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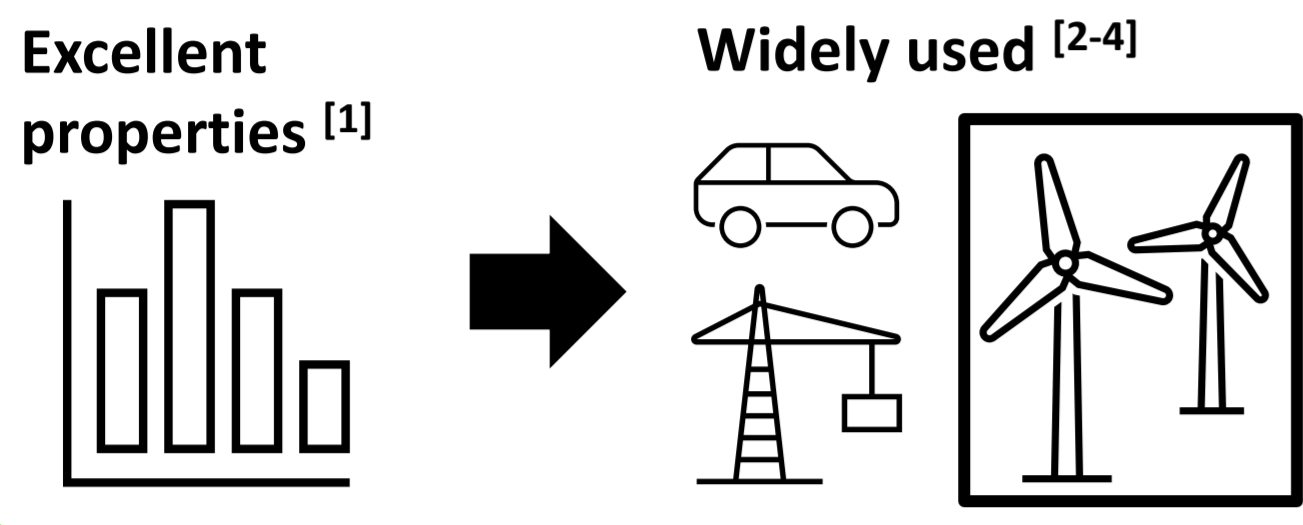
# Wind 2 Shield

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## Efficient Recycling of Rotor Blades from Wind Turbines

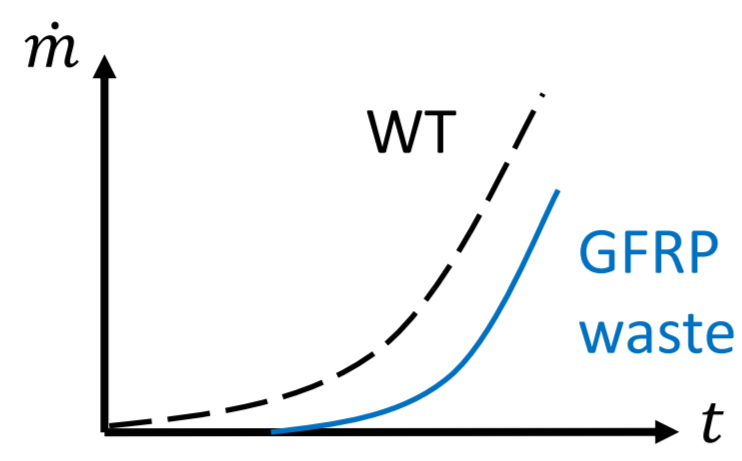
### PROBLEM PROPOSITION

#### Glass Fibre Reinforced Plastics (GFRP):



**German energy transition** [2-4]

- 30,000 wind turbines (WT) in Germany
- Expansion: 500 - 700 WT a<sup>-1</sup>
- 75 t GFRP WT<sup>-1</sup>
- Approx. 20 years service life



**Recycling and potential** [5-7]

- 66,000 t a<sup>-1</sup> GFRP waste from WT globally
- 380 B USD a<sup>-1</sup> market volume, + 7.8 % a<sup>-1</sup>

**Main challenge:** Separation of glass fibre and polymer  
→ **Insufficient recycling of GFRP!**

**chemPLANT 2025:** [3]

- Design recycling process for GFRP materials
- 5,000 t GFRP a<sup>-1</sup> capacity
- Various rotor blades available as feedstock

**Requirements:**

- Economic viability
- Ecology
- Innovation
- Product design

**Previous approaches** [1]

- Incineration:** No material recovery
- Downcycling (e.g., in concrete):** Low-quality products
- Solvolysis/Pyrolysis:** Downstream too complex

### Inputs & Products

→ Batch capacity 4 t GFRP  
→ Vestas + SGRE blades, most common [8]

Component	Share [wt.-%]
Glass fibre	58.5
Epoxy resin	28
Wood	2.5
Metals	3.5
Coatings	2
PVC foam	2
PU	3.5

**Oleogelator** (12 € kg<sup>-1</sup>)

- ✓ 1 t batch<sup>-1</sup>
- ✓ Binding spilled oil from environment
- ✓ Market volume industrial oil binders 3.17 B USD [10]

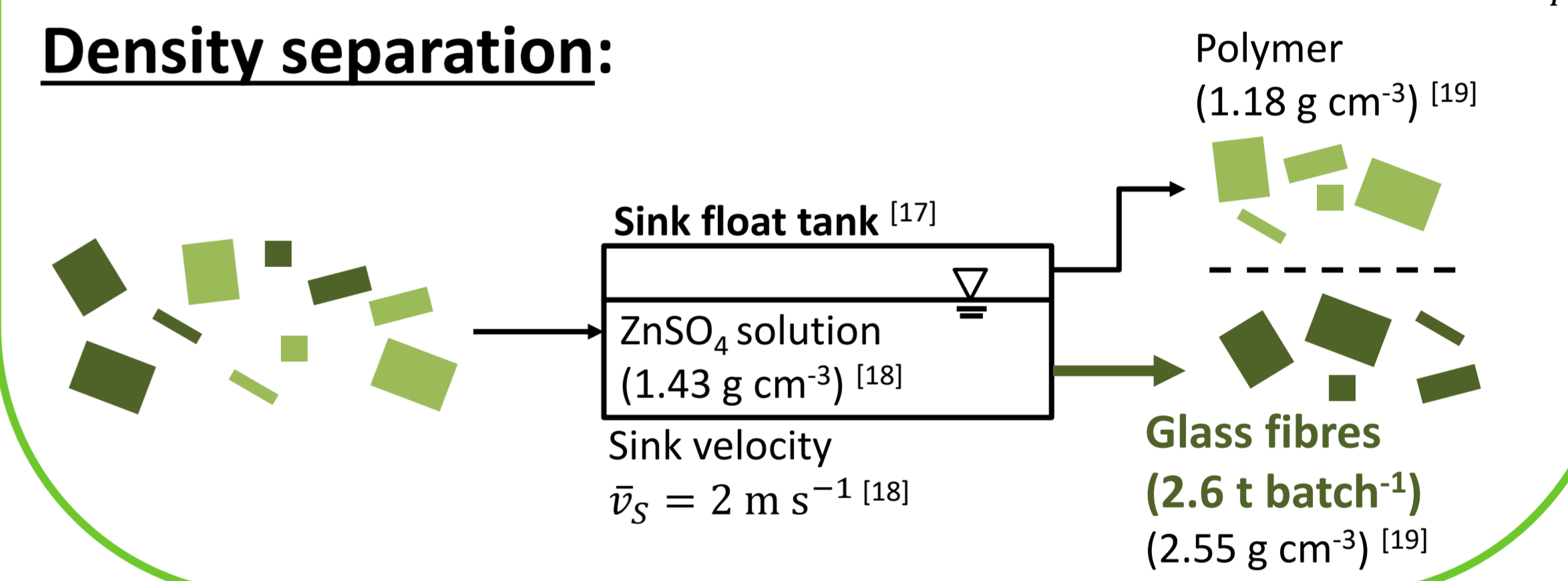
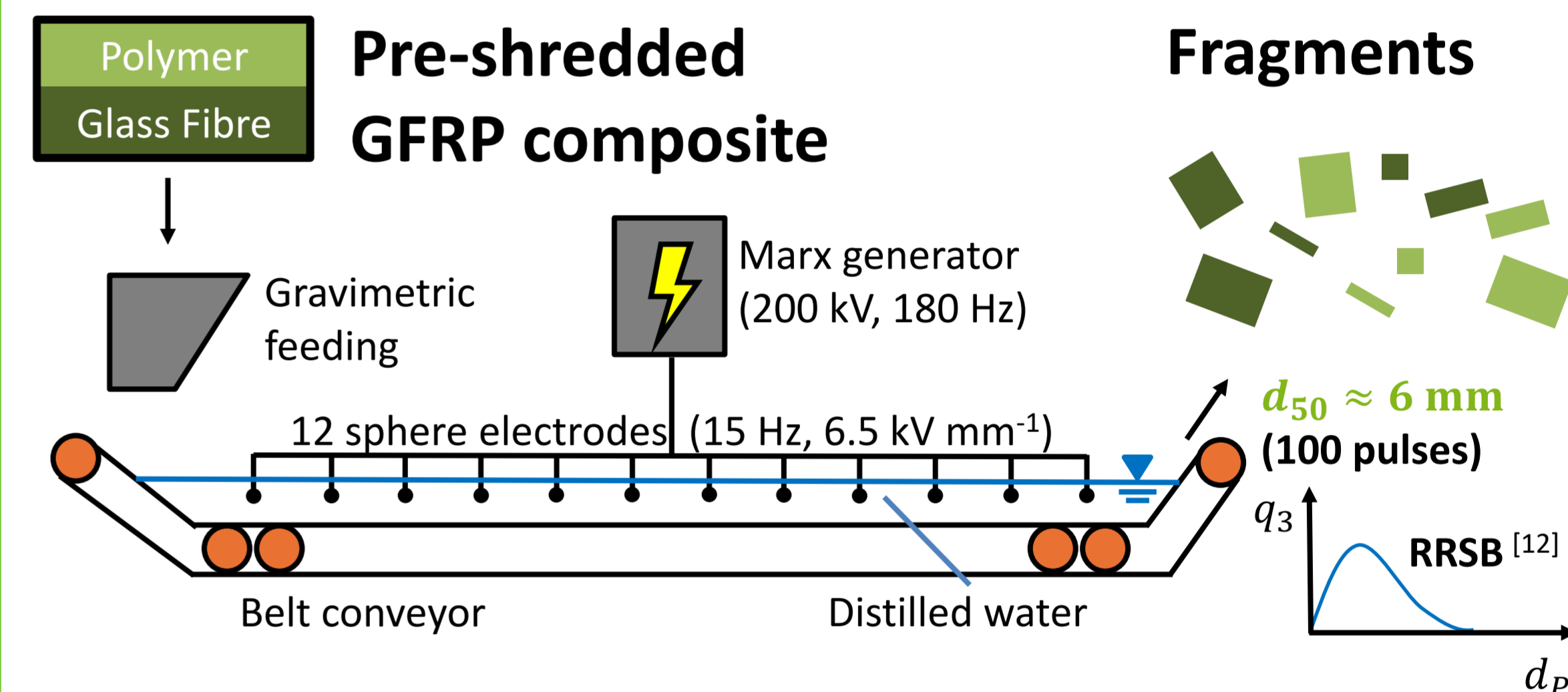
**Glass fibre fragments** (0.8 € kg<sup>-1</sup>)

- ✓ 2.6 t batch<sup>-1</sup>
- ✓  $d_{50} = 6 \text{ mm}$
- ✓ Tensile strength mostly preserved [12]
- ✓ Possible applications:
  - Modular flood prevention
  - Battery case covers

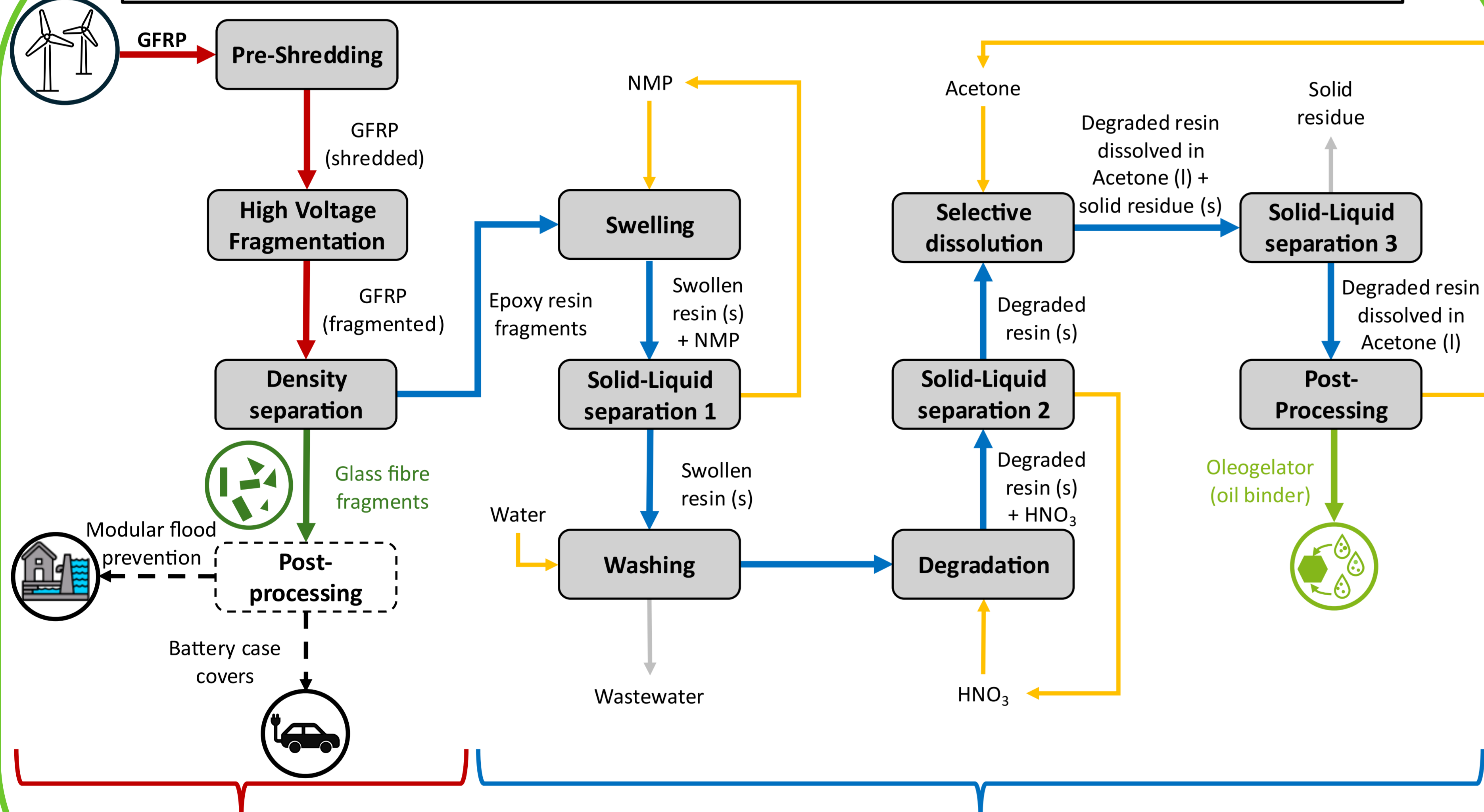
### GFRP-SEPARATION AND GLASS FIBRE RECOVERY

Supplied rotor blade cuts 1 m x 1 m x 0.1 m  
→ **Pre-shredding** to  $\bar{d}_p \approx 40 \text{ mm}$  [13]

**High Voltage Fragmentation:** Selective detachment along material boundaries by high voltage pulsation: [12, 15, 16]



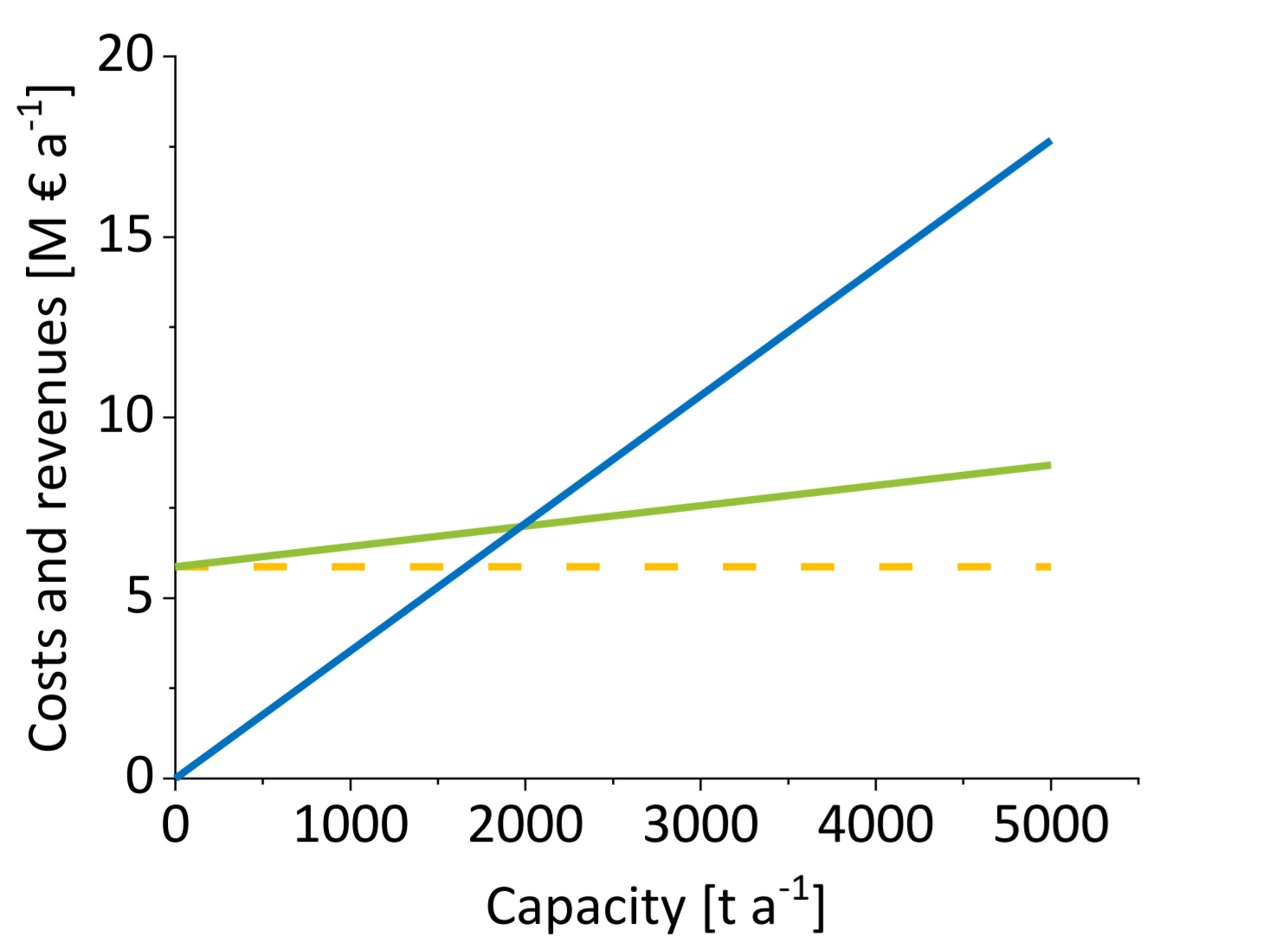
### 4 t GFRP batch<sup>-1</sup>, sequential scheduling using multipurpose equipment



**Process Section A: GFRP-Separation and removal of glass fibre fragments (for all GFRP wastes)**

**Process Section B: Processing of polymer matrix (only for amine cured epoxy resins → 42% of all epoxy resins [13])**

### ECONOMIC VIABILITY



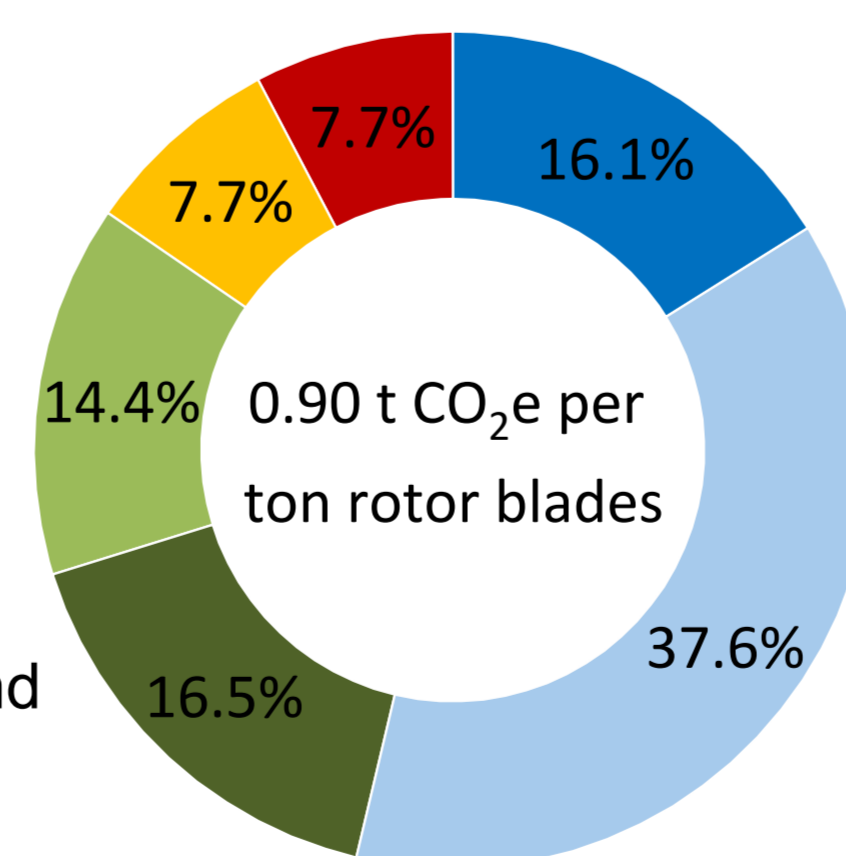
8.99 M € a<sup>-1</sup> profit [22]

87% of revenue: oleogelator  
13% of revenue: glass fibre fragments

### SUSTAINABILITY

#### CO<sub>2</sub> balance

- Power consumption (green electricity)
- HNO<sub>3</sub>
- Acetone
- Heating steam
- NMP
- Apparatus construction and transportation routes



80% less CO<sub>2</sub> than established recycling processes due to mild process conditions [23]

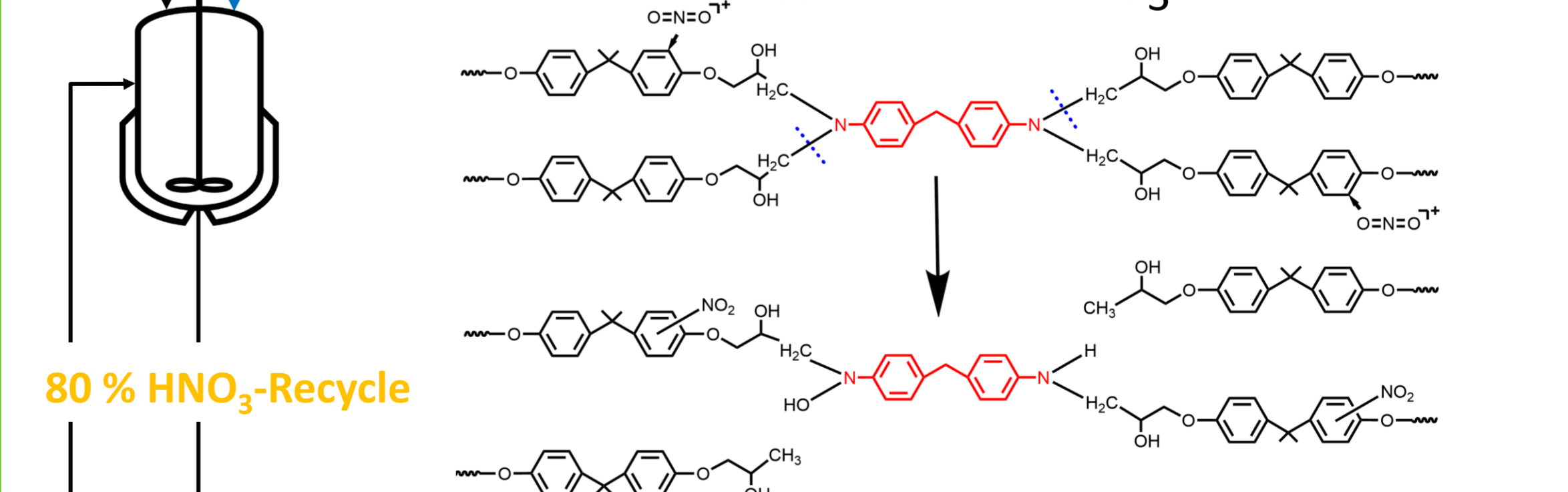
Valuable material recycling contributes to circular economy

### PROCESSING OF POLYMER MATRIX

**Swelling of amine cured epoxy resin with N-Methyl-2-pyrrolidone (NMP)** [20]  
T = 80 °C; 20 g<sub>Resin</sub> (100 mL<sub>NMP</sub>)<sup>-1</sup>; p = 1 atm  
→ Swelling degree: 40% [20]

**Centrifugation + Washing of suspension**

**Selective Cleavage with HNO<sub>3</sub> (4 mol L<sup>-1</sup>)** [20]  
T = 60 °C; 1 g<sub>Resin</sub> (20 mL<sub>HNO3</sub>)<sup>-1</sup>; p = 1 atm



→ Degradation of 93.7% of the resin [20]

**Vacuum belt filtration** [21]  
Residual moisture of deg. resin: 20%

**Selective dissolution of deg. resin in Acetone + Filtration**

Product recovery by **thin-film evaporator & hammer mill**

Oleogelator (1 t batch<sup>-1</sup>)

[1] Qureshi, J. Sustainability 14 (24), 16855. DOI: 10.3390/su142416855. [2] Bundesministerium für Wirtschaft und Klimaschutz (BMWK). Erneuerbare Energien in Zahlen. Nationale und internationale Entwicklung im Jahr 2023, 2024. [3] VDI Verein Deutscher Ingenieure e.V. Aufgabenstellung chemPLANT 2025. [4] Grimm, R. Baustoffe aus Windkraft-Rotoblättern. https://www.baustoffwissen.de (retrieved on: 14.09.25). [5] Daniel Hautmann. Woraus Windräder bestehen. https://energiewinde.orsted.de (retrieved on: 14.09.25). [6] Gonçalves, R. M. et al. Materials 15 (4). DOI: 10.3390/ma15041596. [7] Research and Markets. Fiber Reinforced Polymer (FRP) Composites Market. Forecasts from 2023 to 2028, 2023. [8] Hühn, S. Windkraft: Das sind die größten Windradhersteller der Welt. https://www.ingenieur.de (retrieved on: 14.09.25). [9] FryAway. FryAway: Cooking Oil Solidifier. https://fryaway.co (retrieved on: 14.09.25). [10] https://researchintelo.com/ (retrieved on: 14.09.25) [11] SELFrag AG. High Voltage Pulse Fragmentation Technology to recycle fiber-reinforced composites. https://cordis.europa.eu/project/id/323454 (retrieved on: 14.09.25). [12] Schmidt, J. et al. Chemie Ingenieur Technik 4, 96 (7), 976-986. DOI: 10.1002/cite.202300208. [13] Epoxy Curing Agent Market Size & Share Analysis - Growth Trends & Forecasts (2025 - 2030). https://www.mordorintelligence.com (retrieved on 14.09.25). [14] Weima. https://weima.com/de (retrieved on: 14.09.25). [15] Mativenga, P. T. et al. CIRP Annals 65 (1), 45-48. DOI: 10.1016/j.cirp.2016.04.107. [16] Bluhm, H. et al. IEEE Trans. Dielect. Electr. Insul. 7 (5), 625-636. DOI: 10.1109/94.879358. [17] Schwiter, K.; Leven, V. Verfahrenstechnik für Ingenieure., 2013. DOI: 10.3139/9783446431362. [18] Vielma, T. et al. J. Chem. Eng. Data 66 (1), 45-57. DOI: 10.1021/acs.jced.0c00767. [19] Suter Kunststoffe AG. Faserverbund-Werkstoffdaten. www.swiss-composite.ch/pdf/Werkstoffdaten.pdf (retrieved on: 14.09.25). [20] Tian, F.; Wang et al. ACS Sustainable Chemistry & Engineering 8 (5), 2226-2235. DOI: 10.1021/acsschemeng.9b06013. [21] Esselent Solutions. https://esselent.eu/downloads/ (retrieved on: 14.09.25). [22] Horst, S. et al. Chemie Ingenieur Technik 92 (8), 1033-1043. DOI: 10.1002/cite.202000023. [23] Karuppanan Gopalraj S. et al. Polymers 13 (24): 4430. https://doi.org/10.3390/polym13244430