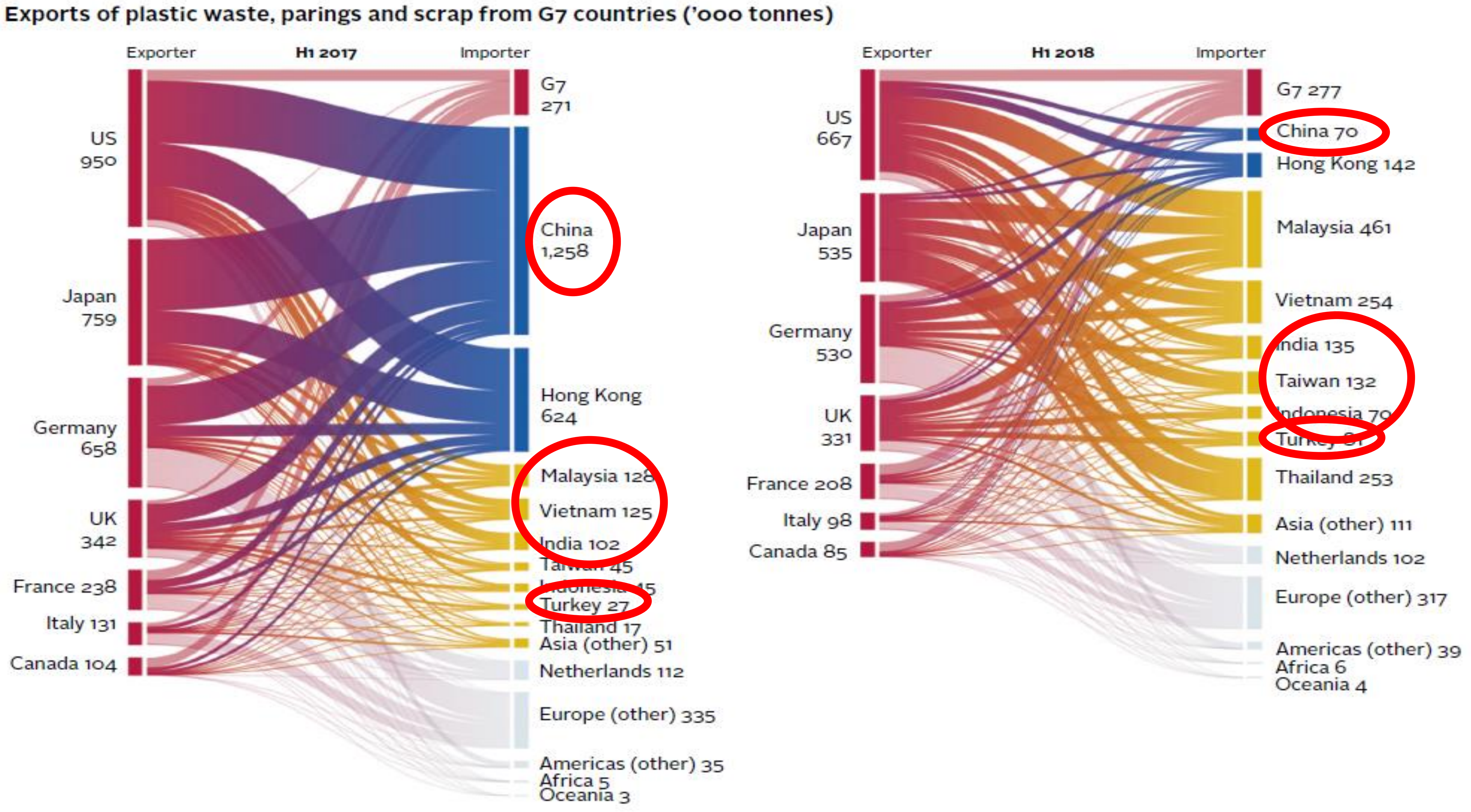
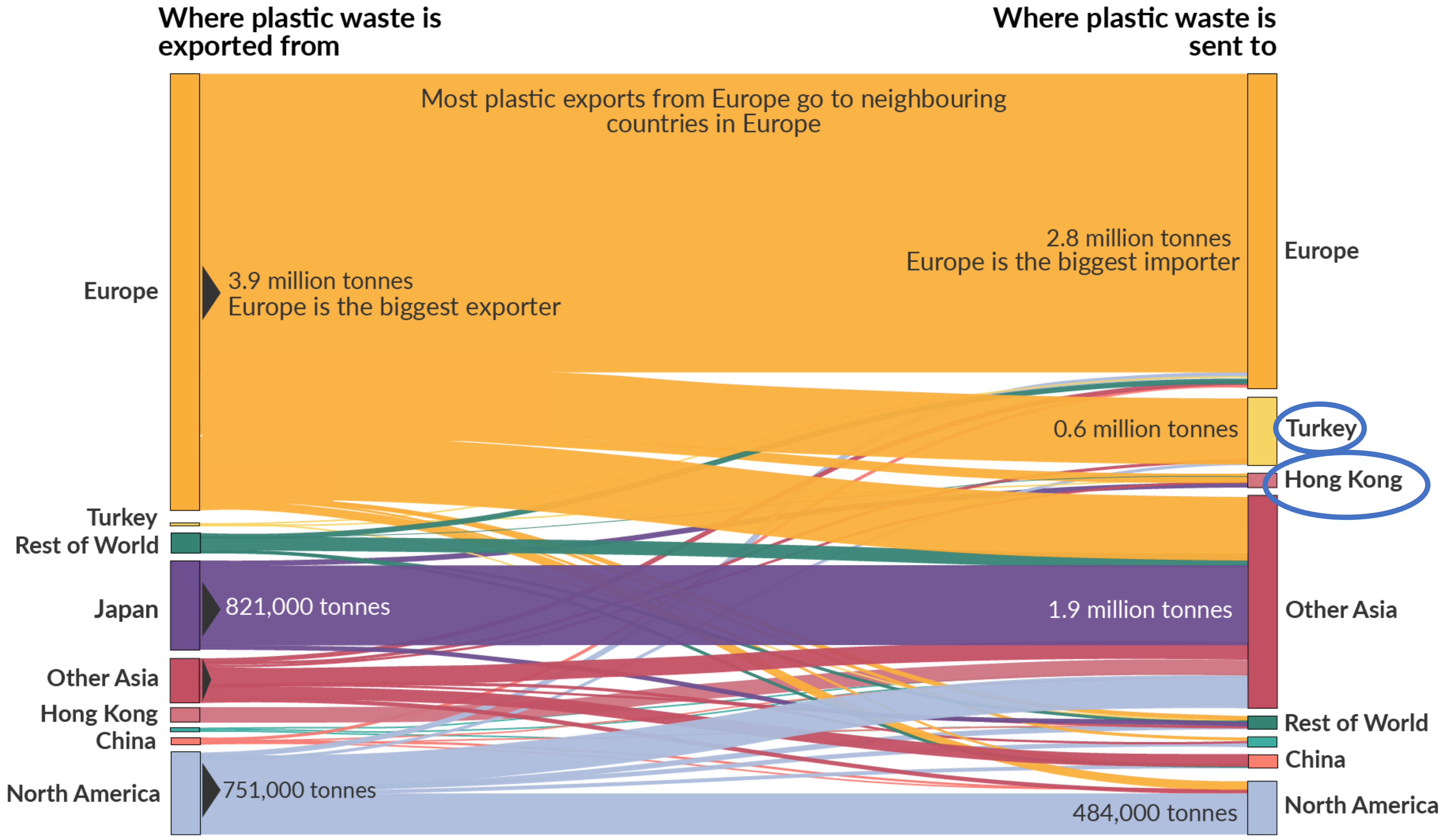


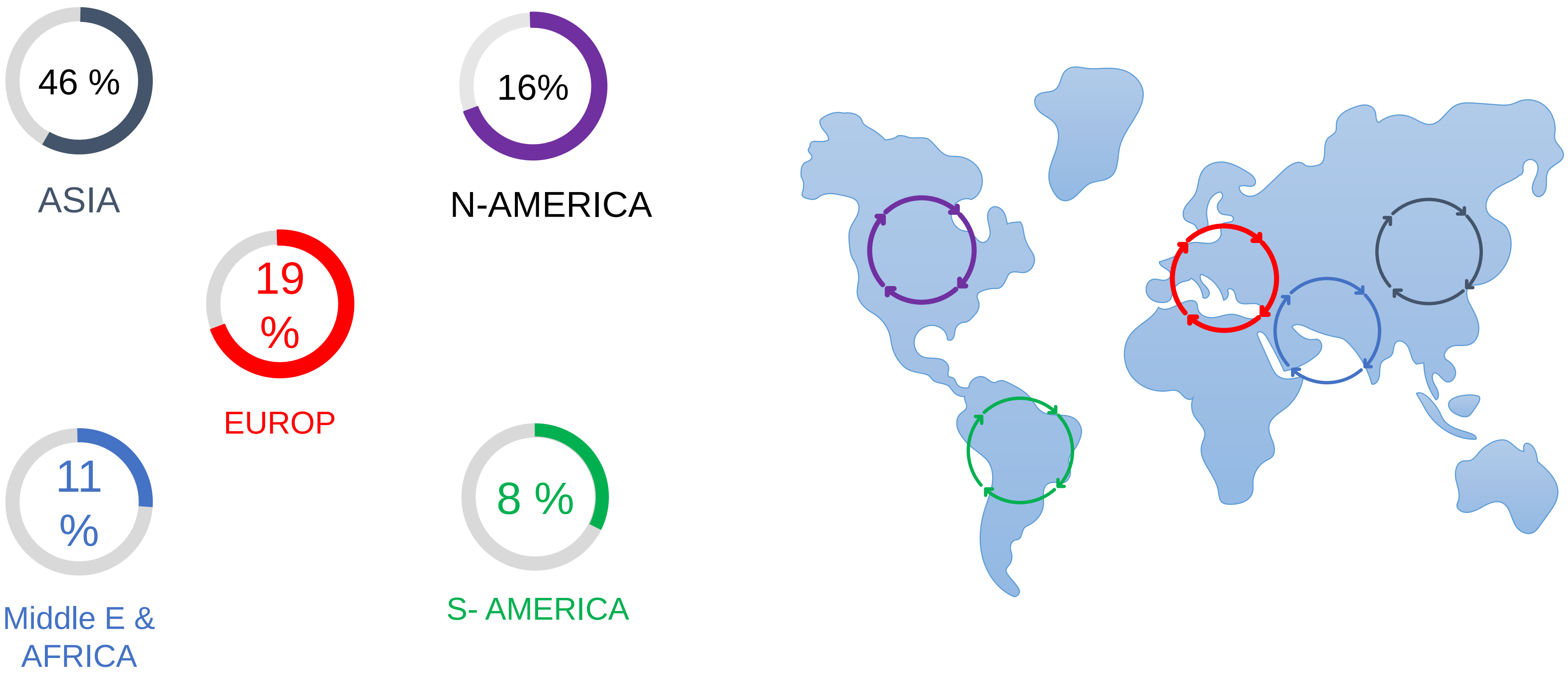
Figure : Global flows of plastic waste and the impact of China's restrictions on plastic imports in 2018. Source: FT



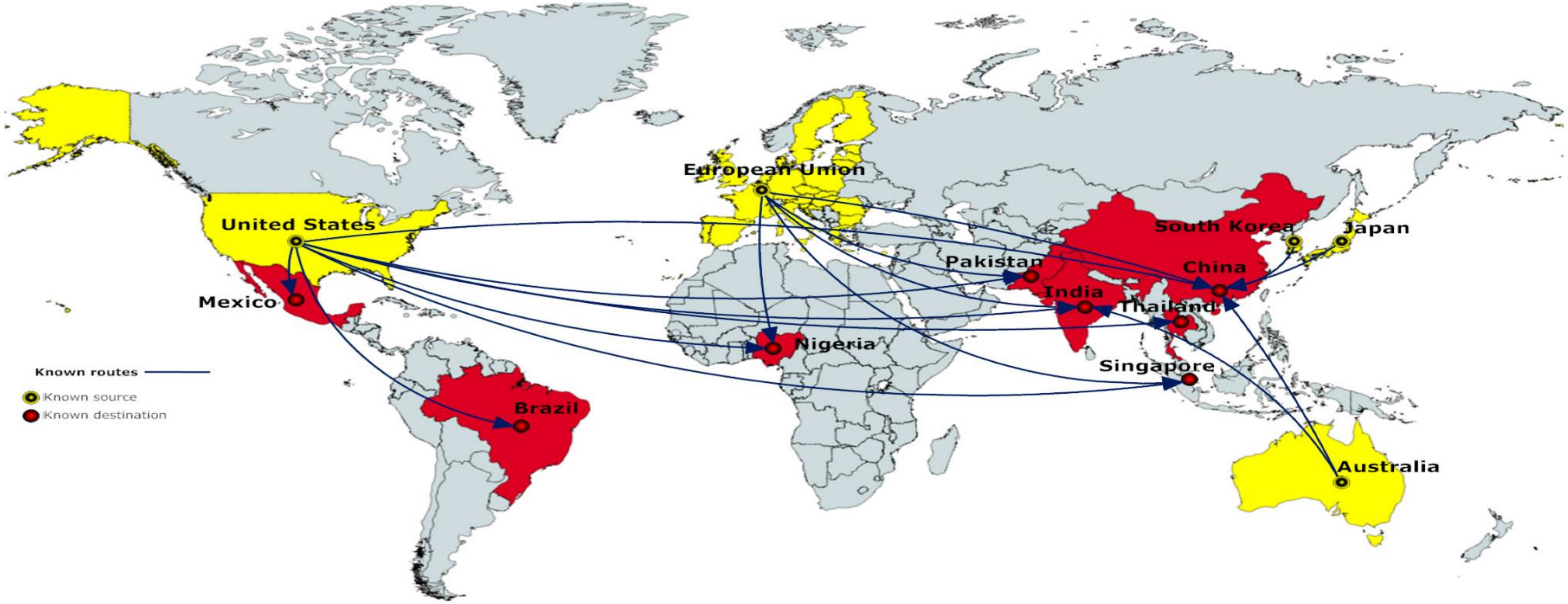


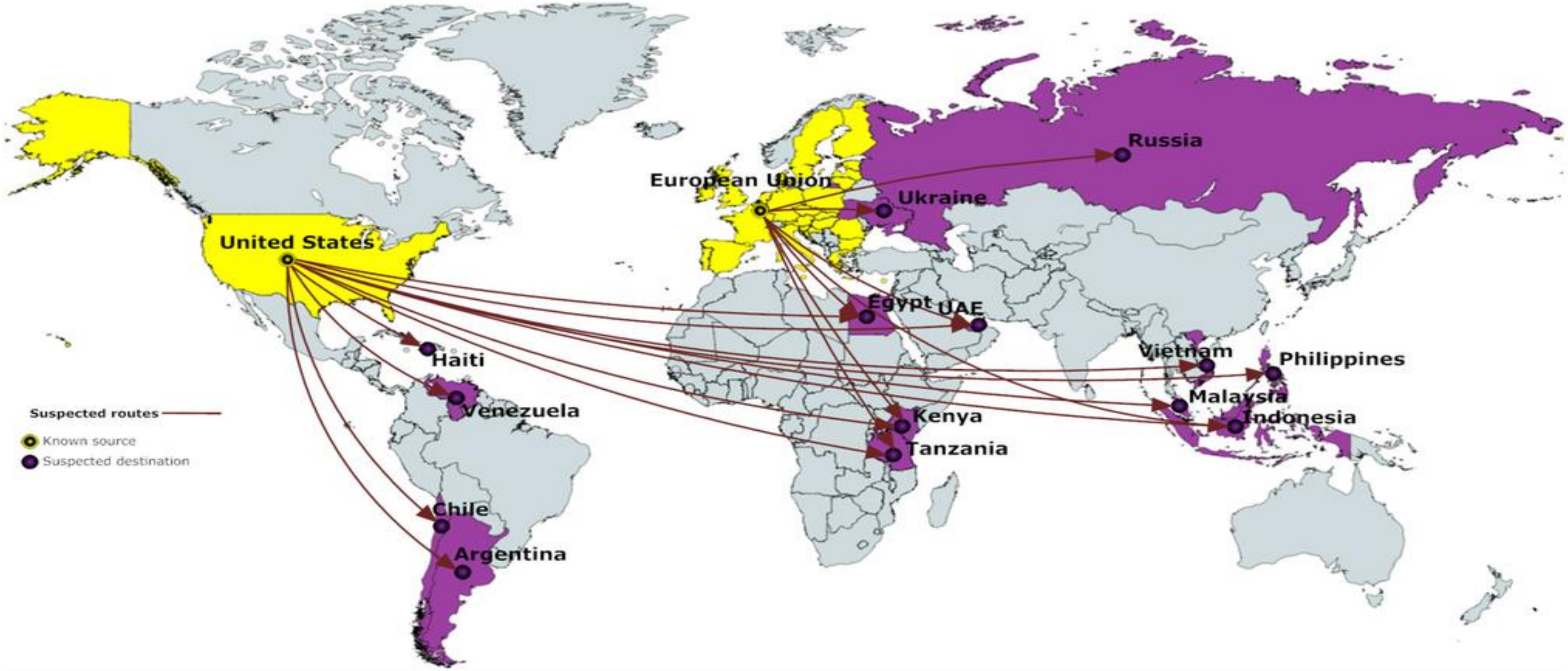
Where plastic waste is exported from
Where plastic waste is sent to
Most plastic exports from Europe go to neighbouring countries in Europe
Europe
3.9 million tonnes
Europe is the biggest exporter
2.8 million tonnes
Europe is the biggest importer
Europe
0.6 million tonnes
Turkey
Hong Kong
Turkey
Rest of World
Japan
821,000 tonnes
1.9 million tonnes
Other Asia
Other Asia
Hong Kong
China
Rest of World
China
North America
751,000 tonnes
484,000 tonnes
North America

PLASTIC WASTE MARKET, BY REGION 2024 – 37.9USD B

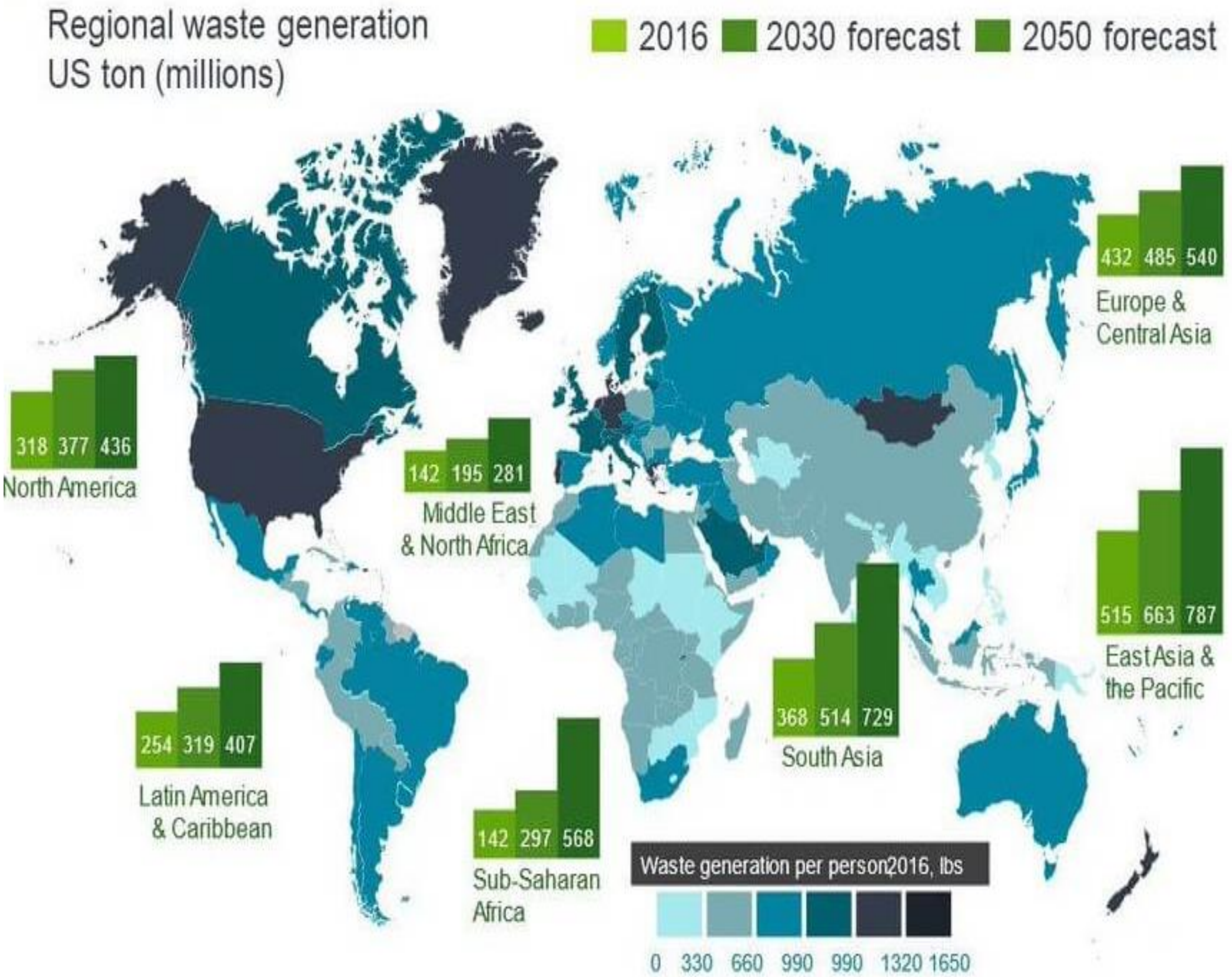


Known routes of illegal e-waste trade

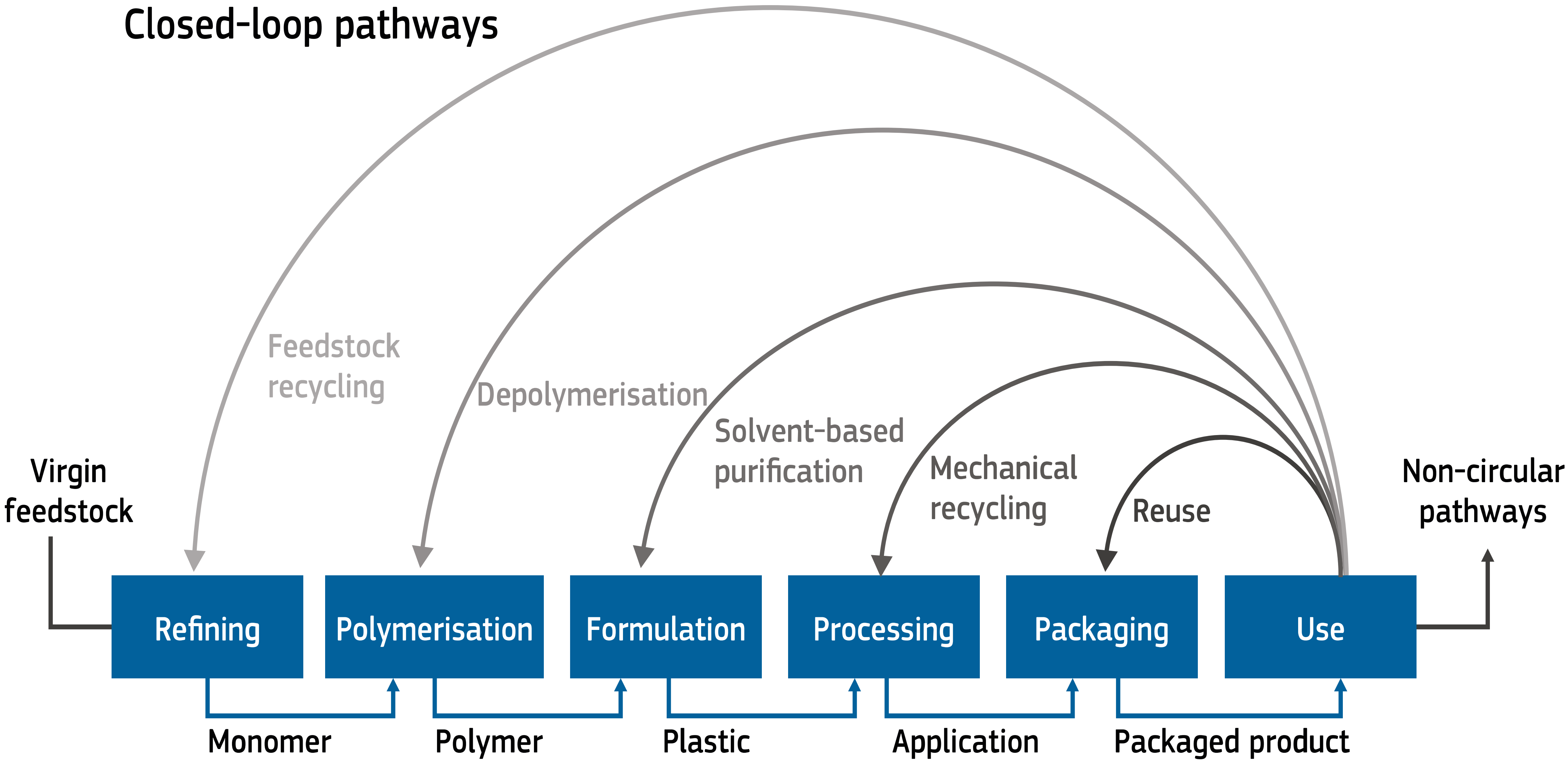




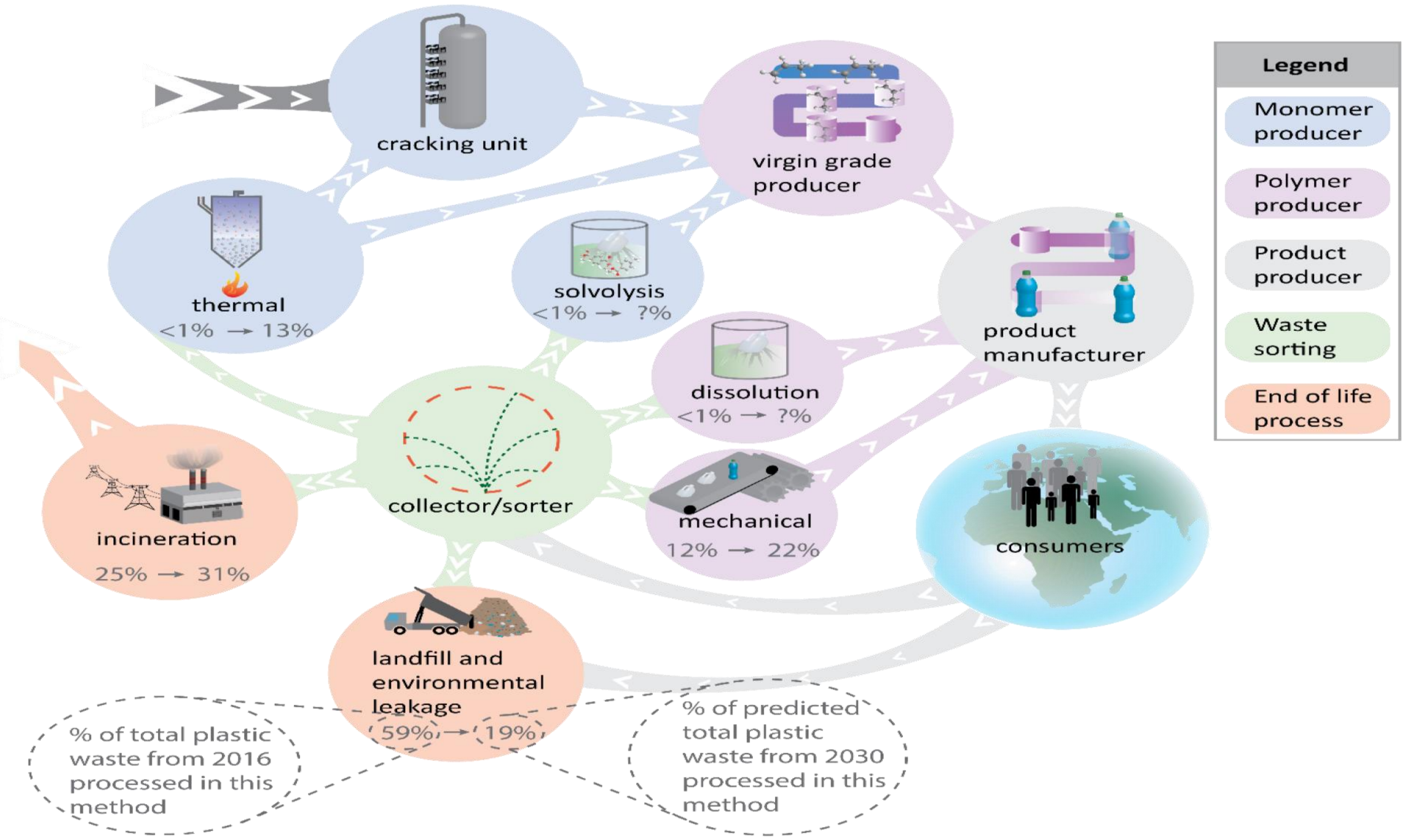
• **A THROWAWAY WORLD**



Recycling

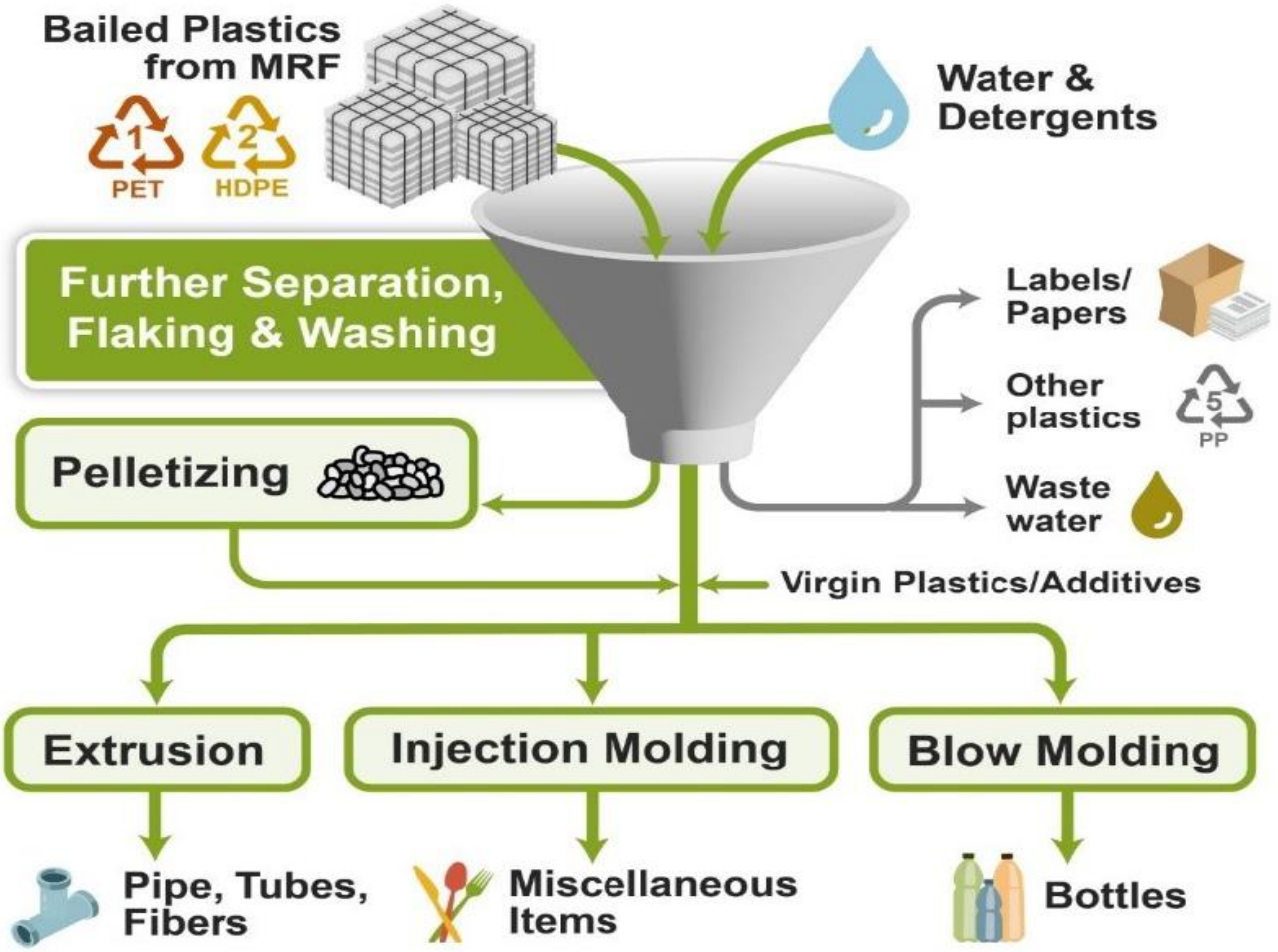


Closed-loop pathways
Feedstock recycling
Depolymerisation
Solvent-based purification
Mechanical recycling
Reuse
Virgin feedstock
Non-circular pathways
Refining
Polymerisation
Formulation
Processing
Packaging
Use
Monomer
Polymer
Plastic
Application
Packaged product

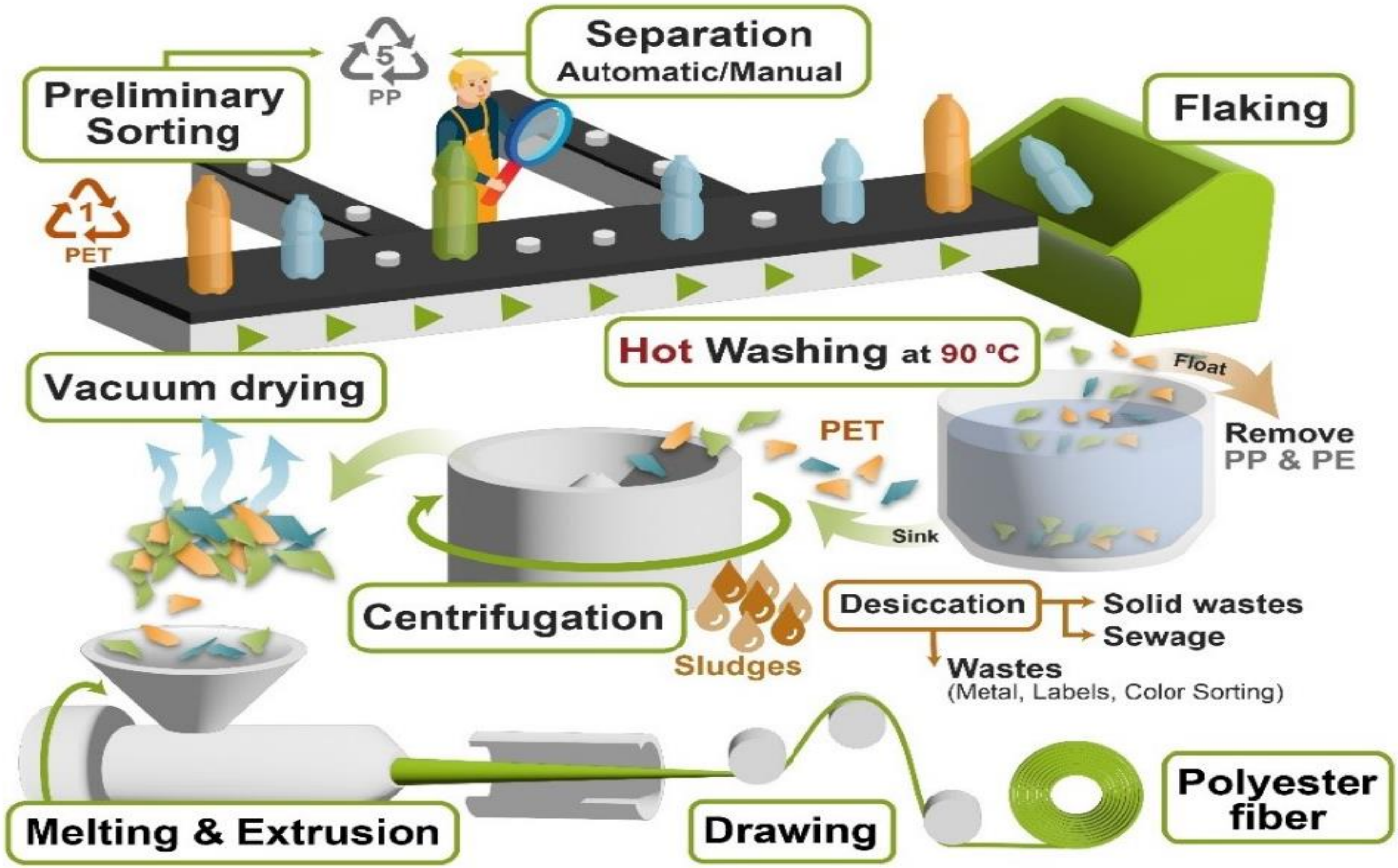


cracking unit
virgin grade producer
thermal
<1% → 13%
solvolysis
<1% → ?%
dissolution
<1% → ?%
product manufacturer
collector/sorter
mechanical
12% → 22%
incineration
25% → 31%
consumers
landfill and environmental leakage
59% → 19%
% of total plastic waste from 2016 processed in this method
% of predicted total plastic waste from 2030 processed in this method
Legend
Monomer producer
Polymer producer
Product producer
Waste sorting
End of life process

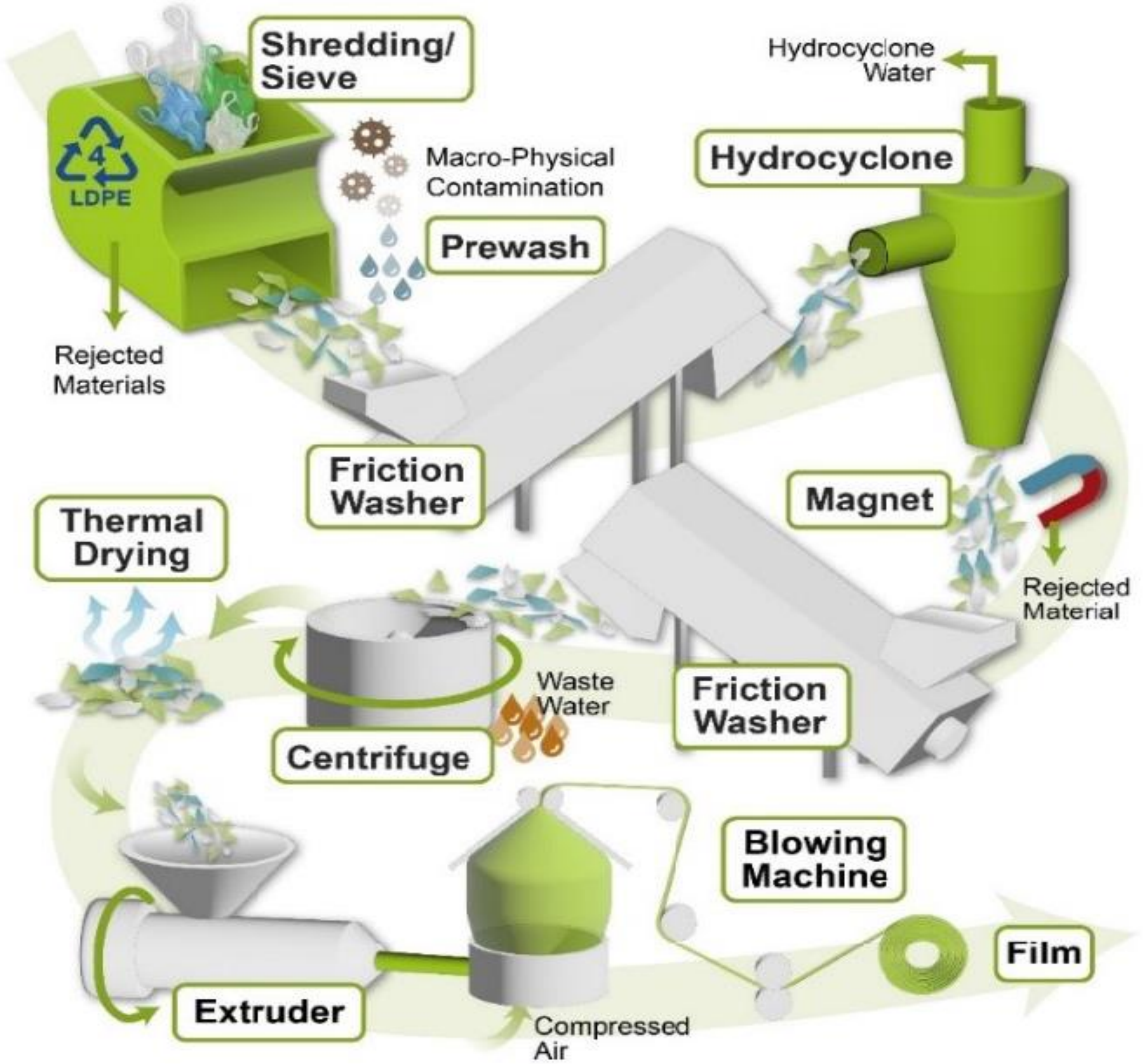
Mechanical Recycling



Various approaches for mechanical recycling of PSW (Plastic solid waste).



A generalized process flow diagram for a recycling of PET bottles.

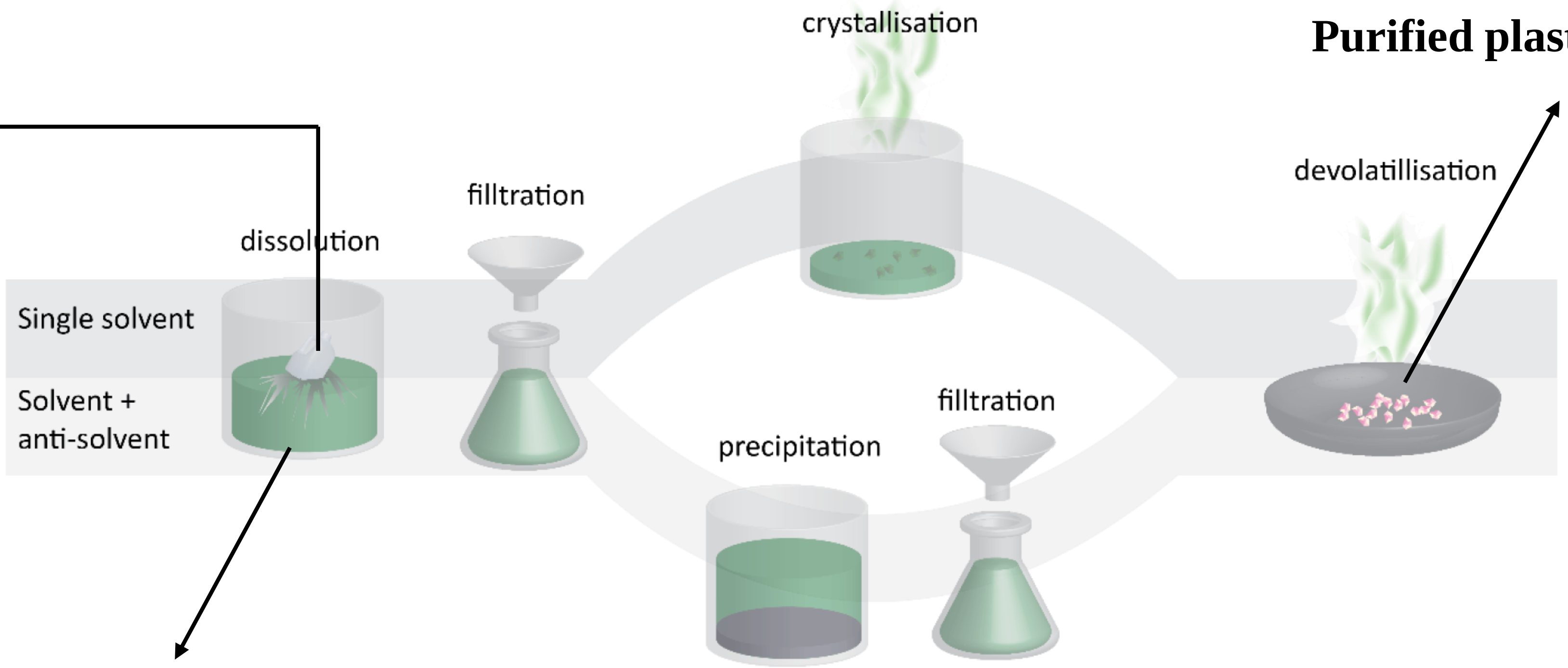


Mechanical recycling process of polyethylene plastic film at an industrial plant.

Purification (Dissolution/precipitation processes)

Purified plastic polymers

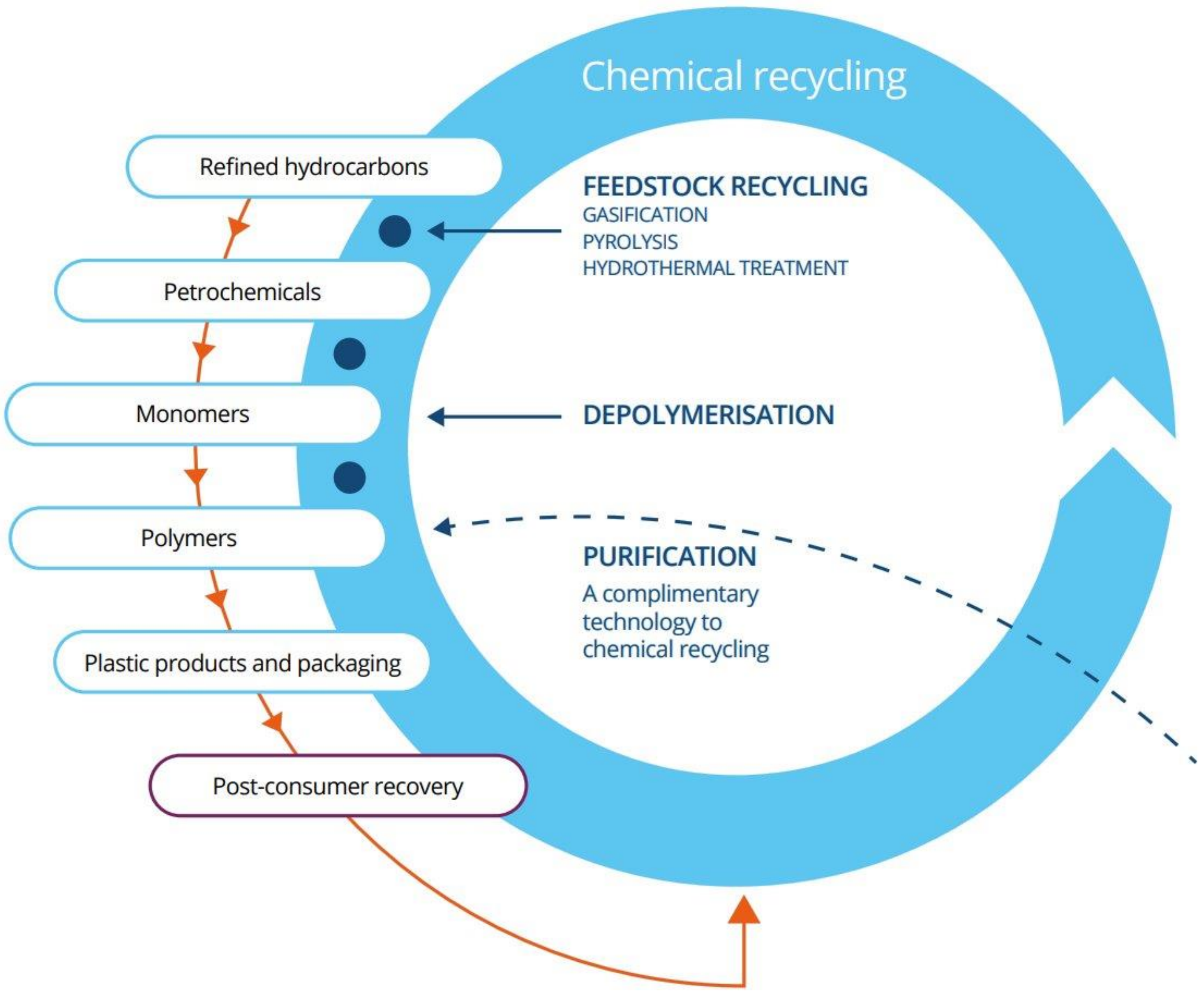
PVC
PS
PE
PP
and others



selective solvent

W. S. Khan et al., Elsevier, ISBN: 9780128224618, 2022.
R. Francis et al., Wiley-VCH, ISBN:9783527338481, 2016.

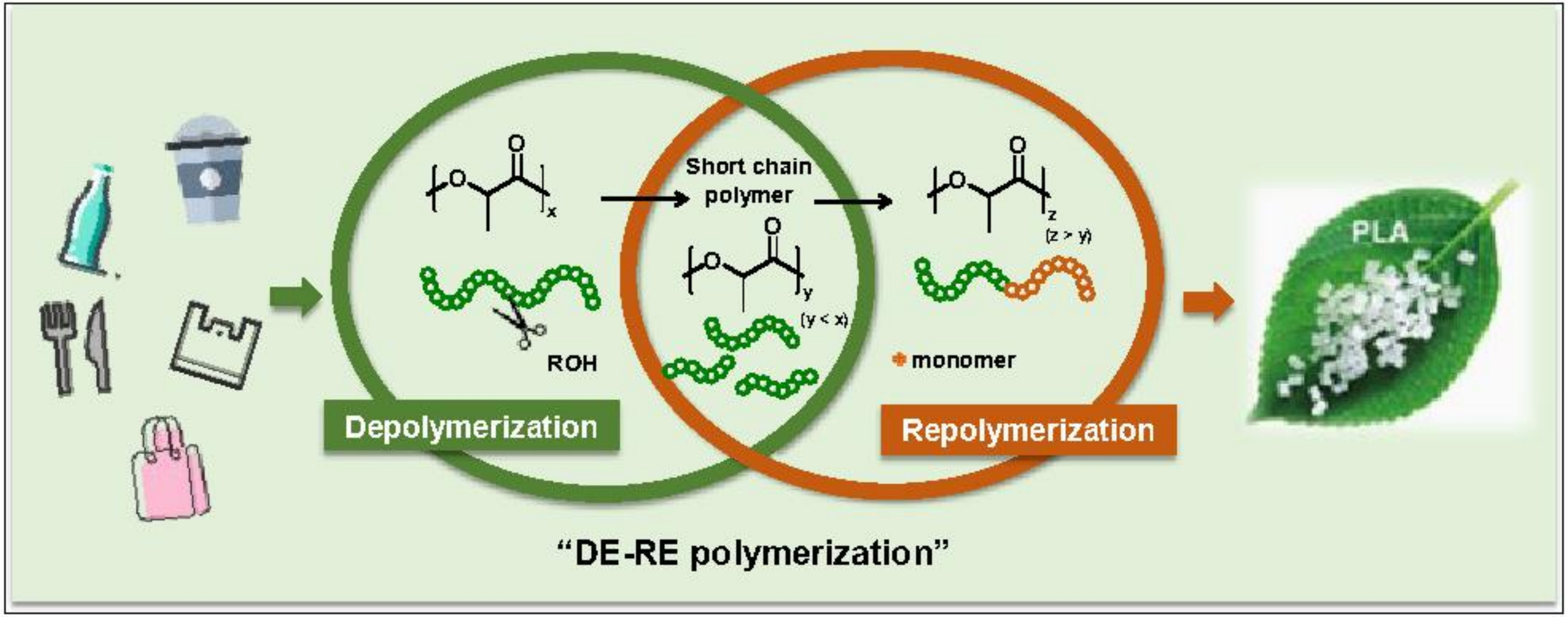
Chemical Recycling



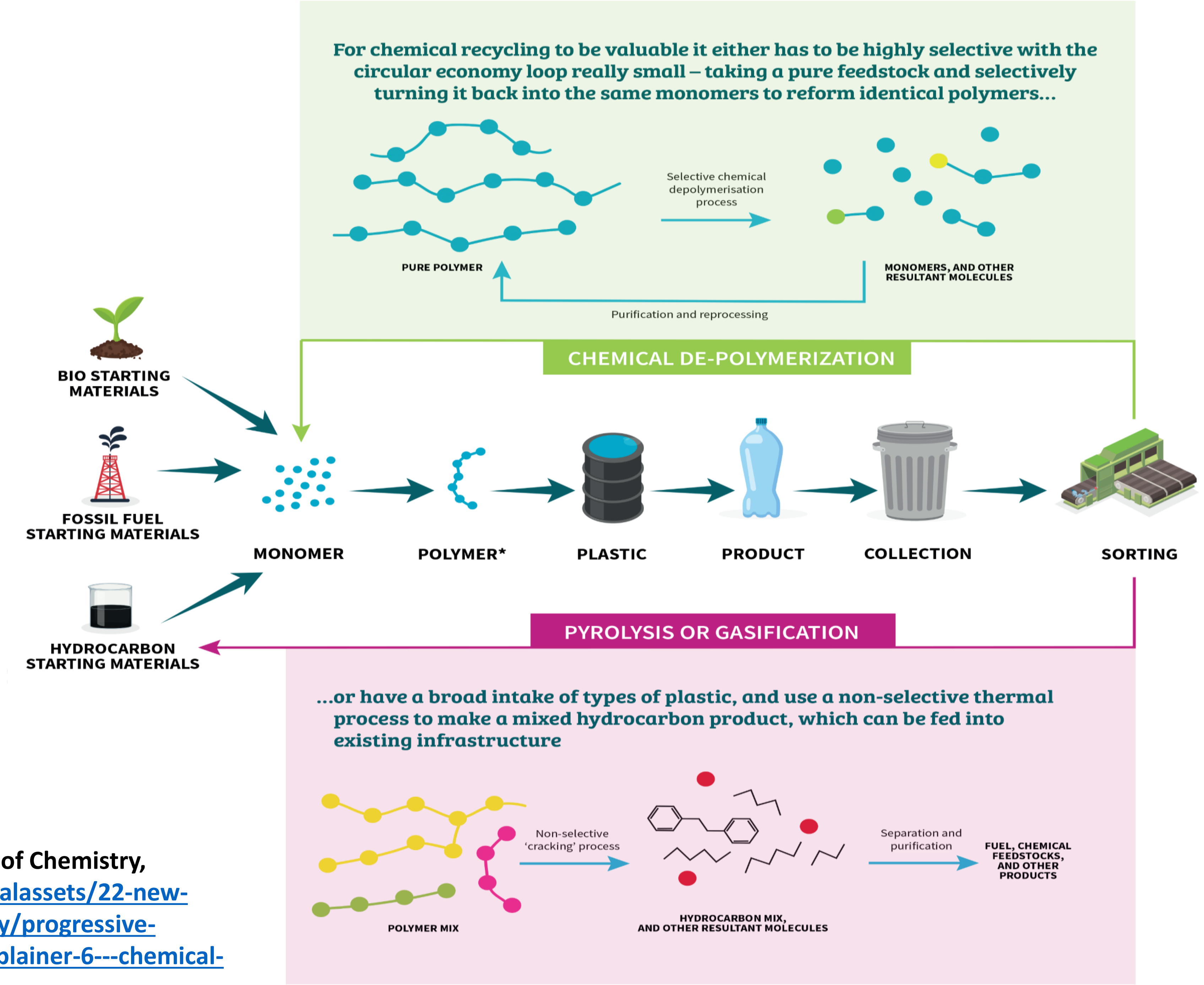
https://www.bpf.co.uk/plastipedia/chemical-recycling-101.aspx

Chemical recycling

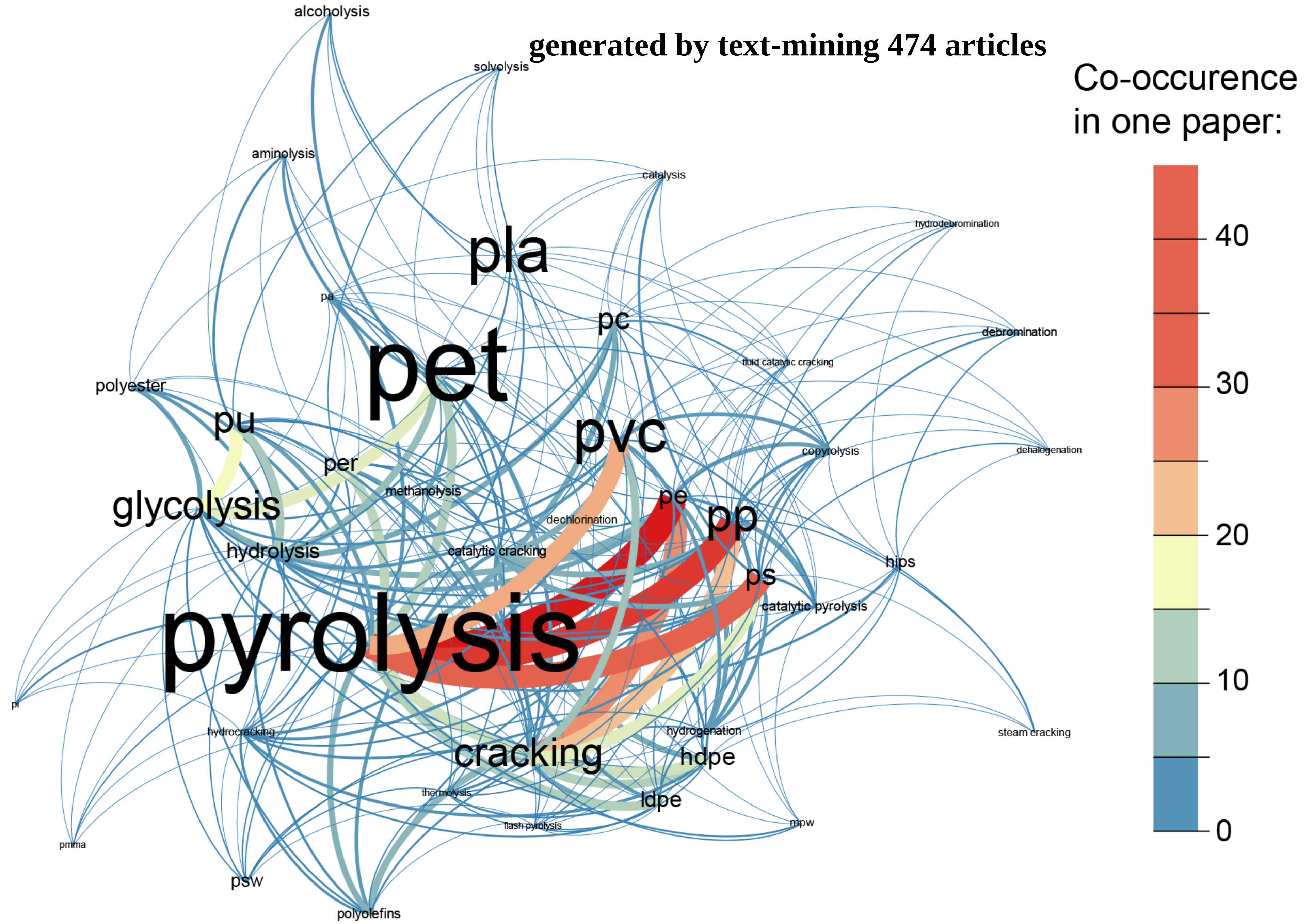
turning plastic waste back into base chemicals and chemical feedstocks



R. Yang et al., Macromolecules, vol. 55, 1726–1735, 2022.

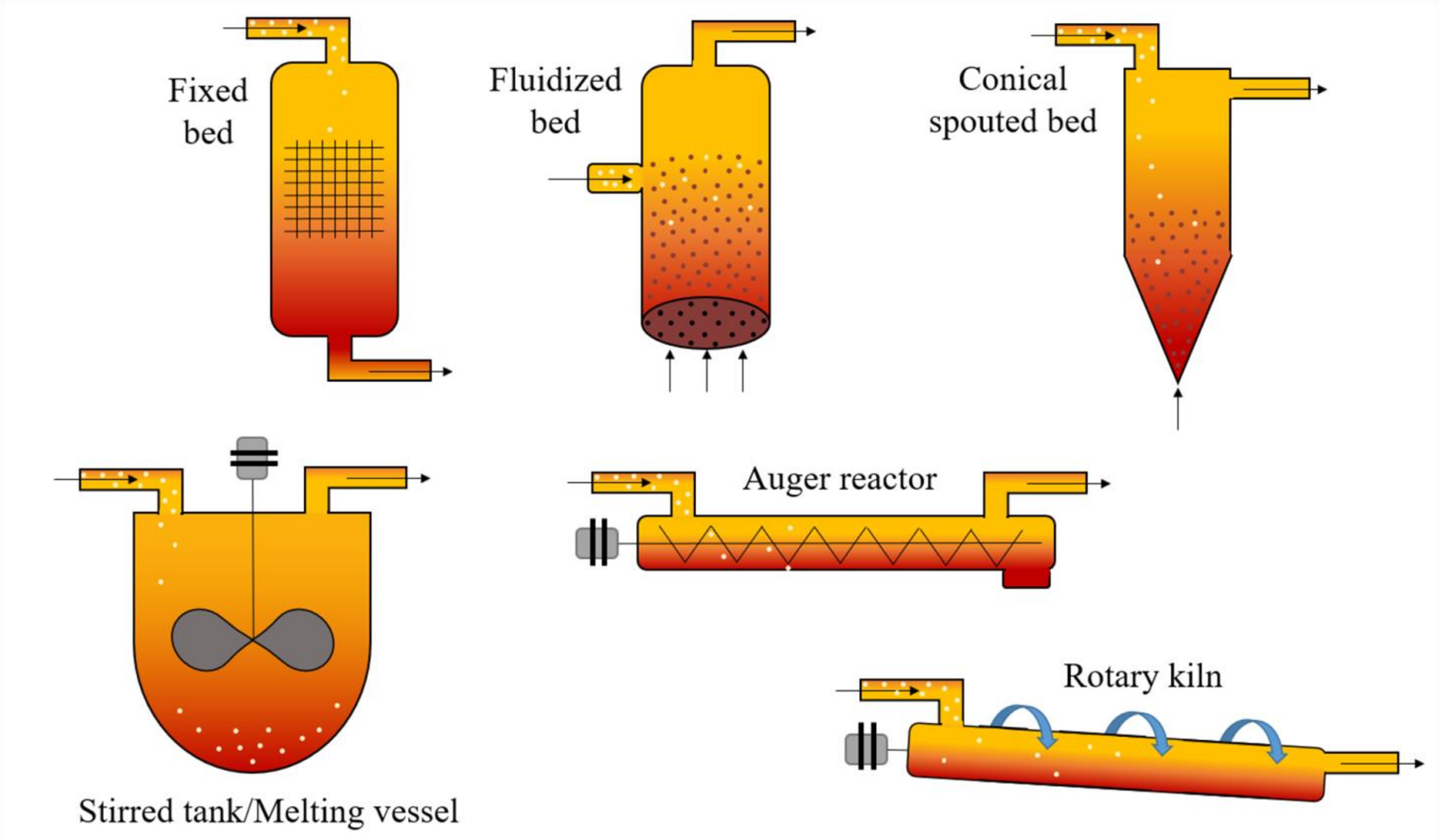


S. Wagland, Royal Society of Chemistry, https://www.rsc.org/globalassets/22-new-perspectives/sustainability/progressive-plastics/explainers/rsc-explainer-6---chemical-recycling.pdf



keyword	occurrence
pyrolysis	2267
pet	2156
pla	1236
pvc	1166
pp	879
glycolysis	705
pu	662
pc	500
ps	498
pe	380
hydrolysis	279
aminolysis	108
polyolefins	107
methanolysis	83
solvolysis	70
catalysis	47
pa	44

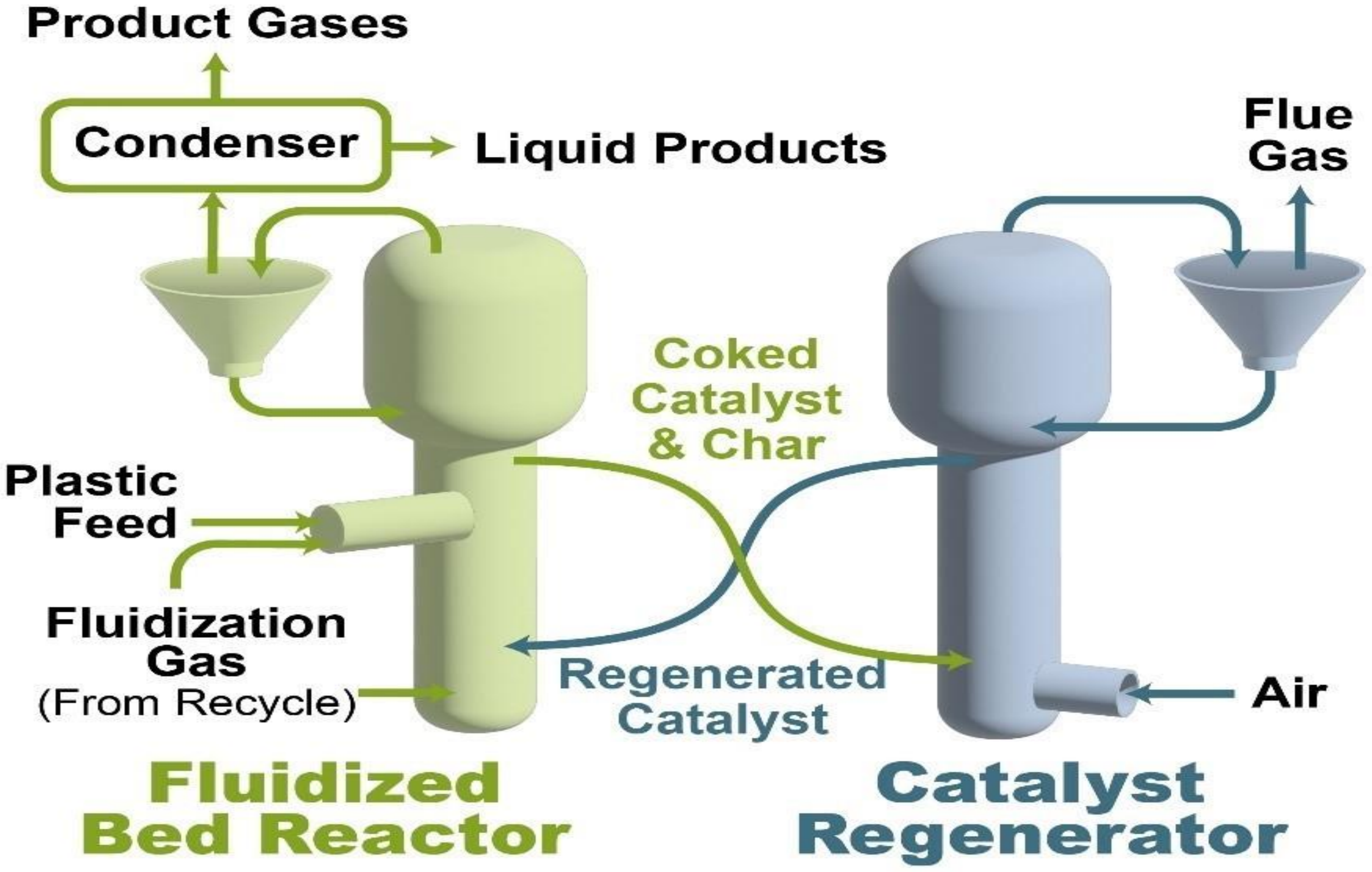
I. Vollmer et al., Angewandte Chemie International Edition, vol. 59, 15402-15423, 2020.

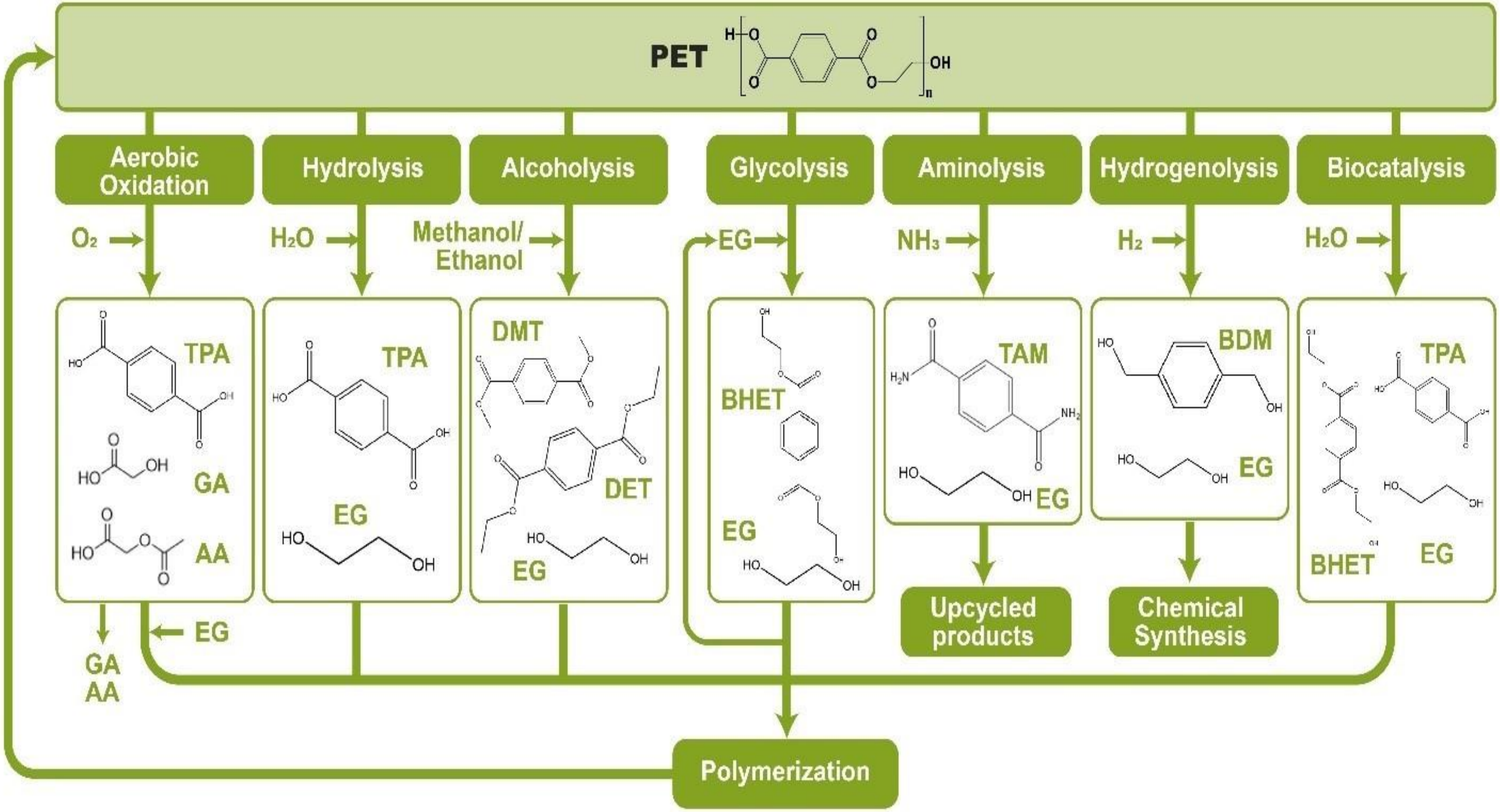


H. Li et al., Royal Society of Chemistry, volume 24, Pages 8899-9002, 2022.

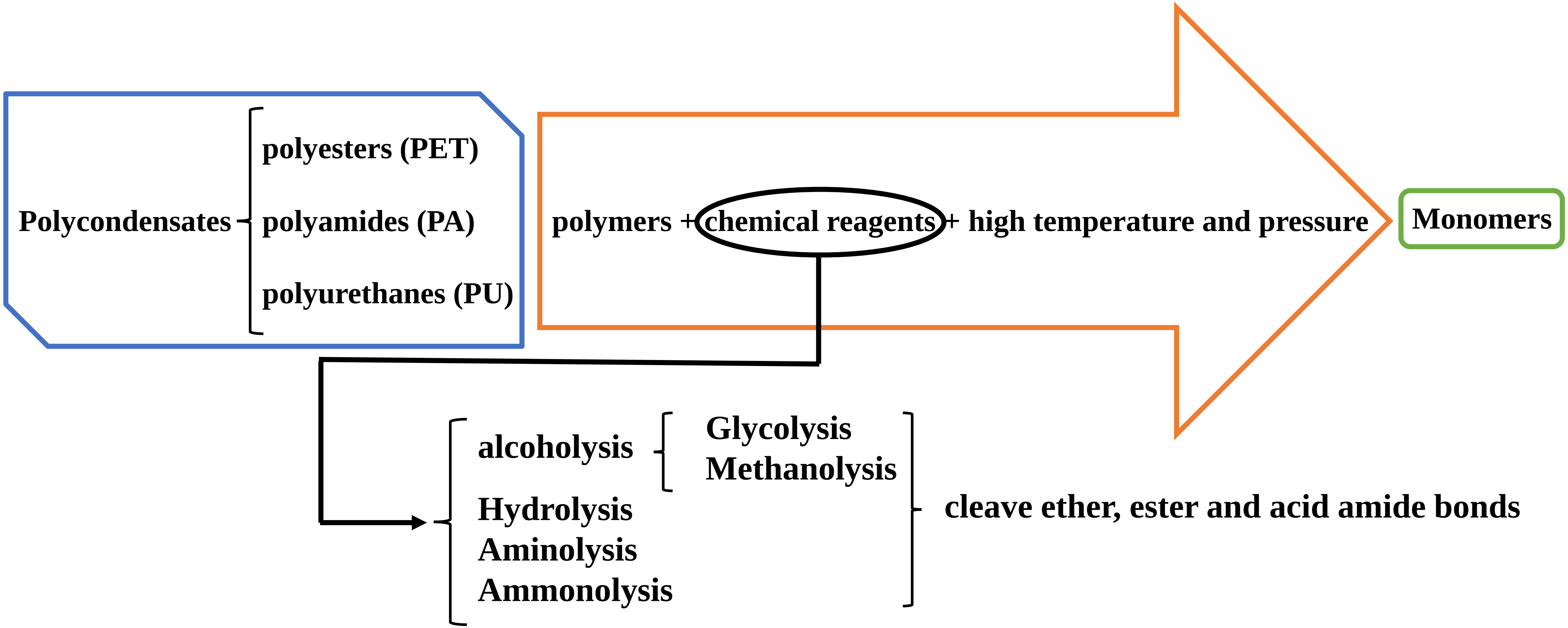
Process	Usual input	Usual output	Benefits	Limitations
Solvolysis	Polycondensates	Monomers and oligomers	Produces monomers and oligomers, which can then be reformed into polymers	- Cannot be used to break carbon–carbon bonds, so only works on polymers with specific groups in their chain - Often requires a very pure waste stream
Pyrolysis	Polyolefins, Polystyrene (PS) and mixed plastics	Hydrocarbon products including gases, oils, and waxes	Can be useful for mixed streams, or where different polymers cannot be separated, eg for multilayer film	- Poor selectivity in product, requiring further purification and processing before use as feedstock - Uses high temperatures, and therefore a lot of energy especially in the absence of catalysts
Gasification	All plastics	Synthesis gas (‘syngas’) made up of CO and H2 mainly	Can take mixed waste, but can require pre-treatment	- Requires further processing from syngas to hydrocarbons and then to monomers or polymers - Need large infrastructures to be profitable, generally on larger scale than pyrolysis plants - Very high energy due to temperatures needed
purification	Polyolefins, Polystyrene (PS), PVC and others	Pure recycled polymers	- Useful when there is a known additive to be removed before reformulation - Produces a high purity recycled polymer - Theoretically a step-by-step solvent process could deal with a mixed polymer stream	- Potentially high environmental impact depending on type of solvents used - Polymer can be degraded during process as with mechanical recycling

Fluidized bed reactor for plastic pyrolysis




PET
H
O
O
OH
n
Aerobic Oxidation
Hydrolysis
Alcoholysis
Glycolysis
Aminolysis
Hydrogenolysis
Biocatalysis
O₂
H₂O
Methanol/ Ethanol
EG
NH₃
H₂
H₂O
TPA
GA
AA
TPA
EG
DMT
DET
EG
BHET
EG
TAM
EG
BDM
EG
TPA
BHET
EG
GA
AA
EG
Upcycled products
Chemical Synthesis
Polymerization

Depolymerization (Chemo lysis / solvolysis)

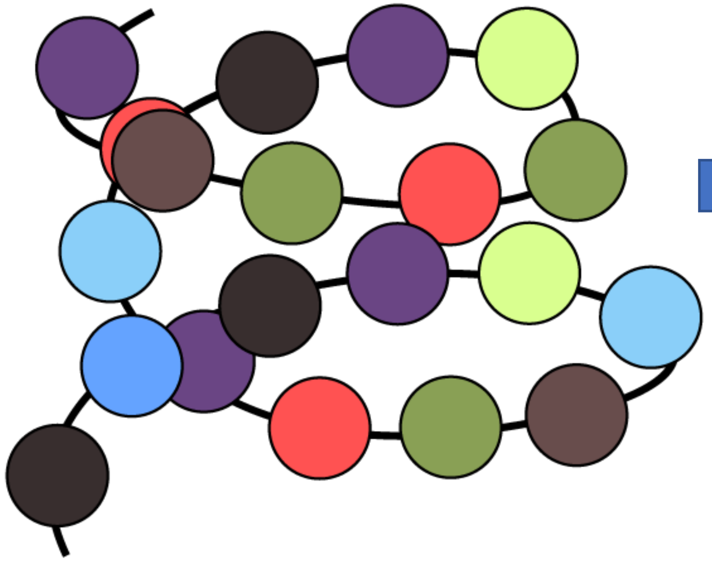


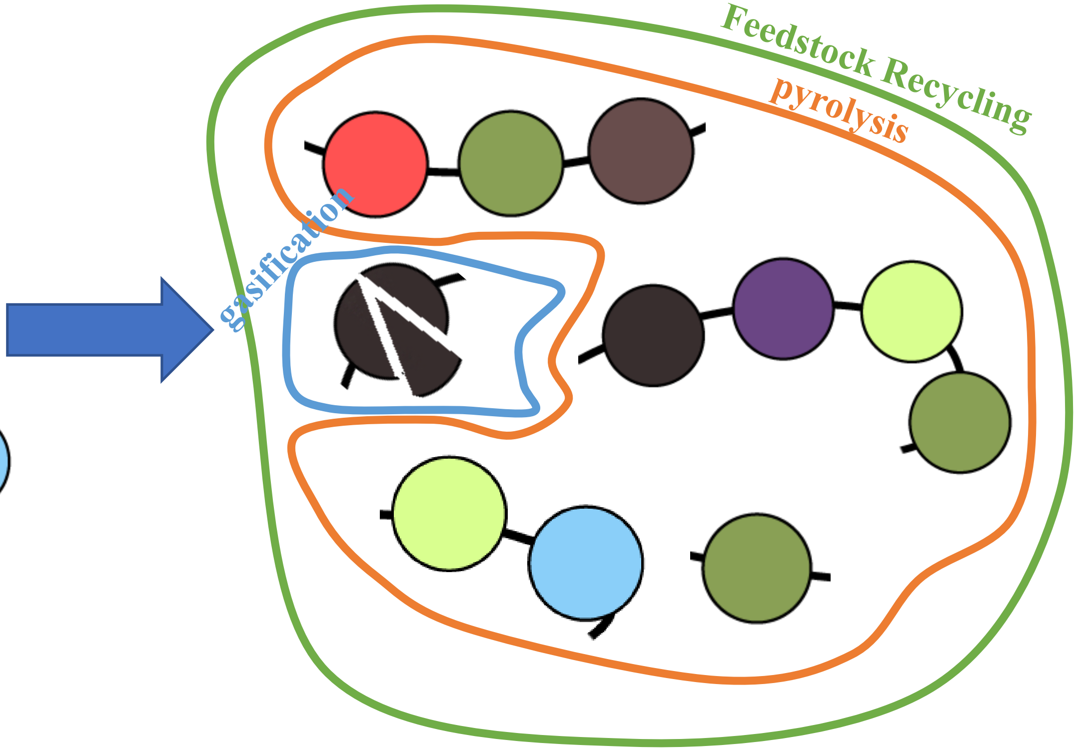
W. S. Khan et al., Elsevier, ISBN: 9780128224618, 2022.
R. Francis et al., Wiley-VCH, ISBN:9783527338481, 2016.

Feedstock Recycling

polymers → **any thermal process** → simpler molecules (feedstock for petrochemical-type processing)

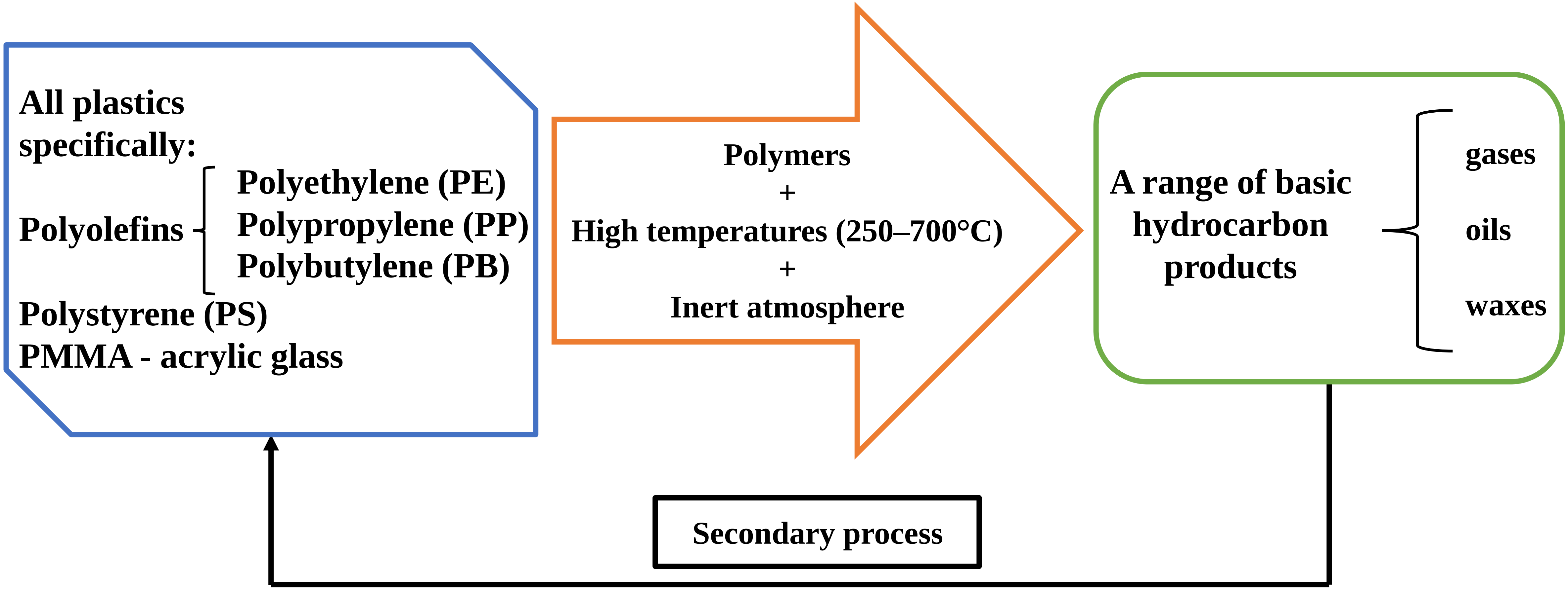
The two main processes:
pyrolysis
gasification





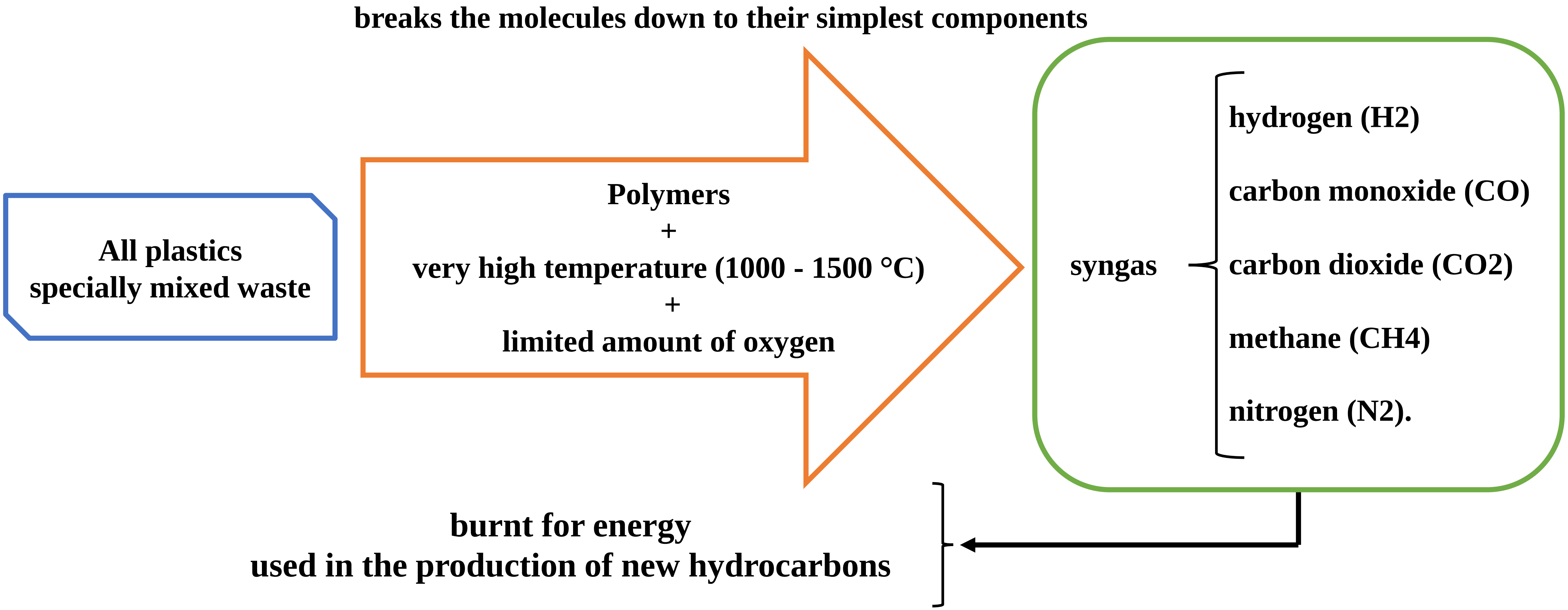
W. S. Khan et al., Elsevier, ISBN: 9780128224618, 2022.
R. Francis et al., Wiley-VCH, ISBN:9783527338481, 2016.

Pyrolysis



W. S. Khan et al., Elsevier, ISBN: 9780128224618, 2022.
R. Francis et al., Wiley-VCH, ISBN:9783527338481, 2016.

Gasification



W. S. Khan et al., Elsevier, ISBN: 9780128224618, 2022.
R. Francis et al., Wiley-VCH, ISBN:9783527338481, 2016.

Summary of waste plastic techno-economic analysis pyrolysis articles by feedstock, products, region, capacity, capital cost, and return on investment (ROI).

Technology	Feedstock	Major Products	Region	Capacity (kton/year)	Capital Cost (MM USD)	NPV ($) Net present value
Pyrolysis	PS, PP, PE	Heavy oils Petrochemical feedstock	United Kingdom	0.7 – 701	1.36 – 77.2	0.44 /kg – 0.71 /kg
Pyrolysis + upgrading	PS, PP, PE, PET	Hydrocarbon Fuel	Korea	260	$ 118MM	0.062 /gal
Pyrolysis	PE, PP, PET	Diesel Power Char	Australia	14.6	3.76 MM	2.03 MM
Pyrolysis & Heat Integration	HDPE	Ethylene Propylene	United States	193	118.5MM - 120.5 MM	$367.8MM - $383MM
Fast Pyrolysis (Open-loop & closedloop)	Mixed Polyolefins mainly LDPE and residual PP	Naphtha	Belgium	120	Not disclosed	open loop: 32.5/ton Closed loop: 2.72 /ton
Pyrolysis	Plastic waste (PP, PE, PS)	Light oil Heavy oil	Malaysia	120	58.6 MM	20.9 MM

Literature reporting liquefaction of typical waste plastics

Type of Plastics	Temp. (°C)	Pressure (MPa)	Time (h)	Concentration	Solvent/Gas/Catalyst (%)	Products	Oil Yield (wt%)	Year
				Liquefaction under pressurized gases				
PE, PP, PS (continuous reactor)	400	-	-	-	w/ or w/o ZSM-5	Majority aromatics, some aliphatic liquids and gases	85% (PE, PP); 90% (PS)	1992
MDPE, HDPE, PP, PET or mix	420-450	5	1	66% plastics in Tetralin/waste oil	H_2; w/ or w/o 1 wt% HZSM-5/Ferrihydrite catalyst	Hydrocarbon oil and gases	w/o to with catalyst): 11 to 96% (HDPE); 83 to 98% (PP); 33 to 93% (MDPE)	1994
Mix of HDPE, LDPE, PET and PS	400-440	5.6	0.5-2	50% plastics in Tetralin, decalin, dodecane, C_{12}-C_{20} alkanes	H_2; 10-20 wt% HZSM-5/FCC catalysts	Hydrocarbon oil and gases	56.2-75.8% conversion (mixture); 90-100% conversion (individual plastics)	1996
PS and SBR	350-450	3.45-17.23	0.25-2	1-5 wt% Fe_2O_3/SO_4^{2-} and ZrO_2/SO_4^{2-}		Aromatics (PS); Aromatics and C_5-C_9 paraffins/cycloparaffins.	80.3% (PS); 72% (SBR)	1996
LDPE, PET, PVC	420-440	5.5	0.25-0.3	70% in Tetralin	Hydrogen	C_9-C_{40} hydrocarbons and gases	59% (LDPE)	1996
MDPE, HDPE, PP	> 420	0.68-5.5		30-50% in Tetralin; H_2 or N_2; HZSM-5 or Al_2O_3-SiO_2-ferrihydrite		Light, medium and heavy oils	> 90% (all plastics)	1996
HDPE, PP, PB	350-450	3.5-13.8	0.5-3	n-octadecane; H_2; 1-2 wt% Fe_2O_3/SO_4^{2-} and ZrO2/SO42-		Gasoline range paraffins as major products	> 90%	1997
PE and PP	500	0.79	0.5	Hydrogen		Light and heavy oils	up to 60%	1998
Post-consumer plastic (PCW) mixture	415-455	1.4	0.5-1	H_2, 1-5 wt% of HZSM-5 and others		Higher gasoline range oil with catalysts	up to 85%	1999
PE, PP, PS, PVC, and PET (standalone and mixed)	500	1	1	Nitrogen and Hydrogen		Hydrocarbon oil and gases with high concentrations of alkanes and single-ring aromatics	Calculated mix vs. PCW (DSD/Waste Fost Plus): 72.3% vs 32.5/64.1% (N_2); 75.12% vs 48.2/70.6% (H_2)	2007

Type of Plastics	Temp. (°C)	Pressure (MPa)	Time (h)	Concentration (%)	Solvent/Gas/Catalyst	Products	Oil Yield (wt%)	Year
					Hydrothermal Liquefaction			
PVC	200-600	1.6-55.7	1	0.1-2	None	Low-molecular weight aromatic and aliphatic compounds	179ppm (300°C), 396ppm (400°C)	2004
Model mix of PE, PP, PS and PVC	200-400	1-5		100-200	glass powder additive	Chlorine content after NaOH-based dechlorination	40-120 ppm in oil (negl.)	2011
PBT, PC, PLA, PMMA, POM, PPO, PVA, SB.	400	25	0.25	10	None	Oil%/solid%: nil/50.8 (PBT), 99.8/nil PC), /68.5 (PET), 48/nil (PMMA), 13.7/8.1 (POM), 78.9/8.8 (PPO), 35.4/2.9 (PVA), 80.8/1.2 (SB)		2017
High Impact PS (HIPS)	350-550	30	0.12-1	1-9	None	Ethylbenzene (51.3wt%), Toluene (14wt%) and other polyaromatics (490°C/1 h)	Maximum carbon Liquefaction rate of 77wt% (490°C, 1 h)	2019
PP	425-450	23	0.5-4	-	None	80% naphtha	91% (2 h/425 °C; 1 h/450 °C)	2019
ABS, PA6, PA66, PET, Epoxy, PC, PUR, HDPE, PVC, LDPE, PP, PS	350	corresp. to T	0.33	5.6	KOH	Bisphenol-A & phenol (PC, Epoxy), caprolactam + (PA6, PA66), TE & EG (PET), TDA + (PUR) and no polyolefinderived products		2020
PP, PS, PC and PET	350-450	25+	0.5-1	0.06-0.35	None	32% (PP, 425°C, 30 min), 16% (PET, 450°C, 30 min), 86% (PS, 350°C, 30 min), and 60% (PC, 425°C, 30 min).		2020
PC	350-450	corresp. to T	0.03-0.5	5	None	IPP, IPrP, phenol, BPA, and other alkylphenols	57.7	2020
HDPE	400-450	corresp. to T		57.1	None	Naphtha, heavy oil and heavy waxes	86-87% (425°C, 2.5 h or 450°C, 0.75 h)	2020
LDPE, HDPE	380-450	corresp. to T	0.25-4	20	1% acetic acid	Alkanes, alkenes, cycloalkanes, aromatics, and negligible alcohols	85-90% (425-450°C, 1 h)	2020

Example of a continuous tubular reactor design for hydrothermal liquefaction of plastics (Extracted from the US patent US 8,980,143 B2).

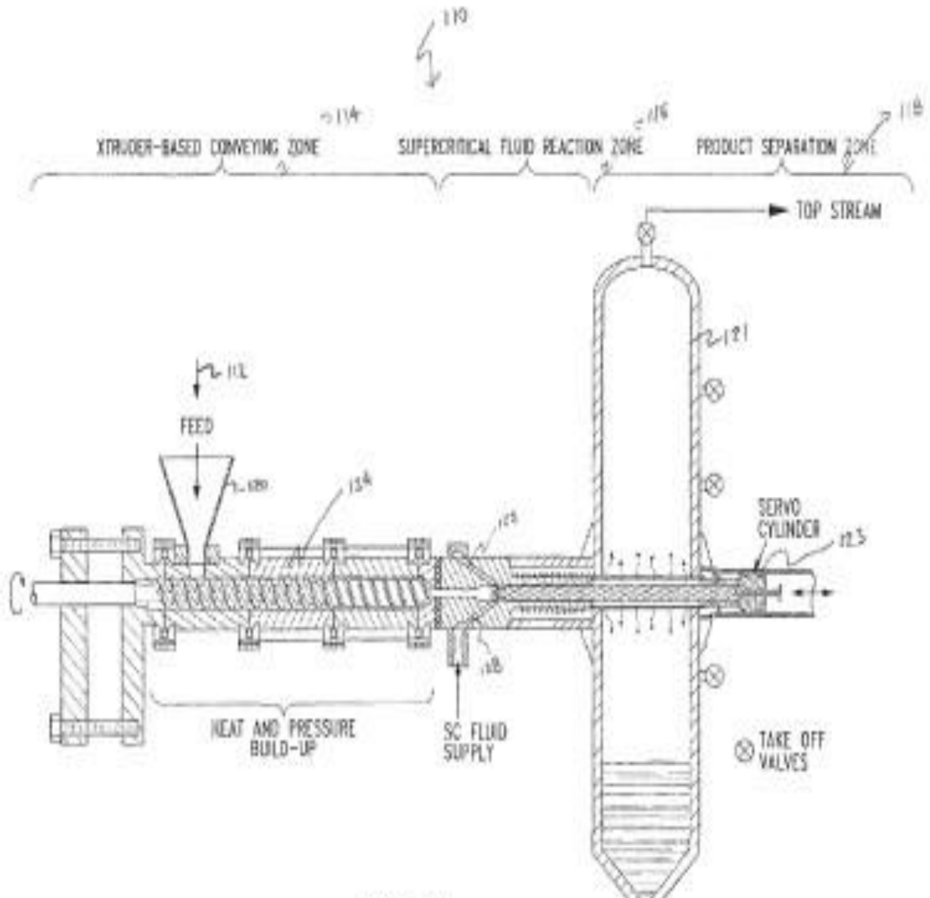
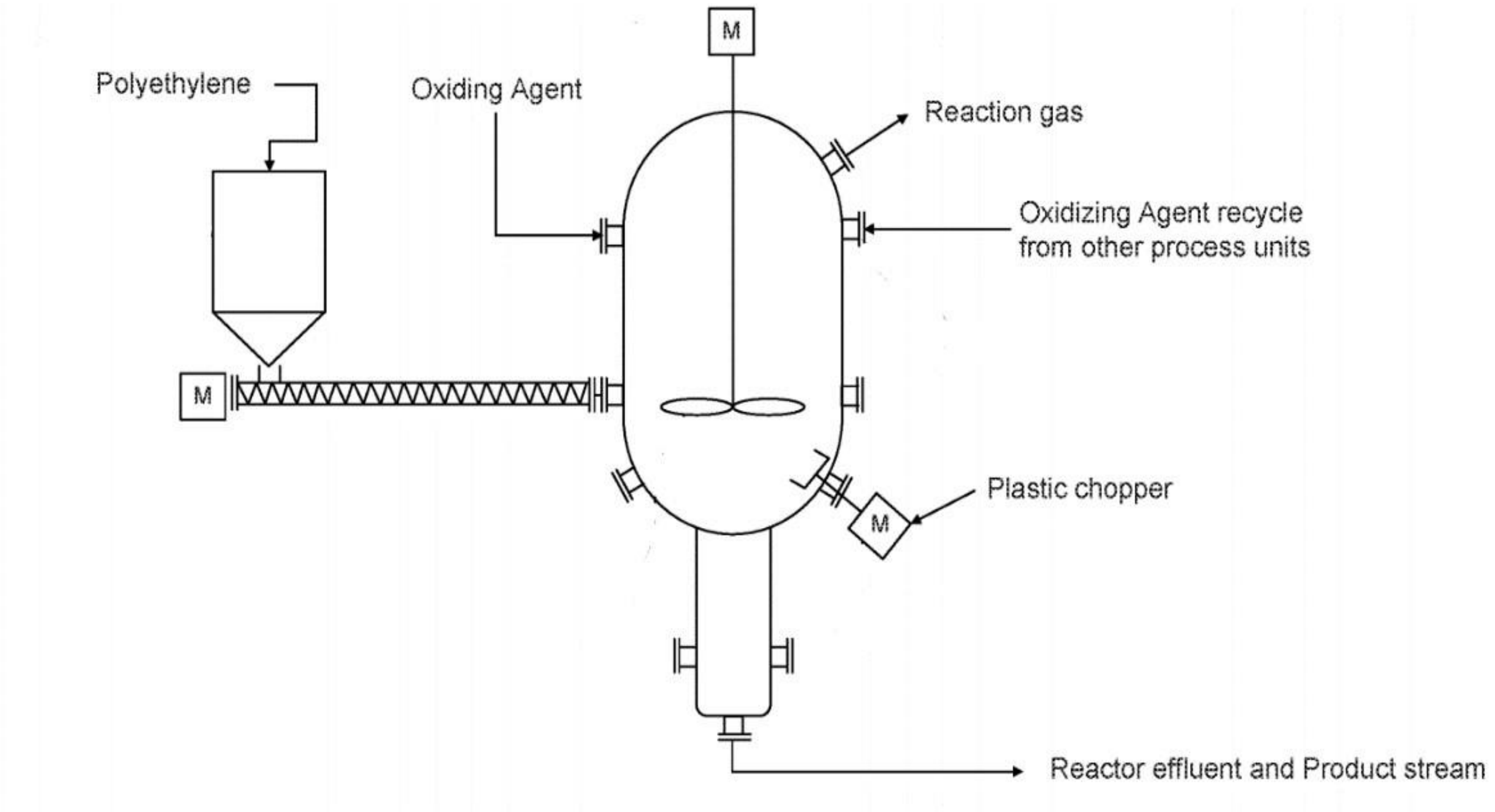


Fig. 1

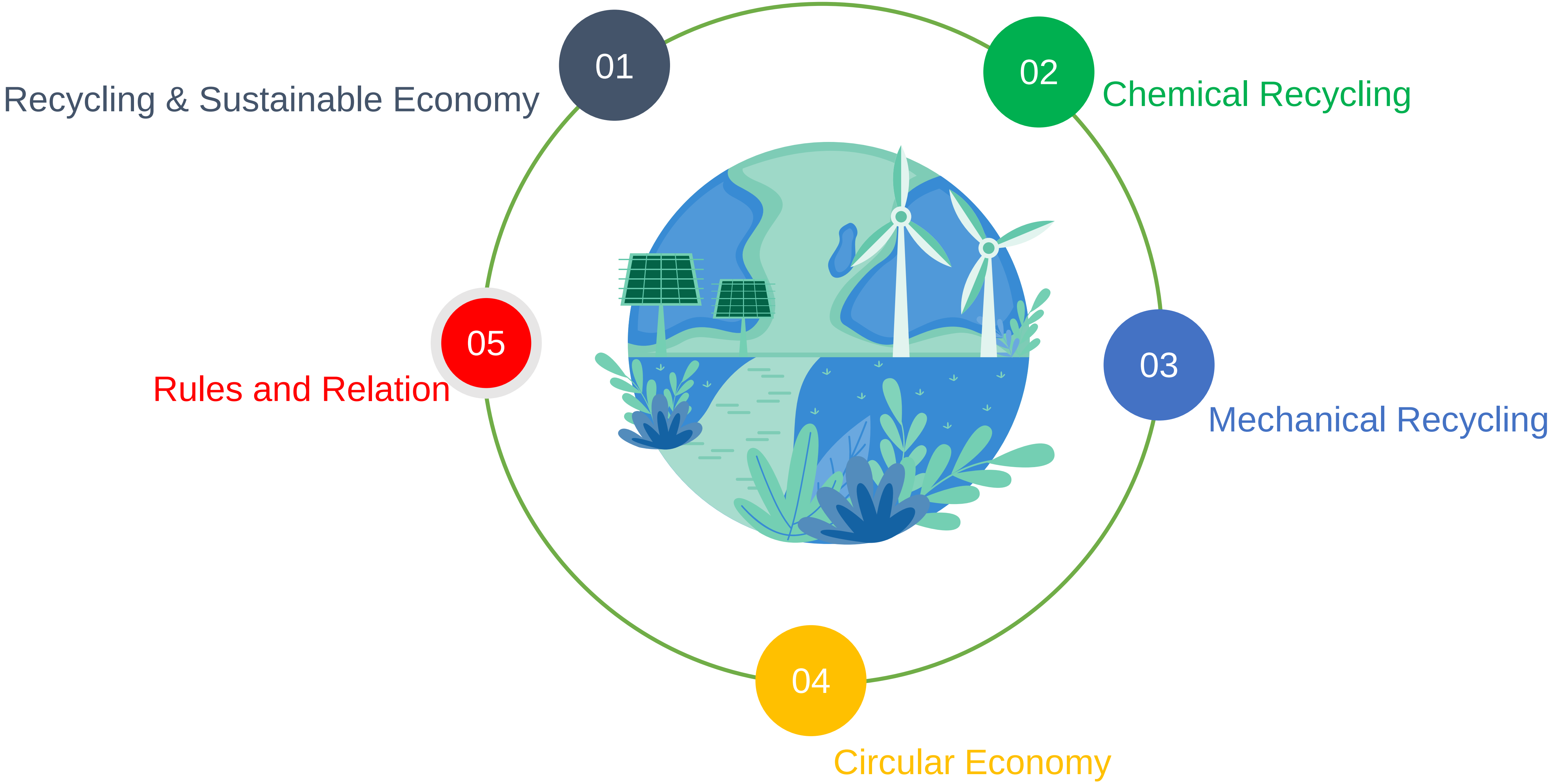
Hydrogenolysis of Plastics into Various Hydrocarbons in Batch Reactors.

Catalyst	Polymer	Temperature (°C)	Pressure (Bar)	Time(h)	Polymer/Catalyst (Mass)	Products
Ru/CeO_2	**LDPE, HDPE, PP**	**200-240**	**20-60**	**5-24**	**34**	**Liquid fuels, waxes (C5-C45)**
Ru/TiO_2	**PP**	**250**	**30**	**8-16**	**20-40**	**Lubricants (C20-C60), C1-C2 gases**
Ru/Nb_2O_5	**PET, PS, PC**	**200-320**	**3-5**	**12-16**	**1-2**	**Aromatic hydrocarbons**
5Ru/C	**PE, LDPE**	**200-225**	**20**	**16**	**25**	**Liquid alkanes (C3-C13), light gases (C1-C6)**
5Ru/C	**PP**	**250**	**35**	**8-24**	**14**	**Liquid alkanes (C5-C32), light gases(C1-C5)**
Ru/FAU	**LDPE, PP**	**300-350**	**50**	**3**	**50**	**Methane, light paraffins (C2-C11)**
Ru/WO_3/ ZrO_2	**LDPE**	**250**	**30**	**2**	**40**	**Lubricants, waxes, diesel (C4-C35)**
Ru/C	**HDPE**	**220**	**30**	**1**	**2**	**Lubricants, liquid fuels (C6-C38)**
Pt/WO_3/ ZrO_2 +Zeolite	**LDPE**	**250**	**30**	**2**	**10**	**Liquid fuels (C5-C22)**
Pt/$SrTiO_3$	**PE**	**300**	**12**	**96**	**5**	**Lubricants, waxes (Mw 2001000 Da)**
SiO_2/Pt/SiO_2	**HDPE**	**300**	**14**	**24**	**88**	**Fuels, lubricants (C8-C32)**
Pt/C	**PP**	**300**	**15**	**24**	**10**	**Lubricants (C5-C45)**

Strategies in functionalization of plastics: (A) Functionalization of polyolefins; (B) oxidation of polyisobutene; (C) PLA amination; (D) reactive extrusion



Conclusion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Recycling & Sustainable Economy
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Chemical Recycling
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Rules and Relation


Thanks for your Attention