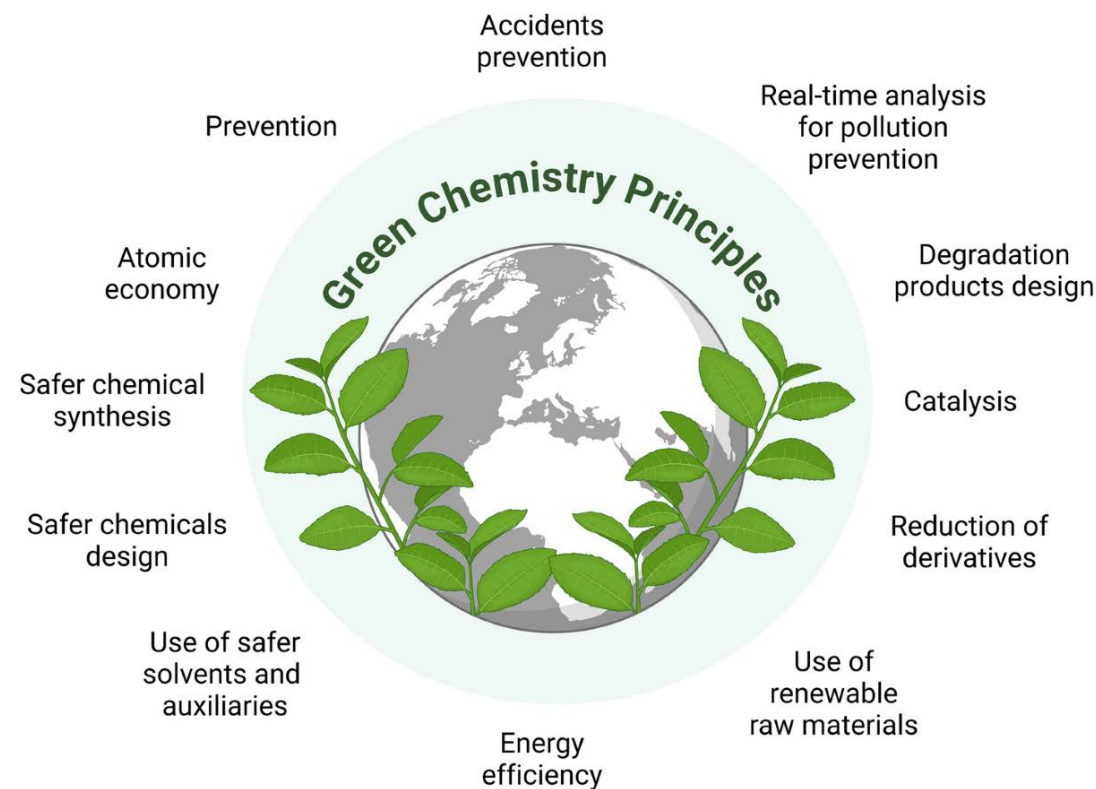


Sustainable Chemistry via Recycling? – Opportunities & Challenges of Mechanical vs. Chemical Recycling

Witold-Roger Poganietz, Karlsruhe Institute of Technology
Kaede Misawa, Roh Pin Lee, Brandenburg University of Technology

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Background

Transforming the chemical industry seems to be obvious, considering its current direct and indirect dependency on fossil fuels as resource base and energy carrier

Chemical industry

- offers intermediates and products, which are crucial for today's society, e.g. fertilizer or hygienic products and thus,
- plays a key role in the needed society's sustainability transformation

The route for a sustainable chemistry entails the transformation from

- fossil to renewable energy carriers (*decarbonization*) and resource base (*defossilization*)
- linear to circular economy by recirculating carbon-containing wastes back into the production cycle
- dependency on imported carbon resources to utilization of available domestic sources, i.e. carbon-containing wastes, to increase the sector's resilience

➔ A key concept for *defossilization*: recycling of carbon-containing wastes

Background

Generally, two recycling routes are available:

- mechanical recycling (MR), i.e., processing of carbon-containing wastes *without* breaking down their polymer's chemical structure
- chemical recycling (CR), i.e. processing of carbon-containing wastes *with* breaking down their polymer's chemical structure

→ Both routes differ in nearly all relevant socio-economic-technical factors widely



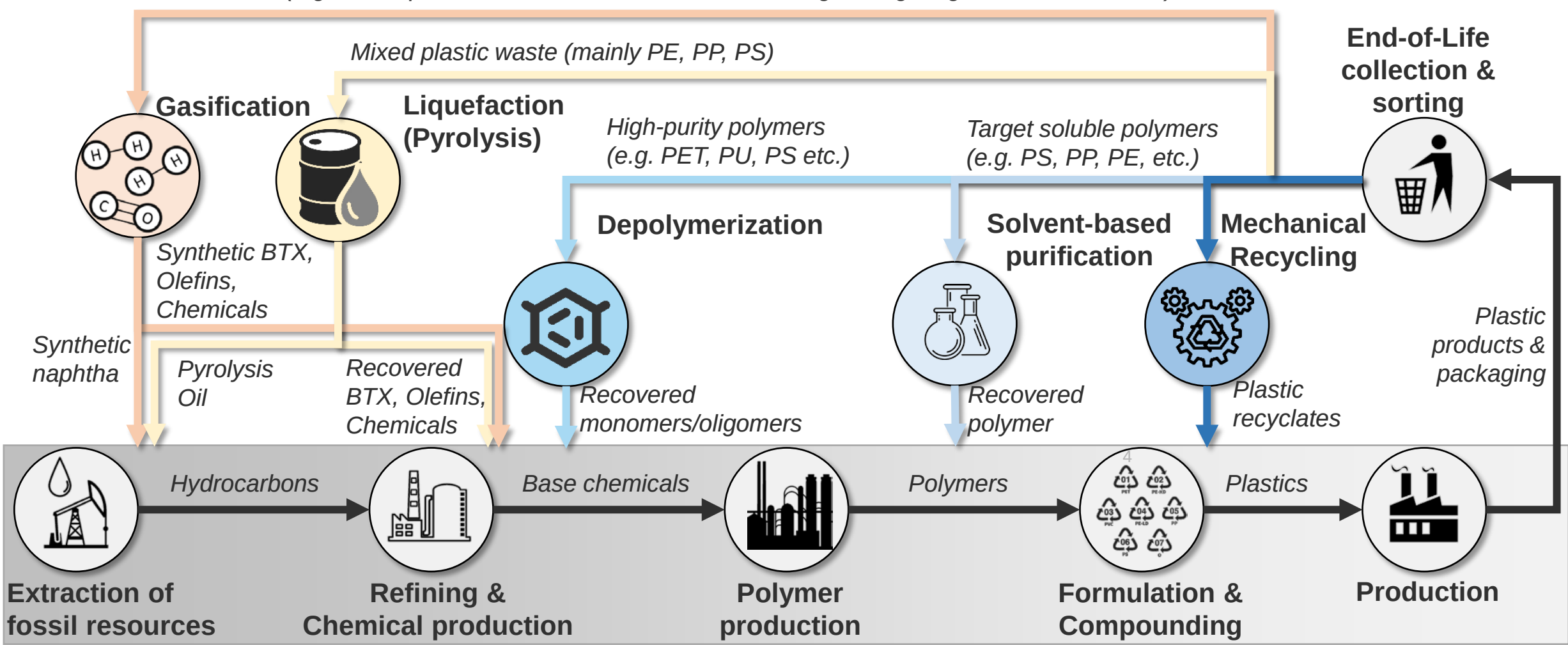
→ What are the prospects of each route?

→ What is the relation between both routes considering the socio-technical frame?

Mechanical & Chemical Recycling Pathways

Mixed wastes (e.g. Mixed plastic waste but also RDF, ASR, sewage sludge, agricultural waste etc.)

Mixed plastic waste (mainly PE, PP, PS)



Source: Seidl, L.G., Lee, R.P., Gräbner, M., Meyer, B. 2021. Overview of Pyrolysis and Gasification Technologies for Chemical Recycling of Mixed Plastic and other Waste. Keynote Lecture. DGMK Conference "Chemical Recycling – Beyond Thermal Use of Plastic and other Waste", 06-07.10.2021, Online Event.

Figure 1: Recycling pathways

Desired feedstocks

Distinct requirements:

- MR: clean, sorted, and relative homogenous waste streams, like PET
 - High-quality collecting and sorting systems as well as cleaning systems are crucial
- CR: mixed, contaminated, and difficult-to-recycle waste streams that are unsuitable for MR, like mixed plastics
 - The composition and contamination degree of available wastes influence the quality of the generated product (impurities!) and the potential application field, e.g. restrictions in respect of food packaging

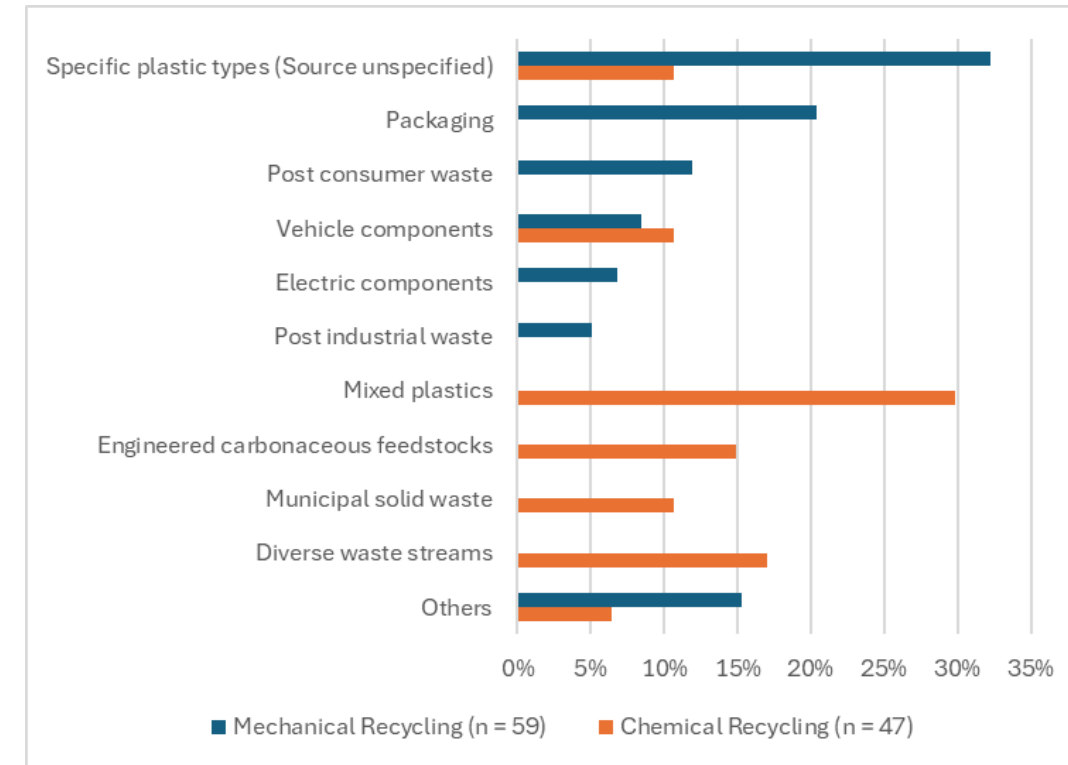


Figure 2: Results of a survey asking international actors in industry about the most desirable wastes

Note: n = number of responses

Source: Own survey carried out in 2025

Challenges

Equal challenges

- *Cost competitiveness* compared to fossil fuelled based products
- *Regulatory compliance*
- *Feedstock and supply chain* regarding availability of appropriate wastes

Distinct challenges

- *Quality and material properties* – MR have (generally) higher quality needs
- *Market acceptance* – CR sees (still) comparable higher quality fluctuations of the recycled products
- *Technical barriers* – CR is (still) an emerging technology

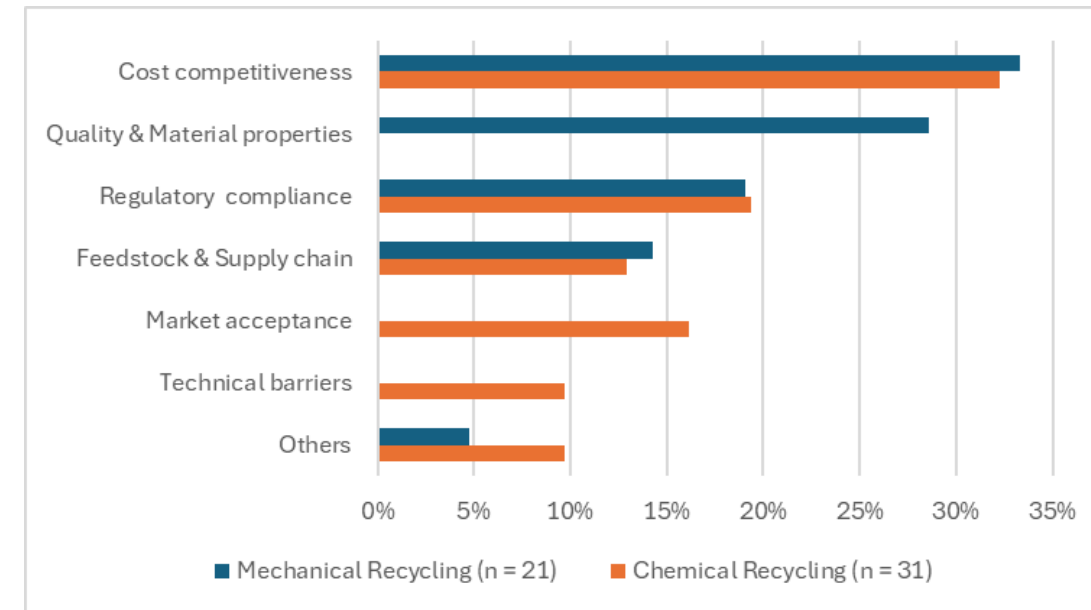


Figure 3: Results of a survey asking international actors in industry about the perceived challenges

Note: n = number of responses

Source: Own survey carried out in 2025

Opportunities

Equal opportunities, but clear differences in relevance

- *Technological innovations*
 - CR: overcoming technical barriers and achieving reliable product quality
 - MR: improving sorting quality
- *Environment and circularity (MR)*
- *Market expansion*
 - CR: offering a wider product portfolio (materials and fuels)
 - MR: increasing the market share of recycled products
- *Economic factors (MR)*

Distinct opportunities

- *Regulation and policy (CR)*

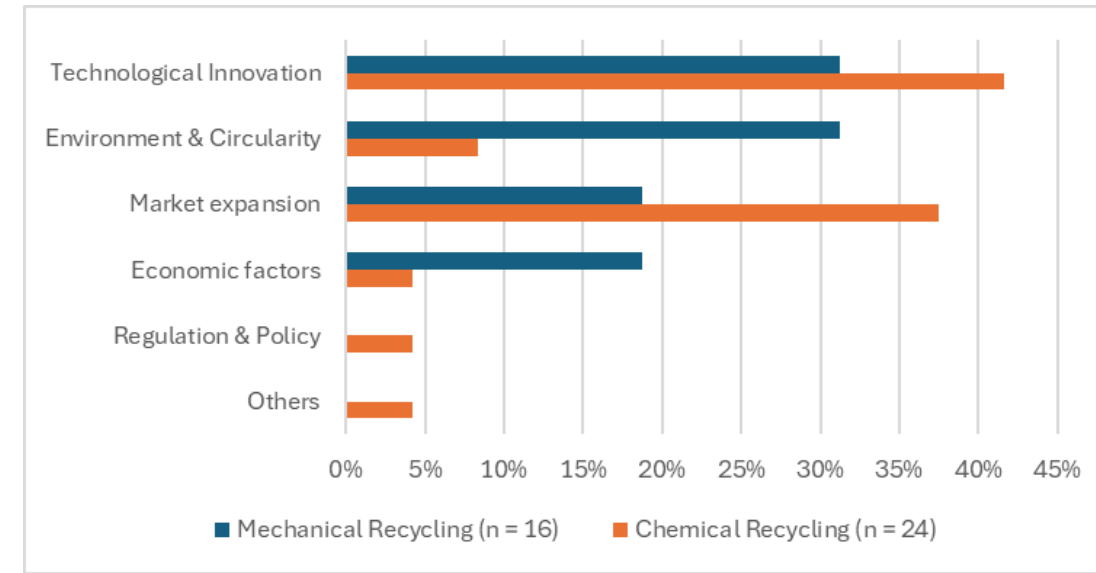


Figure 4: Results of a survey asking international actors in industry about the opportunities

Note: n = number of responses

Source: Own survey carried out in 2025

Expectations on the perspectives of the routes

Globally, a quite diverse development is expected

- High CR potentials are concentrated in three regions: W Europe (19.4%), N America (15.5%), E Asia (14.6%)
→ T3 = 49.5%
- The potentials of MR is more evenly distributed over six regions, ranging from 12.7% (S Asia) to 10.3% (Africa and E Europe)
→ T3 = 35.7%
- For W Europe and E Asia for both technologies high potentials are expected: high potentials for CR (W Europe #1, E Asia #3) and for MR (W Europe #2, E Asia #3)

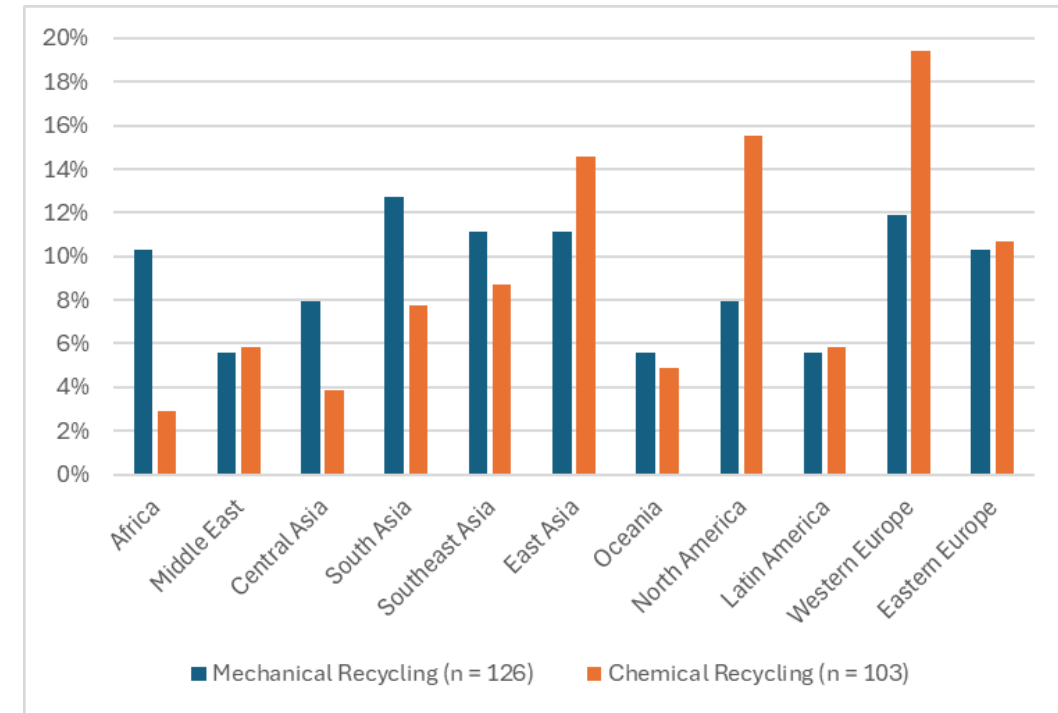


Figure 5: Results of a survey asking international actors in industry which regions are perceived as having significant market or development potential for MR and CR

Note: n = number of responses

Source: On own survey carried out in 2025

Expectations on the perspectives of the routes

- Prospects of a technology depend on a wide range factors (mentioned before plus social factors like (local) acceptability), with varying relevance between technologies and regions, e.g. sorting of plastics at home – MR vs. CR and Germany vs. Singapore
- Key are respective regulations, ensuring (or impeding) the turning of a “bad” to a “good”, i.e. establishing markets
 - Example USA (N America): Roughly 25 States have adopted some form of legislation recognizing CR as manufacturing with lower regulatory compliance demands (e.g., lower participation requirements), partly also allowing fuels as an eligible product, with awaiting support by the EPA for lifting environmental rules
 - Example China (E Asia): acknowledgment of CR as a recycling route to recycle film and flexible packaging waste that are difficult for MR
- But regulations need time to be accepted and need respective infrastructure
 - Example Singapore: reluctance to separate wastes at home → CR as a relevant option for recycling?
 - Example Germany: impurities in separated wastes are still a challenge → CR as a relevant supplement?

Summary and concluding remark

- Modern societies depend on chemical industry, which is in need to transform as a contribution to the required transformation of the economies
- Chemical industry must defossilize the resource base with recycling carbon-containing wastes as a key option
- The prospects of the routes depend on a wide range of factors, which differ in their relevance in the respective regions
- Key are regulations, as these “make” (or “destroy”) markets for recycled products, but also the prospects of each technology route, e.g. USA
 - Note: Regulations could/should be seen as a manifested formulation of the currently prevailing political and societal will, i.e. the outcome of political bargaining processes
 - But behavioural pattern and product demands can constrain the room for bargaining

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