Economic and environmental assessment of chemical recycling via pyrolysis: A case study for engineering plastics

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Engineering plastics in automotive applications

Exterior parts
- PP, ABS

Dashboard
- PP, PC, ABS, PUR, PVC

Roof lining
- PA, PVC, PUR

Carpets
- PET, PP

AC / Ventilation
- PP, PE

Engine / Gear box module
- PA

Bumper
- PP

Radiator grill
- ABS, PC, SAN

Headlights
- PC, PP

Electronics
- ABS, PC, POM

Reflectors
- ABS, PMMA, PC

Underbody
- PP

Seating
- PUR, PET

Door panel
- PP, PE, PUR, PVC

https://www.autoberufe.de//interaktionen/chemie-am-auto/it3/, accessed 18.09.2023
Automotive plastic waste from car workshops (APW)

Chemical recycling might have the potential to produce new polymers with virgin polymer quality from plastic waste that cannot be recycled mechanically.
Assessment of Automotive Plastic Waste recycling via pyrolysis

Technology
- Pyrolysis of complex mixture of engineering plastics
- Characterization of pyrolysis products
- Total and elemental mass balances of pyrolysis process

Techno-economic (TEA) and Life Cycle Assessment (LCA)
- Definition of process chain for chemical recycling of automotive plastic waste
- Balancing of entire process chain
- Calculation of costs and LCA indicators
Feedstock flexible pyrolysis pilot plant

Throughput: 1 kg/h
Temperature: 450 °C
Moderator: Quartz sand
Residence time: 45 min
Pyrolysis mass and elemental balances

![Diagram showing mass and elemental balances for pyrolysis runs.](image)

- **Balance loss**
- **Pyrolysis residue**
- **Aqueous condensate**
- **Pyrolysis gas**
- **Light pyrolysis oil**
- **Heavy pyrolysis oil**
Pyrolysis of engineering plastics is feasible but upgrading of pyrolysis oil is required for use as steam cracker feedstock.
Process chain and system boundaries

APW: Automotive plastic waste
RDF: Refuse derived fuel
Reference system

- APW: Automotive plastic waste
- RDF: Refuse derived fuel

Legend:
- Process
- Sub process
- Intermediate product
- Side product
- Material flow
- Energy flow
- Substitution

Zero Burden Approach

System boundary

Avoided Burden Approach

Municipal solid waste incineration plant

RDF power plant

Primary metal

Energy

Metal recycling

Steel

RDF production

Metal

Avoided Burden Approach

APW

RDF

Energy

Energy

Energy

Energy
## Assessment criteria for TEA and LCA

<table>
<thead>
<tr>
<th>Assessment criteria</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change</td>
<td>kg CO$_2$e / kg waste</td>
<td>Assessed based on GWP100 as defined by Kyoto-Protocol (IPCC 2013).</td>
</tr>
<tr>
<td>Carbon efficiency</td>
<td>% carbon recovered</td>
<td>Carbon recovery in the product compared to carbon contained in feedstock.</td>
</tr>
<tr>
<td>Costs</td>
<td>€ / kg waste</td>
<td>Depreciation of investment and OPEX</td>
</tr>
</tbody>
</table>

Mass balance of APW recycling via pyrolysis

Percentages refer to input mass flow of APW

- 31% of input material is recovered as High Value Chemical (HVC), 9% as scrap metals
Carbon efficiency of APW recycling

Steam cracking of upgraded pyrolysis oil results in carbon recovery > 50 %

Percentages refer to input carbon mass flow of APW
Climate change impact comparison

![Climate change impact comparison chart](chart.png)

- **Energy recovery**: 1.25
- **Chemical recycling**: 0.57

Legend:
- Reward energy
- Reward metal recycling
- Reward HVCs
- Transportation
- Energy recovery
- Landfilling
- Metal recycling
- Steam cracking
- Hydroprocessing
- Pyrolysis
- RDF production
- APW collection
- Sum
Economic comparison

![Graph showing economic comparison between energy recovery and chemical recycling]

-0.5 -0.4 -0.3 -0.2 -0.1 0.0 0.1 0.2 0.3 0.4 0.5 0.6

€ / kg waste

Energy recovery  Chemical recycling

-0.02  0.08

- Reward energy
- Reward metal recycling
- Reward HVCs
- Transportation
- Energy recovery
- Landfilling
- Metal recycling
- Steam cracking
- Hydroprocessing
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- APW collection
- Sum
Sensitivity analysis

Processing costs

- Increase electricity price +10% ER: -15%
- Increase electricity price +10% CR: 9%
- Increase HVC price +10% ER: 0%
- Increase HVC price +10% CR: -6%

Climate change impact

- Decrease CO2-factor electricity mix -10% ER: 3%
- Decrease CO2-factor electricity mix -10% CR: -2%
- Increase energy demand pyrolysis +10% ER: 0%
- Increase energy demand pyrolysis +10% CR: -1%

ER: Energy recovery  CR: Chemical recycling

25.09.2023  Malte Hennig – Assessment of Pyrolysis of Engineering Plastics
Case study conclusions

**Technology**

- Pyrolysis of APW is feasible
- APW pyrolysis oil requires upgrading for use as steam cracker feedstock

**Environment**

- Chemical recycling of engineering plastics is beneficial in terms of climate change impact

**Economy**

- High energy prices favor energy recovery due to higher revenues
Thank you for your attention!

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