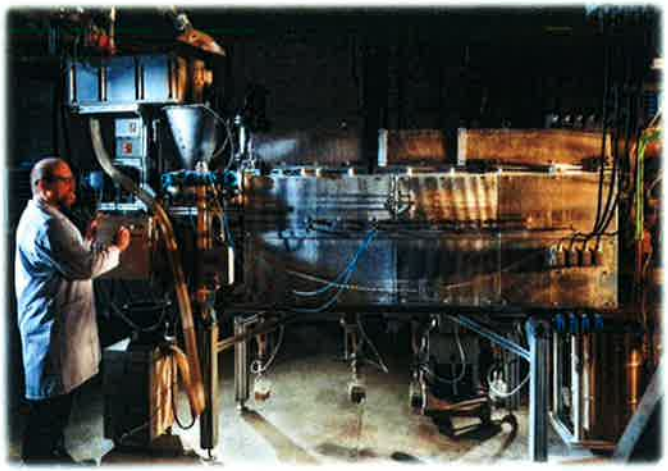
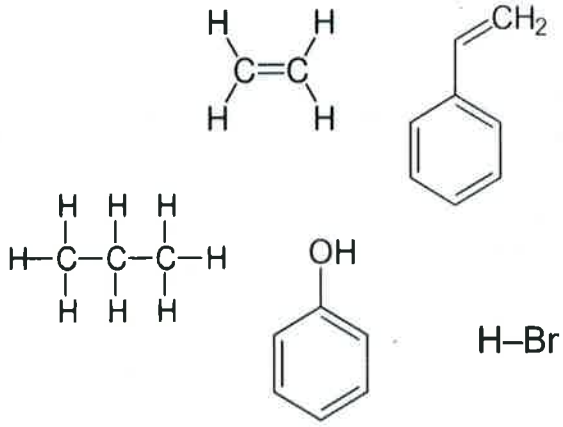
Karlsruhe Institute of Technology

Chemical Recycling of Plastics Waste

ProcessNet/DECHEMA Jahrestagung, Aachen, September 13, 2022

Dieter Stapf





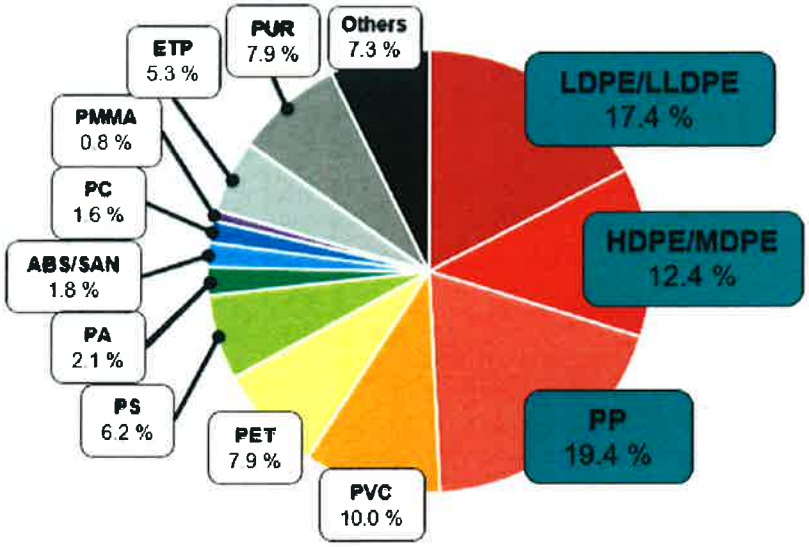
Plastics Production and Plastics Waste Generation

[Mt / year]	EU 28+2*	Germany**
Plastics production	**61.8**	**19.9**
Plastics consumption	51.2	12.6
Plastic waste	**29.1**	**6.2**
- Landfill	7.2	< 0.1
- Energy recovery	**12.4**	**3.2**
- Recycling	9.4 (export 1.8)	2.9 (export: 0.6)

Additional plastics recycling capacity demand (2030): 11 Mt / year

*) Lindner,C. et al.: Circular Economy of Plastics 2018 EU-28+2, Conversio Market & Strategy GmbH, Mainaschaff (2019)
**) Lindner,C., Schmitt, J.: Stoffstrombild Kunststoffe in Deutschland 2017, Conversio Market & Strategy GmbH, Mainaschaff (2018)

Plastics Production and Plastics Waste Generation



Plastics production EU28+NO/CH, 2019*

Plastics products are compounds that consist of (multiple) plastics materials and & multiple functional additives

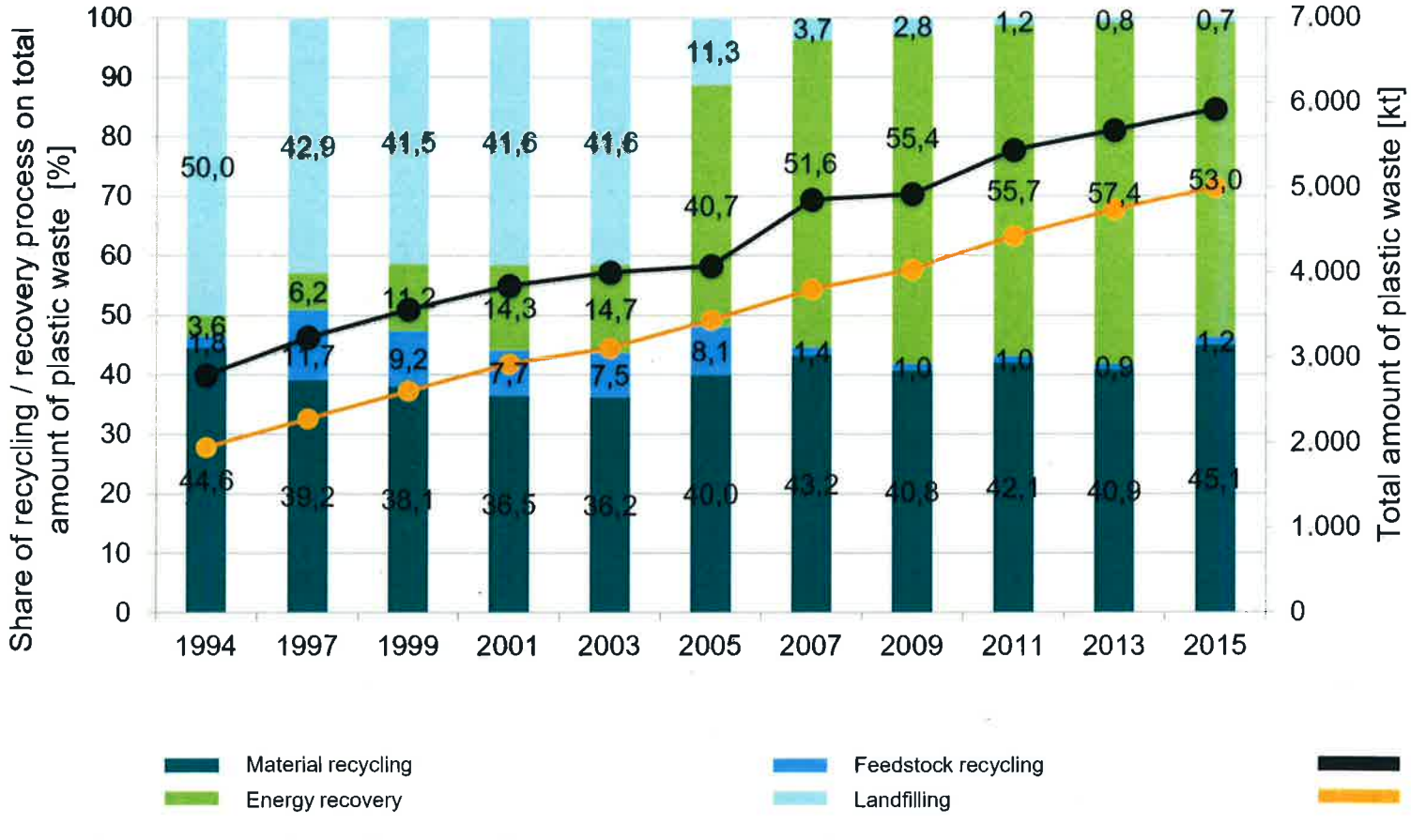
Mineral Additives: fillers, reinforcement, stabilizers, pigments, flame retardants,

Post-Consumer Wastes, 2018*:

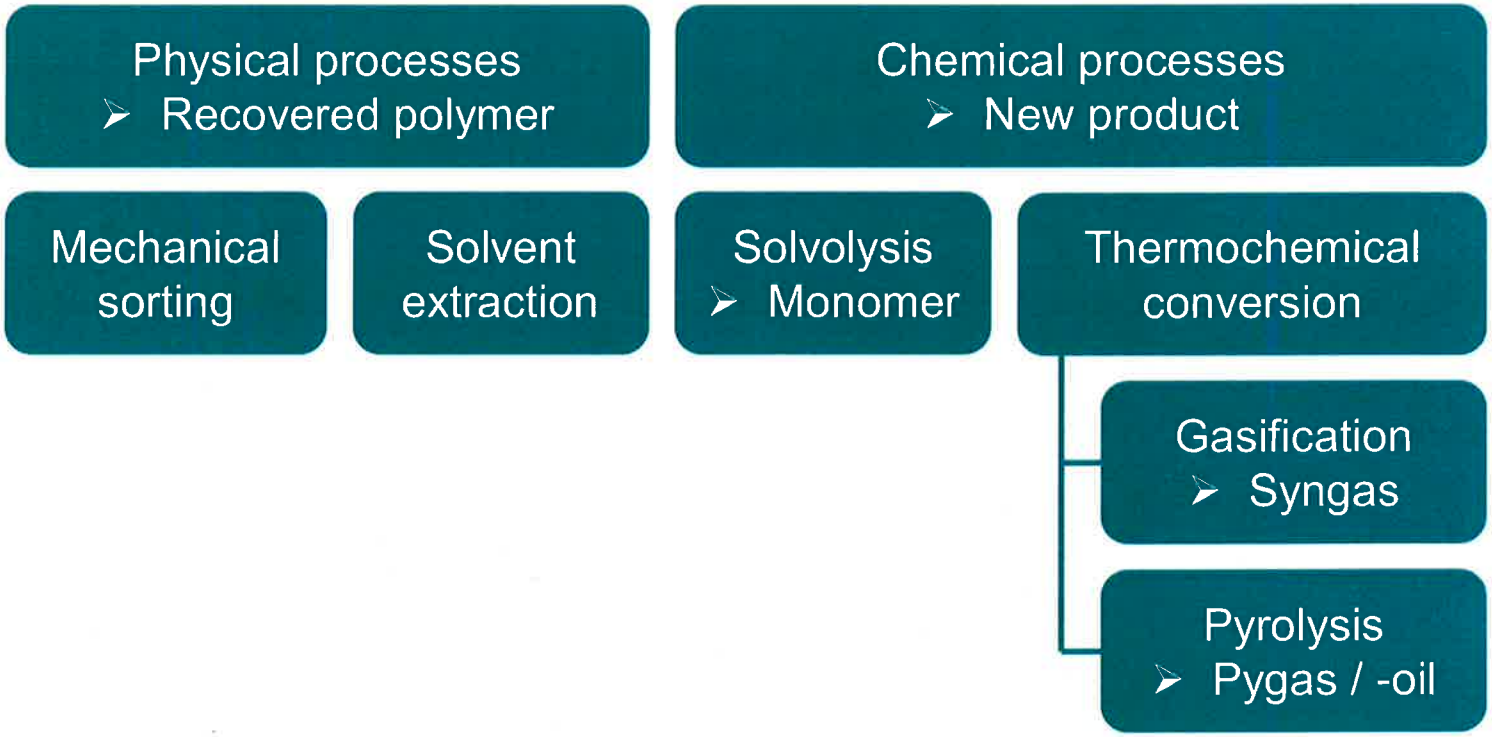
Mechanical Recycling		38.4 %		32.5 %	} **EU recycling objective 2030: 55%**
Chemical Recycling	**GER**	0.2 %	**EU 28+NO/CH**		
Energy recovery	**5.3 Mt**	60.7 %	**29 Mt**	42.6 %	
Landfilling		0.6 %		24.9 %	

*) PlasticsEurope (2020)

Total Plastics Waste Development, Recycling and Recovery in Germany



Recycling Processes for Mixed Plastics Waste and Key Products



applicable to:

- ➢ standard thermoplastics
- ➢ Pure polymers
- ➢ Polycondensates
- ➢ Mixed wastes, composite materials

Capital Investments (excerpt):
Chemical Recycling of Plastics Waste

- Enerkem, CAN
  - ⟶ W2C project, Rotterdam
- Plastic Energy, UK
  - Operations @ Almeria & Sevilla, ES
- Sabic
  - ⟶ Cooperation with Plastic Energy, Geleen, NL
- LyondellBasell
  - ⟶ MoReTec-Pilot plant, Ferrara, IT
- BASF
  - ⟶ Cooperation with Quantafuel, NOR
  - ⟶ Cooperation with Pyrum, GER
  - ⟶ Cooperation with Arcus Greencycling Technologies, GER

www.plasticenergy.com

Recycling of Mixed Plastics Waste: The Pyrolysis Value Chain Example

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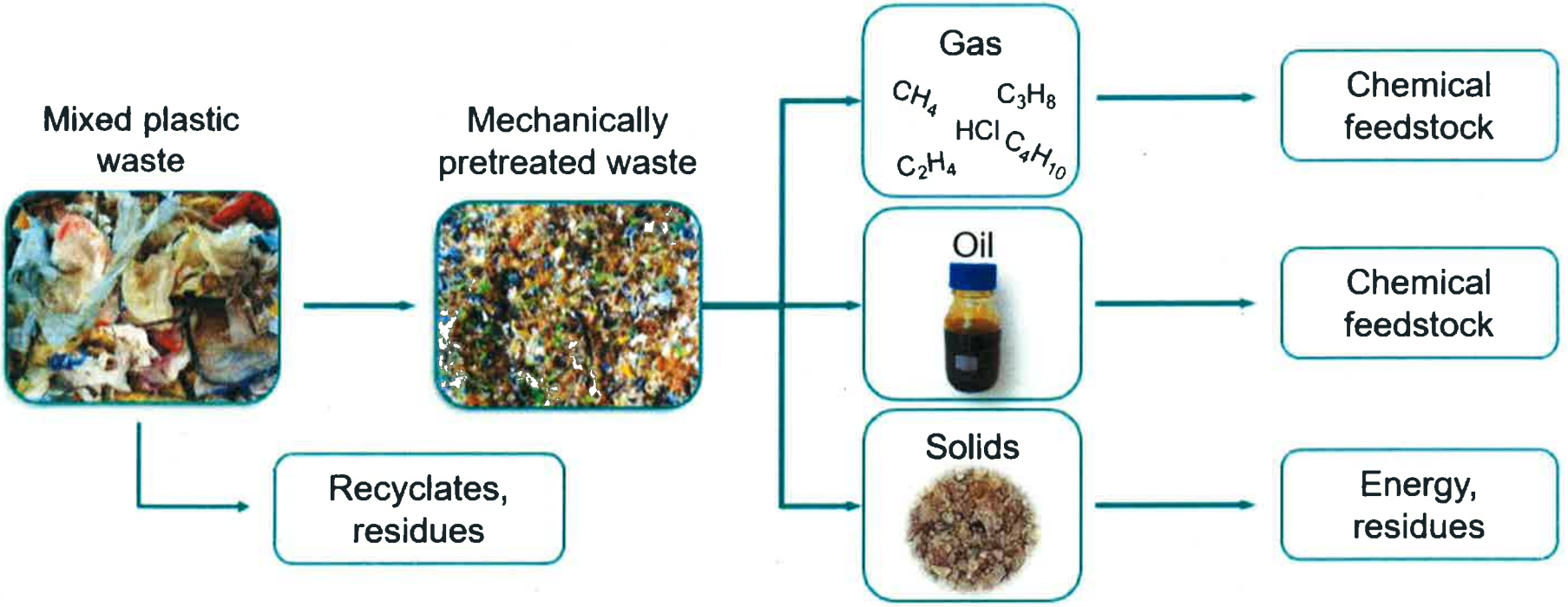
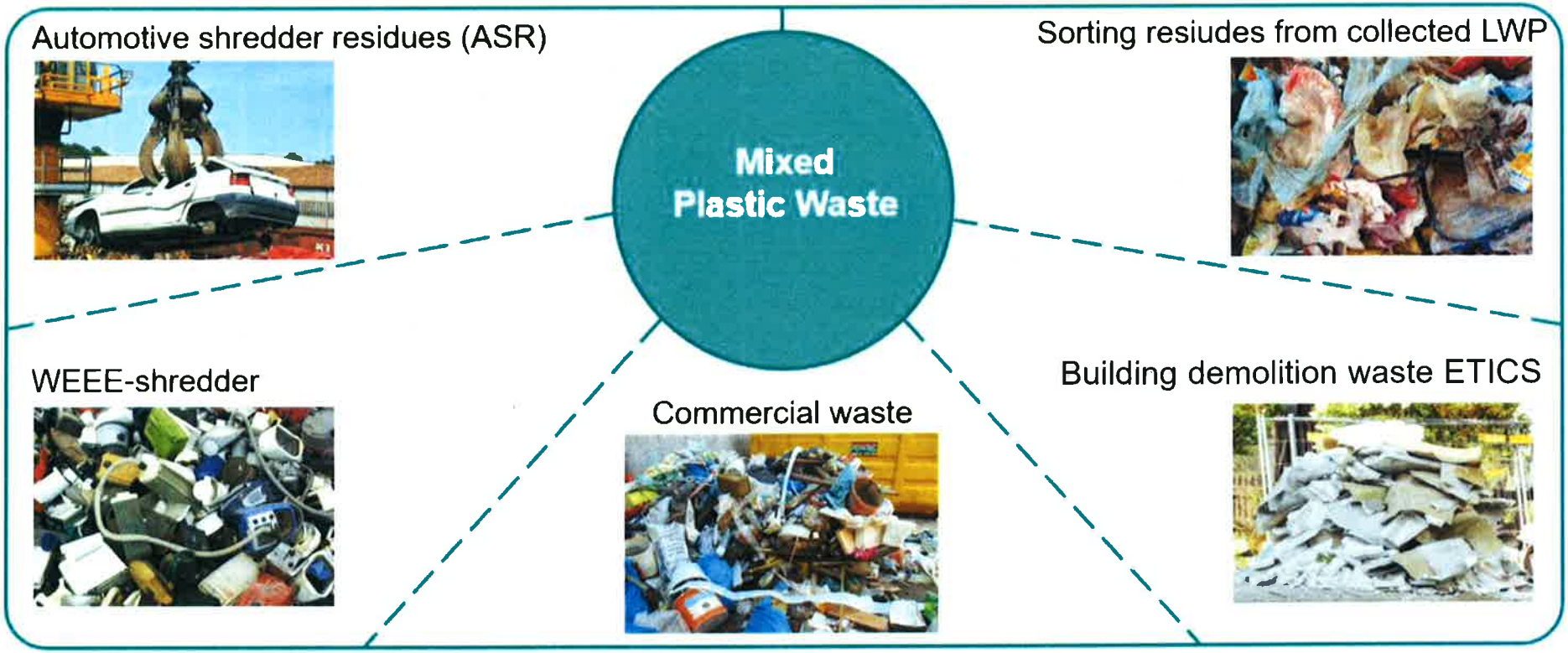


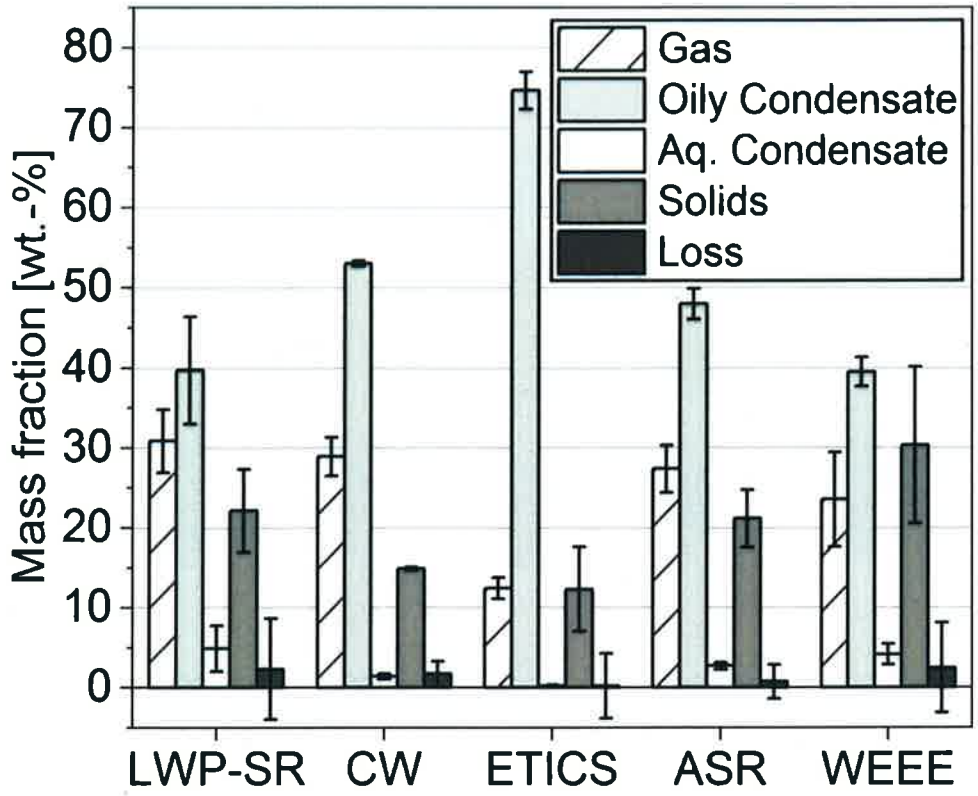
Pretreatment → Pyrolysis → Upgrading & synthesis

Examples of Plastics Waste Produced



WEEE = Waste of Electrical and Electronic Equipment
LWP-SR = Sorting Residues from Light Weight Packaging Waste collected
ETICS = Thermal Insulation Composite System

Pyrolysis Mass Balance



Zeller, M., et al.: Chemical recycling of mixed plastic wastes by pyrolysis. Chem. Ing. Tech. 2021, 93 (11), 1-9. https://doi.org/10.1002/cite.202100102

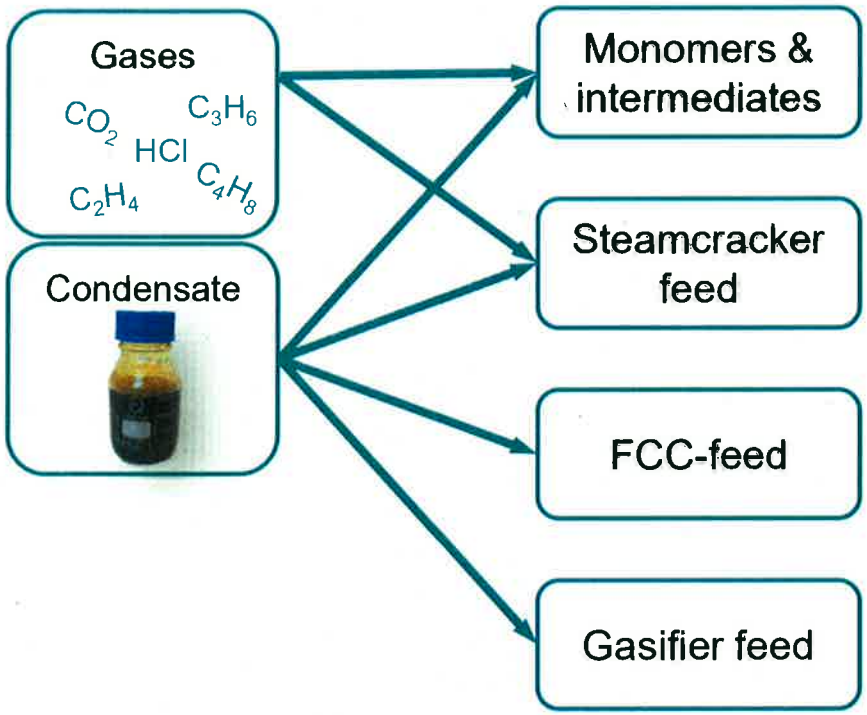
Pyrolysis Carbon Recovery

Feedstock	Fraction of C-feed found back in oily condensate
	[wt-%]
LWP-SR	51.1
CW	60.0
ETICS (XPS)	74.6
ETICS (EPS)	72.9
ASR	57.5
WEEE	60.5

Pyrolysis Energy Balance

Feedstock	Energy demand for heating, melting, thermal degradation, evaporation
	[% of feedstock higher heating value]
LWP-SR	5.1
CW	5.2
XPS	4.9
ASR	5.4
WEEE	3.7

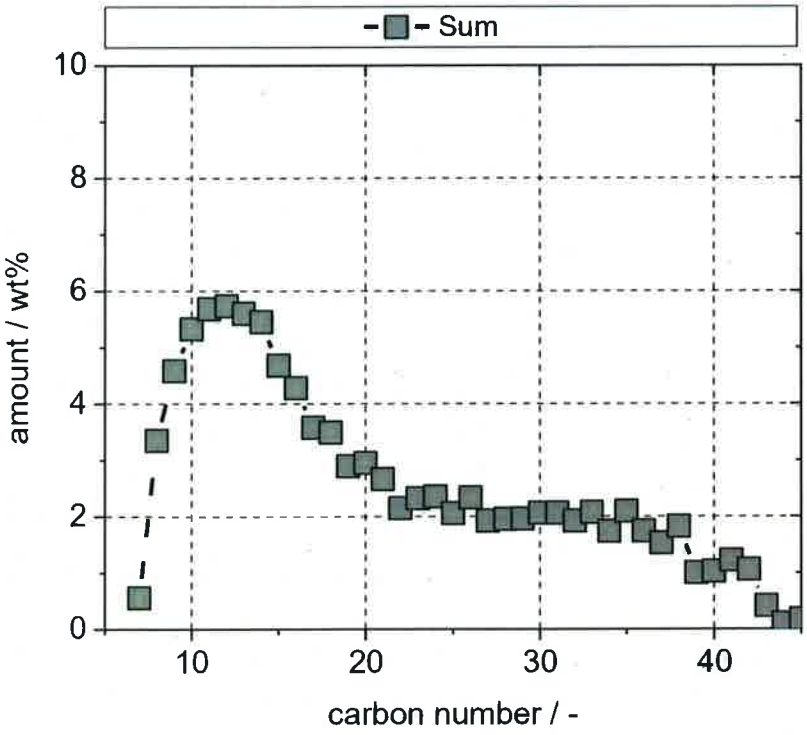
Upgrading of Pyrolysis Products to Secondary Petrochemical Feedstock

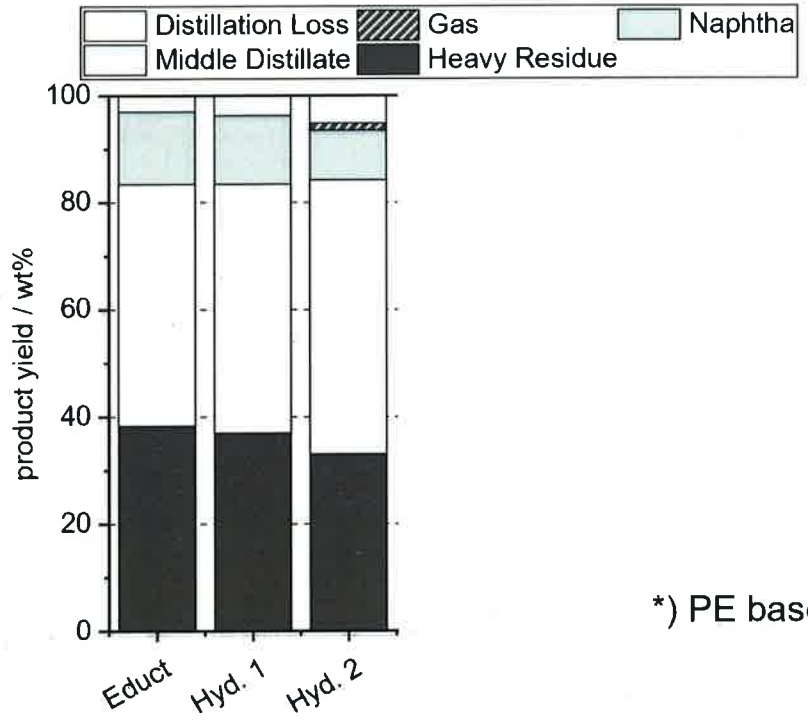


Upgrading of pyrolysis products

- Removal of heteroatoms (N, O, Cl, Br, S, …)
- Fractionating (monomers, petrol refinery boiling cuts)
- Hydroprocessing (adapt HC substance group contents)

Pyrolysis Oil Characterization* and Hydrotreatment

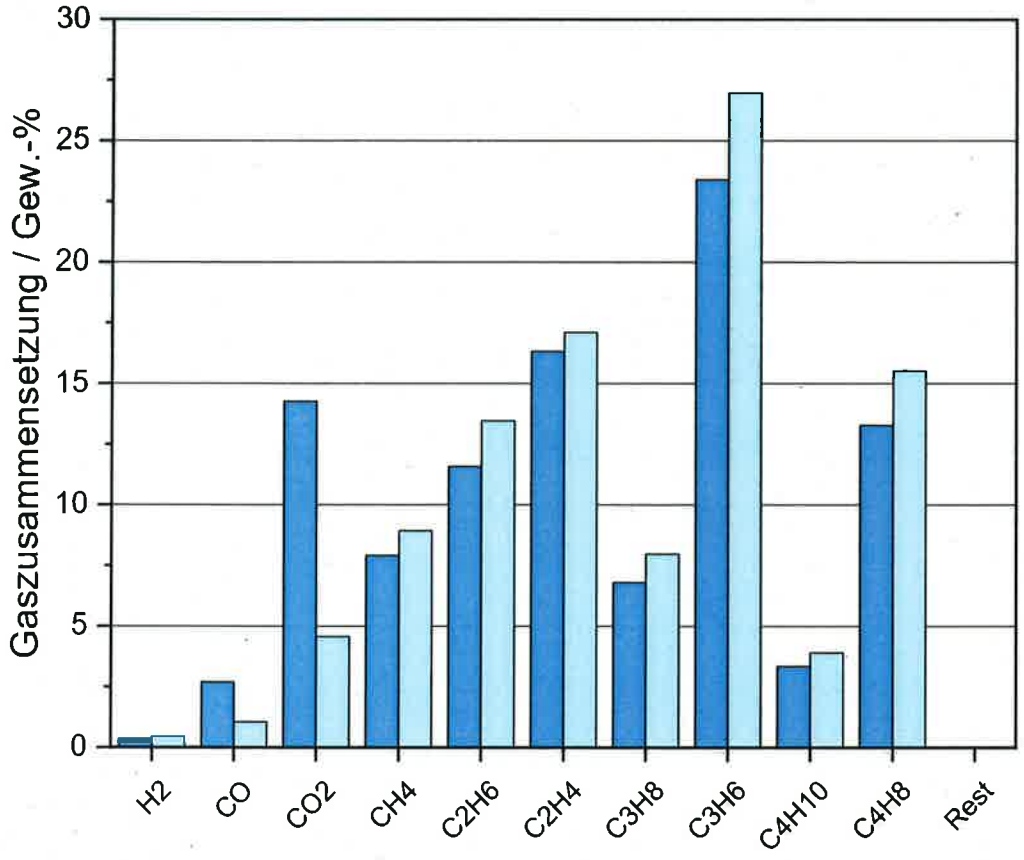




*) PE based wax

Neuner, P. et al.: Chemical Conversion of Fischer–Tropsch Waxes and Plastic Waste Pyrolysis Condensate to Lubricating Oil and Potential Steam Cracker Feedstocks. Reactions 2022, 3, 352–373. https://doi.org/10.3390/reactions3030026

Pyrolysis Gas Characterization*

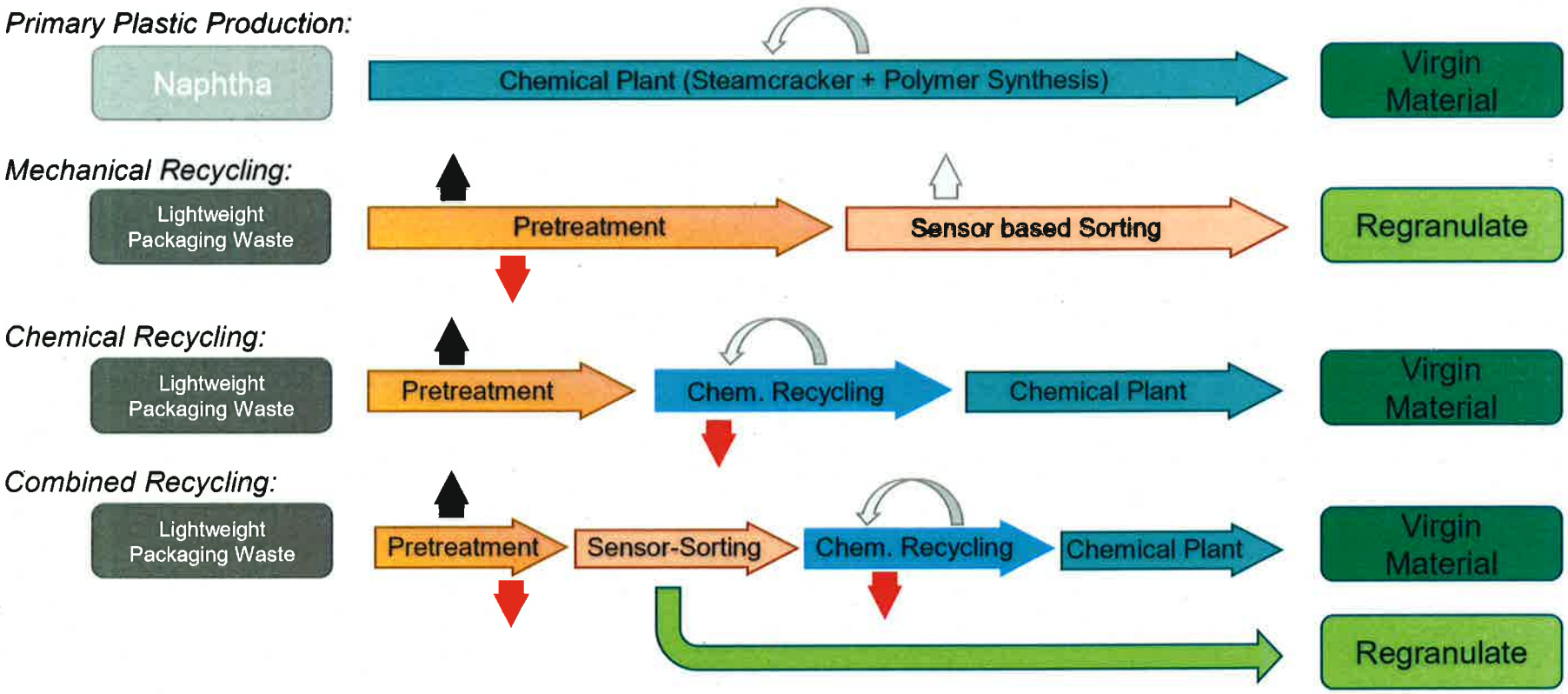


***) Polyolefinic waste based pyrolysis gases as petrochemical feedstock**

- Thermal, non-catalytic pyrolysis of collected waste agricultural films, screw-pyrolysis @ 450°C, 30 min
- Contaminated polyolefinic waste (LDPE basis)
- Average gas composition of 2 waste samples

Case: Recycling of Light Weight Packaging Waste

Comparison of Recovery Routes



Extracted metals via sorting

Heavy contents / Mineral residues that are landfilled

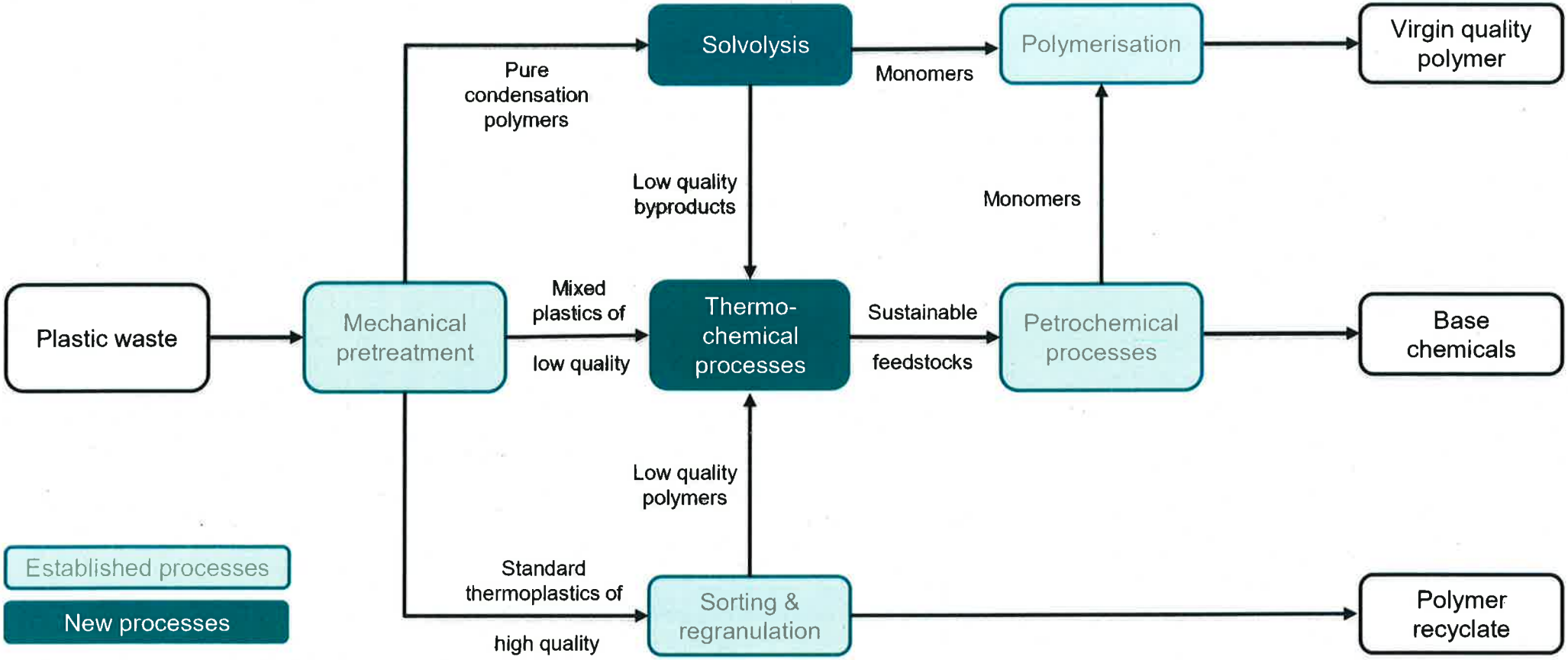
Residues that are used energetically

LWP Waste Recycling Routes Compared to Primary Plastics Production of HDPE

Recycling scenario	Cost [€/kg_{Input}]	CED [MJ/kg_{Input}]	GWP [$kgCO_2e/kg_{Input}$]	Overall Carbon Recycled
Mechanical, 42% yield	**-0.16**	**-18.1**	**0.2**	**42%**
Mechanical, 22% yield	-0.08	-6.9	0.6	22%
Chemical recycling	**-0.24**	**-15.9**	**0.3**	**59%**
Combined recycling, mech. 42%	-0.29	-30.1	-0.2	74%
Combined recycling, mech. 22%	-0.25	-23.1	0.0	66%

Volk,R., et al.: Techno-economic Assessment and Comparison of Different Plastic Recycling Pathways - a German Case Study, Journal of Industrial Ecology, 2021, 1-20; https://doi.org/10.1111/jiec.13145

Technology Infrastructure of a Circular Economy of Plastics



Conclusions

Assessment of Combined Mechanical and Chemical Recycling

Comparison of the production of plastics from fossil raw materials with the combined mechanical / chemical recycling of mixed plastics post-consumer waste, taking into account energy recovery

- **Costs:** Economic attractiveness of both, mechanical and chemical recycling
- **Energy:** Mechanical and chemical recycling perform similar; advantageous over crude oil based products and PtX
- **CO_2 emissions**: Mechanical and chemical recycling perform similar; advantegous over crude oil based products
- **High recycling rates** can be achieved through a combination of mechanical and chemical recycling, only
- Chemical recycling **technology readiness** is developping towards flexibility and efficiency: mixed plastic waste feedstocks, reactor scale-up, product upgrading, process evaluation

Acknowledgement

Waste feedstock samples supply by:

ARN B.V.

Pre Zero GmbH & Co. KG

Electrocycling GmbH

I.A.R. RWTH Aachen*

Project funding through:

*BMBF-project 033R214D KUBA: Nachhaltige Kunststoffwertschöpfungskette: Pilotfall Kunststoffe in Bauwirtschaft und Gebäuden

KIT/Conversio, 2019: „BKV-Studie" Thermal Processes for Feedstock Recycling of Plastics Waste, http://www.bkv-gmbh.de/infothek/studien.html