Environmental problems of adhesives in bookbinding industry

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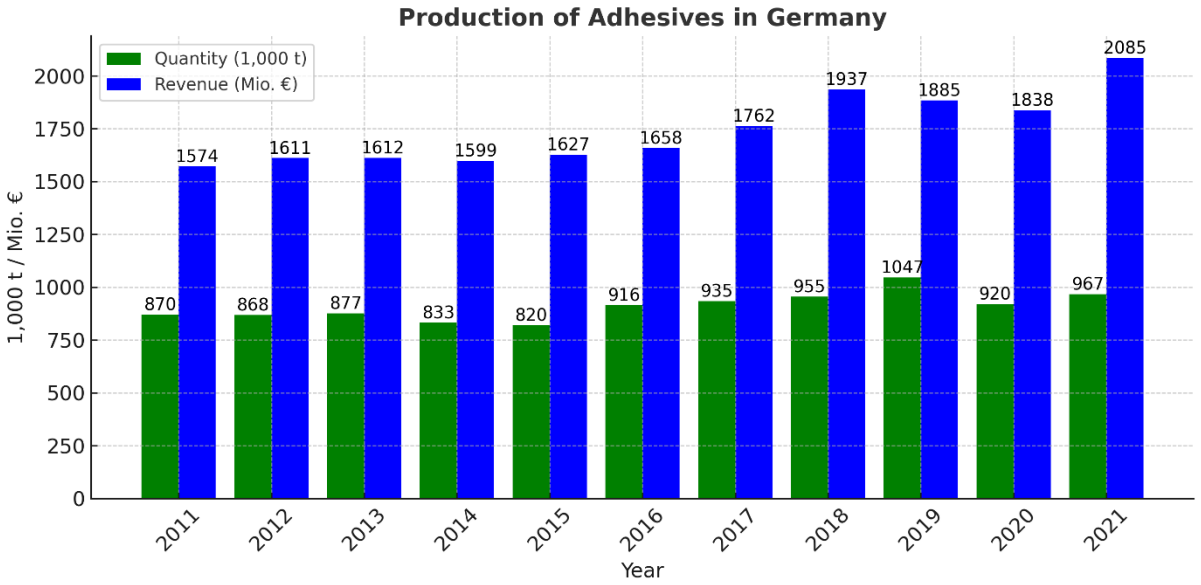
Situation

Adhesive production in Germany in 2021:

- 967.000 t (all applications)
  - 31.000 t paper industry
  - 6.500 t book binding



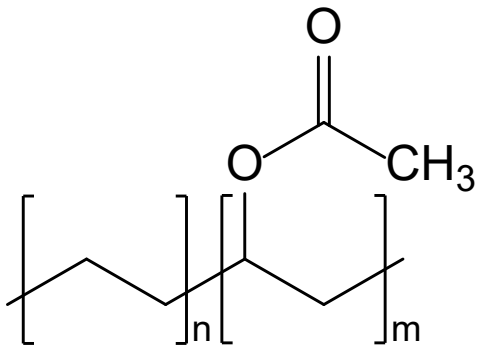
	Share of production in %	2020	2021	2022	2023
Manufacturing industry	**100**	**-9,6**	**-4,3**	**2,9**	**3,8**
Transport	18,1	-21,1	-4,3	3,0	4,8
Food, beverages and tobacco	10,1	-2,4	-0,7	0,3	3,1
Paper (incl. printing)	3,2	-6,3	4,1	3,3	3,4
Metals and metal products	12,4	-11,2	7,8	3,2	2,4
Machinery and equipment	14,5	-11,7	8,7	3,7	4,6
Electronic, Electrical & Optical Equipment	6,2	-5,7	10.3	5,0	4,3
Chemistry	8,5	-0,5	5,5	2,4	3,0
Wood (without furniture)	1,4	6,1	-1,8	0,6	3,0

Statistisches Bundesamt. (30. März, 2023). Umsatz der deutschen Klebstoffindustrie in den Jahren von 2009 bis 2022 (in Millionen Euro)

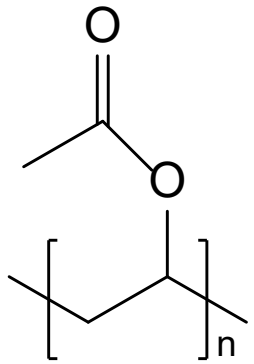
Industrieverband Klebstoffe e.V. (2023) Konjunkturdaten - Industrieverband Klebstoffe e.V

Situation

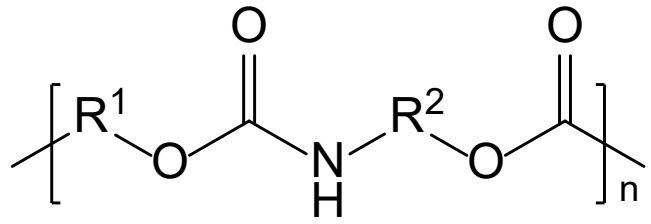
- Petrochemical adhesives are dominating in bookbinding
- EVA, PVAc, PUR
- Excellent adhesive properties
- Cost effective



EVA



PVAc



PUR

Hotmelt

Dispersion

Reactive Hotmelt

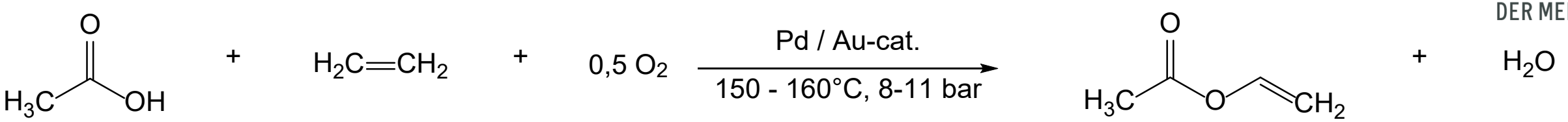
Brockmann, Geiß, Klingen & Schröder, 2012, pp. 291–296; Hu, Tsai & Lee, 1989

Problems

- Synthetic adhesives are not readily biodegradable
  - → Micro plastic in the environment
  - → Huge environmental problems
- Oil is a finite raw material
- Problems in the recycling process
  - → Detachment of adhesive particles leads to increased water consumption in the flotation process
  - → Problems in the reactivating of wood fibres
  - → “Stickies”

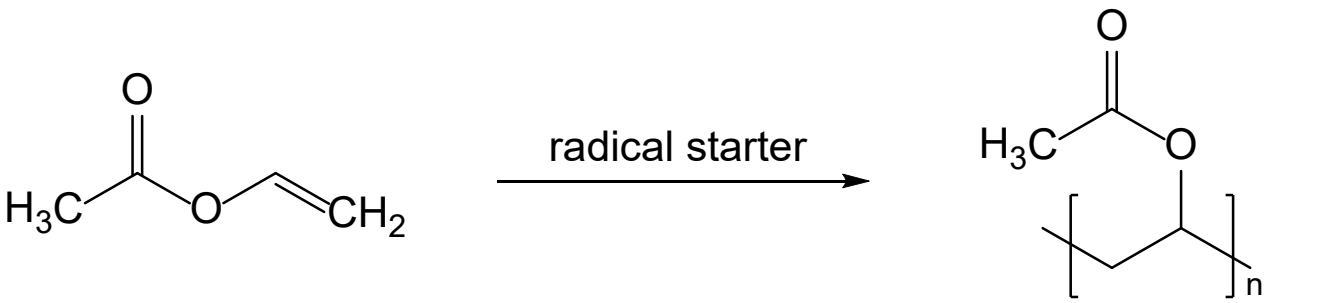
Letcher, T. M. (ed.) (2020). *Plastic Waste and Recycling: Environmental impact, societal issues, prevention, and solutions.* Amsterdam: Elsevier.
Göttsching, Lothar (ed.). (1999). Papier-Lexikon, Band 1, Gernsbach: Dt. Betriebswirte-Verl.

Production



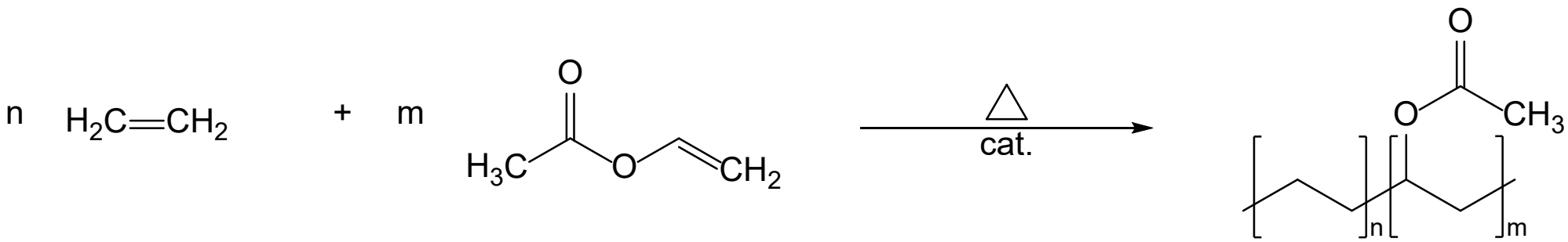
Acetic acid | Ethylene | Vinyl acetate

PVAc:



Vinyl acetate | Poly vinyl acetate

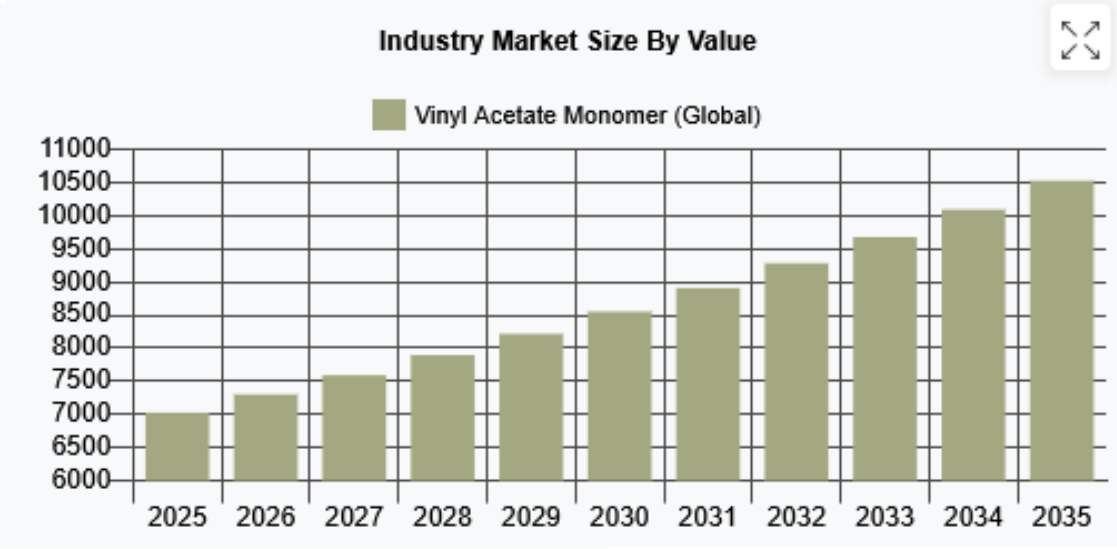
EVA:

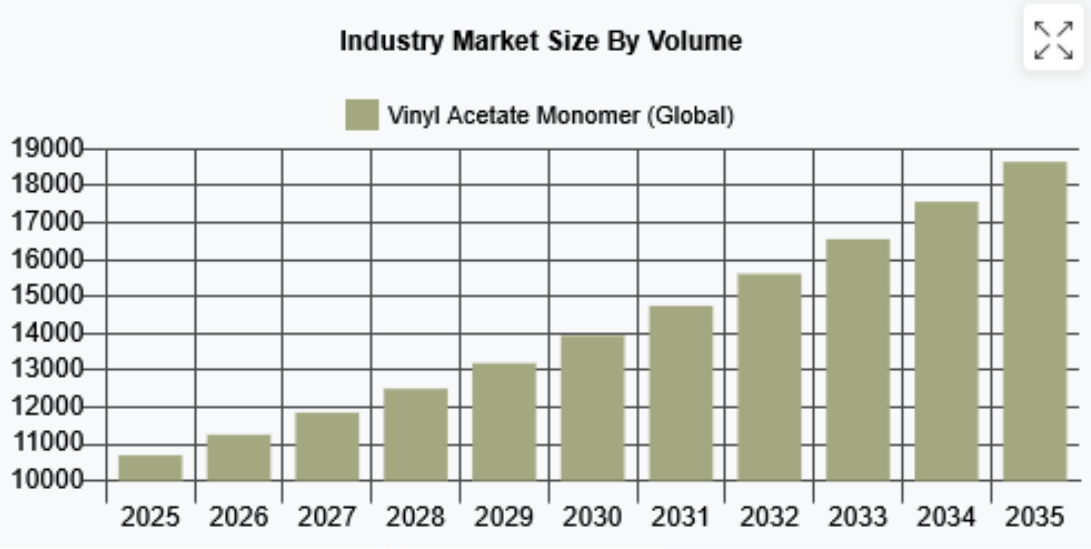


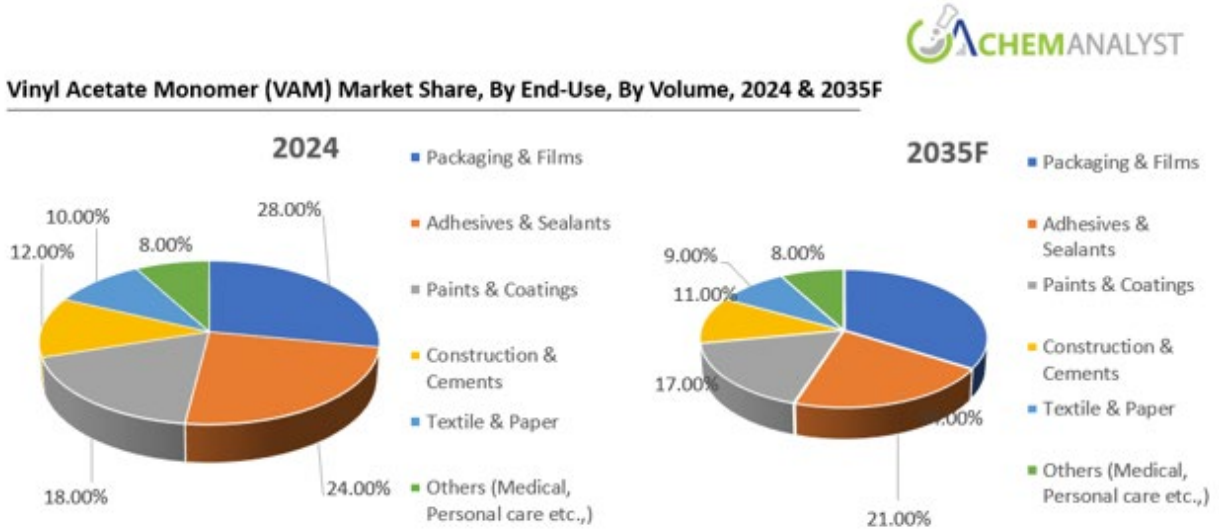
Ethylene | Vinyl acetate | Poly ethylene vinyl acetate

Global demands

[Unit = Value by 'USD million', Volume by '000 Tonnes']







ChemAnalyst (2026) *Vinyl Acetate Monomer (VAM) Market Analysis: Industry Market Size, Plant Capacity, Production, Operating Efficiency, Demand & Supply, End-Use, Foreign Trade, Sales Channel, Regional Demand, Company Share, 2015-2035*, ChemAnalyst

Steam cracking

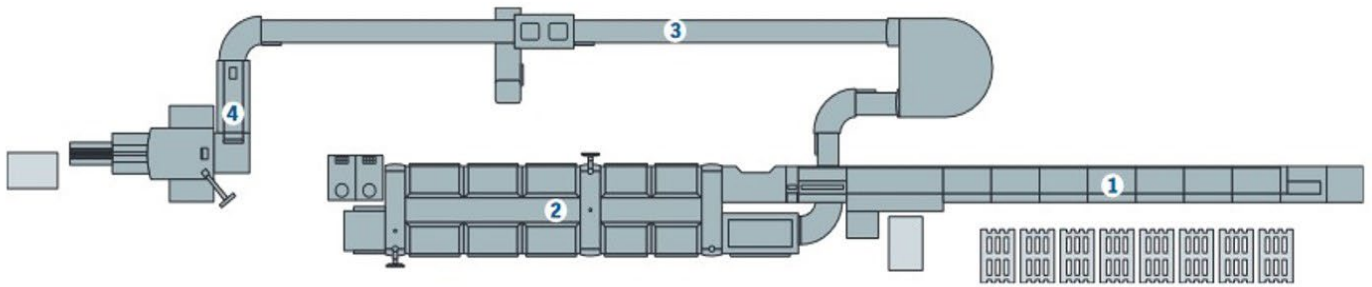
- Steam cracking is the origin of every petrochemical material
- Breaking long chains of carbon hydrogens from oil into shorter carbon hydrogen chains
- Energy consumption very high
  - temperatures up to 850 °C
  - High pressure
  - Cooling down after breaking the carbon chains
- Limited resource
- Generate huge amounts of CO_2

Die Steamcracker der BASF. (2026),

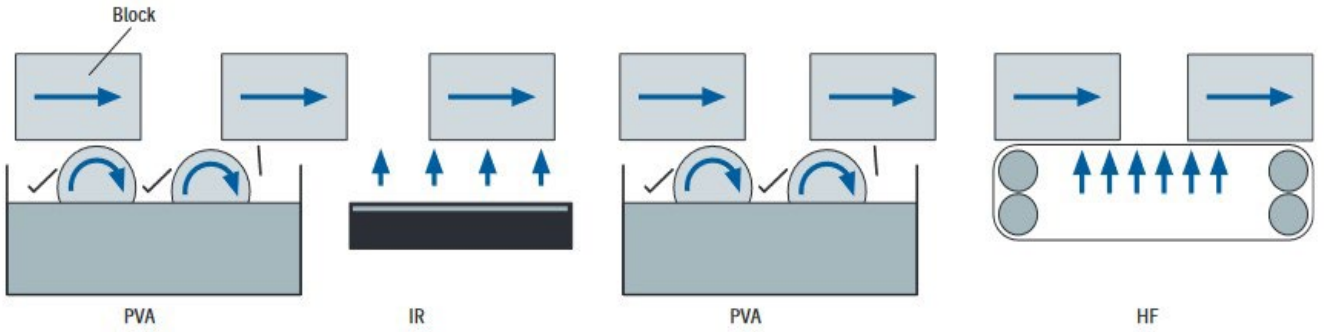
REN, T., PATEL, M., & BLOK, K. (2006). Olefins from conventional and heavy feedstocks: Energy use in steam cracking and alternative processes, *Energy,* vol. 31, no. 4, pp. 425–451,

Application

- Additives in adhesives may have volatine organic compounds
  - Occupational health risks
  - Indoor air quality deterioration
  - Tropospheric ozone formation
- PVAc needs set up times
  - Heaters are necessary in production lines
  - Increased energy consumption
- Hot melts requires heating to typically 150-180 °C
  - Increased energy consumption in production lines



1. Bundle and trimming section
2. Perfect binding
3. Cooling line
4. Three knife cutter

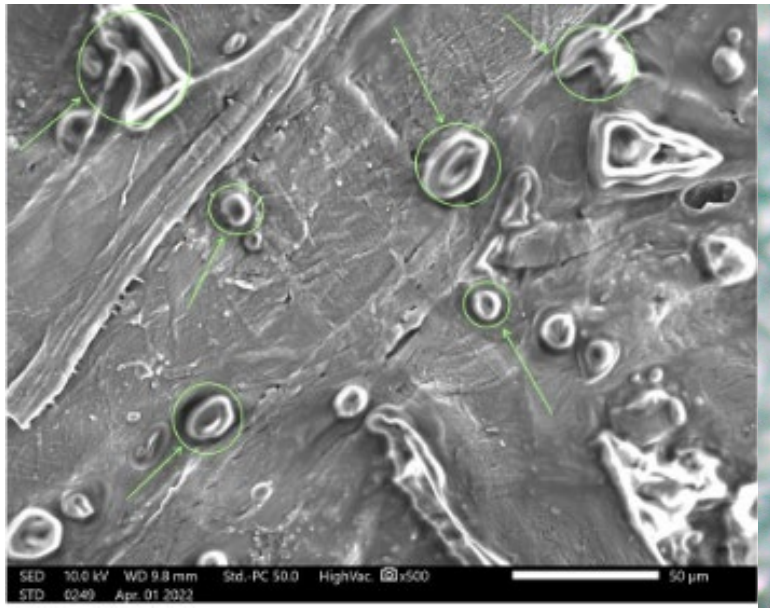


Technologie des Klebebindens - Heidelberg | Mediencommunity 2.0. (2024)

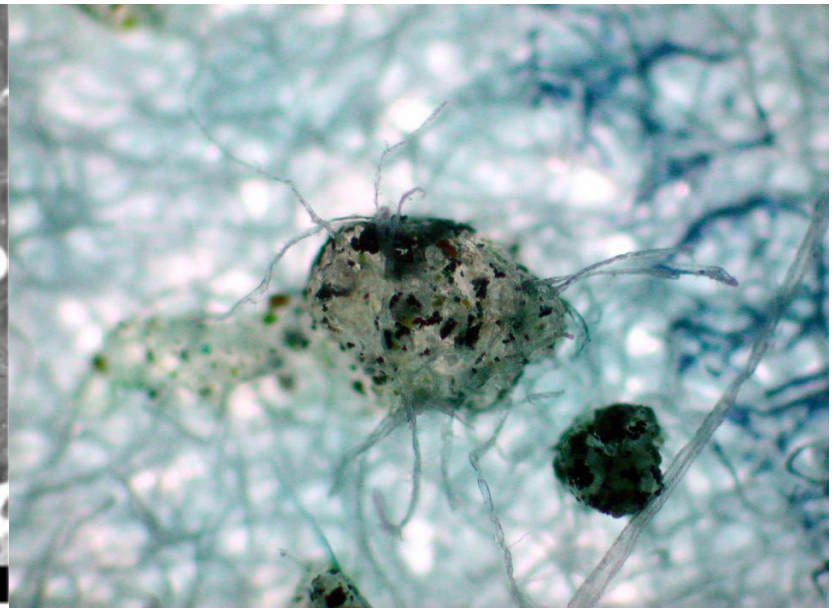
Packham, D. E. (2014). 15 - The environmental impact of adhesives, in F. Pacheco-Torgal, L. F. Cabeza, J. Labrincha & A. de Magalhães (eds), *Eco-efficient Construction and Building Materials*, Woodhead Publishing, pp. 338–367

Recycling process

- Detachment of adhesive particles lead to increased water consumption in the flotation process
- “Stickies”
- Machineries getting clogged
- Reactivating of wood fibers decreases the paper quality
- Cross-linked PUR systems are particularly problematic due to their chemical resistance → very hard to detach



Micro sticky



Macro sticky

Wang, Y., Marcello, C., Sawant, N., Salam, A., Abubakr, S., Qi, D. & Li, K. (2023), ‘Identification and characterization of sticky contaminants in multiple recycled paper grades’, *Cellulose*, 30(3), pp. 1957–1970

Bajpai, P. (2014), *Recycling and deinking of recovered paper*, Amsterdam: Elsevier, pp. 229–250

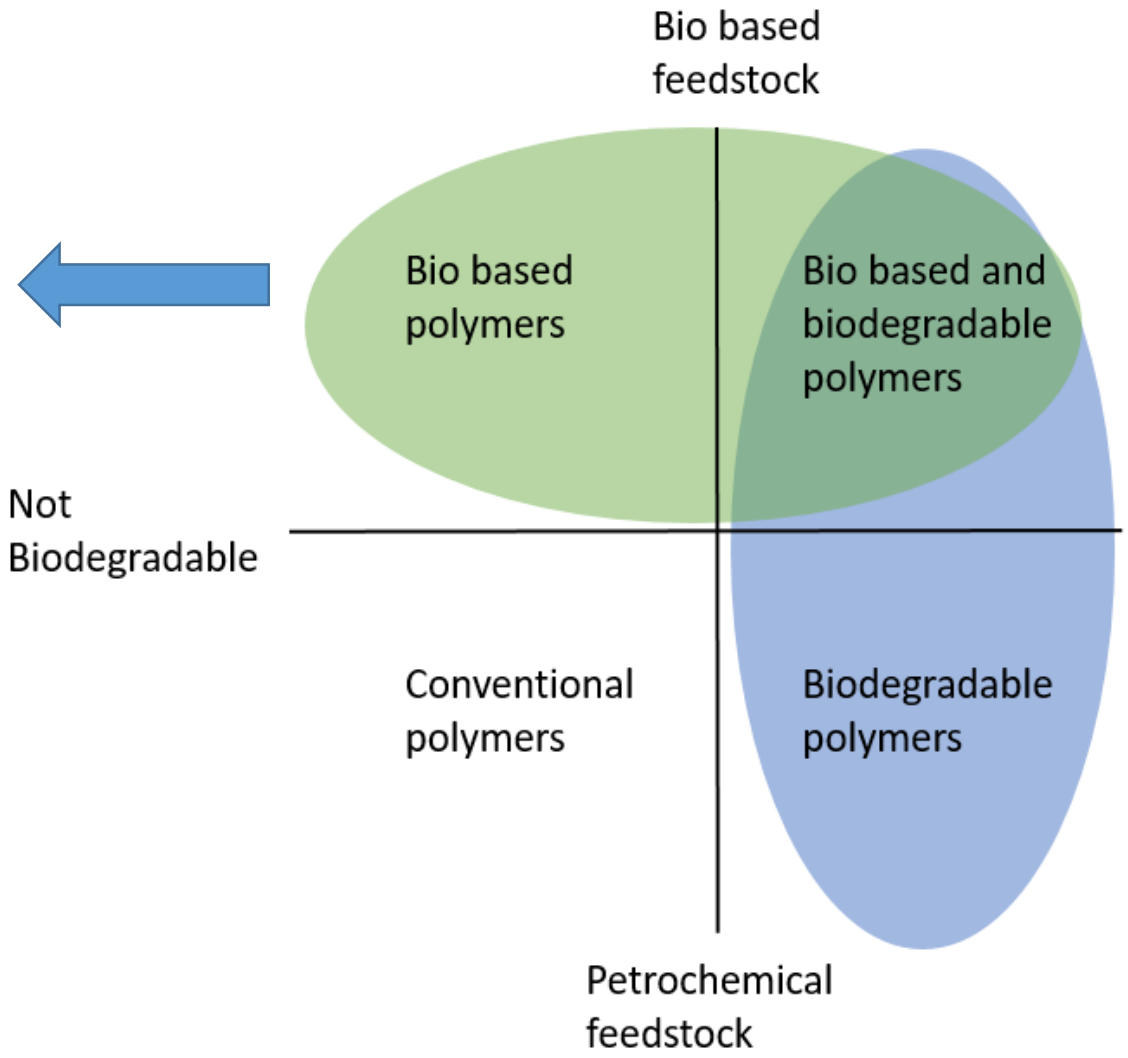
Micro plastic formation and persistence

- Synthetic adhesives are not readily biodegradable
    - Leads to a fragmentation of synthetic polymers to microplastic
- Global persistence of micro plastic in terrestrial and aquatic systems
- Adhesives are not the primary source, their polymeric nature contributes to cumulative plastic pollution

Zhang, Y., Gao, T., Kang, S., Shi, H., Mai, L., Allen, D. & Allen, S. (2022), 'Current status and future perspectives of microplastic pollution in typical cryospheric regions', *Earth-Science Reviews*, 226, 103924,

Bio-based alternatives

- Renewable source but processed and modified
- Bio ethylene from the fermentation of glucose



- Optimum for bio adhesives
- Only few examples, most of them on patent lists
- Most of them starch based Hotmelts

- Short molecule chains
- Many cleavable groups
- Mostly degradable under specific conditions in a very long time period

ENDRES. (2009). TECHNISCHE BIOPOLYMERE, [S.l.]: CARL HANSER VERLAG GMBH. p.6

Future strategies

- Circular economy and design for recycling
  - Reversible adhesive technologies
  - Thermoplastic systems with lower melting points
  - Improved debonding techniques
  - Reduced adhesive application volume
- A system-level approach is required to align adhesive performance with recyclability
- Regulations
  - EU REACH regulations
  - VOC emission standards