Life cycle and experimental assessment of sustainable thermal processing of waste plastics

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LCA BLUF: Advanced Recycling Reduces GHGs

- Wide range of possible outcomes
  Ranges capture results of boundaries and benchmarks assumed
- Majority of scenarios show GHG reduction
  Some show increases in GHG emissions
- Details of each LCA are important
  Scenario comparisons contain multiple variables

Average or representative value does not exist
Methodologies used for the LCA review

• 13 LCAs from Jan. 2020 to May 2022
  focused on recent LCAs \( \rightarrow \) encompasses most recent data
• Incorporated a professional standard
e.g. ISO or European equivalent
• LCAs had to contain broadly applicable results
  large regions with representative energy and used materials processing systems
• Pilot or commercial plants with input processing capacity
  \(~216,000\) Mt\(\text{py} \) – glycolysis
  \(~22,000\) Mt\(\text{py} \) – co-gasification/reforming
  \(~100,000\) Mt\(\text{py} \) – methanolysis
  \(~200,000\) Mt\(\text{py} \) – pyrolysis
• Primary boundaries
  cradle-to-gate (i.e., resource extraction to factory gate)
  cradle-to-grave (i.e., ending with product disposal)
  focus on utilization of AR technology to produce products not fuels or energy

Selection criteria anticipated short time to technology maturity
Some Detail of the GHG Reduction Findings

<table>
<thead>
<tr>
<th>LCA</th>
<th>1</th>
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</thead>
<tbody>
<tr>
<td>CO₂eq reduction (min, max)</td>
<td>100, 137</td>
<td>13, 89</td>
<td>17, 73</td>
<td>79, 185</td>
<td>50, 133</td>
<td>-267, 66</td>
<td>42, 124</td>
<td>-77, 566</td>
<td>39, 139</td>
<td>29, 35</td>
<td>22, 50</td>
<td>-20, 48</td>
<td>-22, 45</td>
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</tbody>
</table>

- Coal replacement, Heat, MP
- Pyrolysis, Resin, HDPE
- Hydropyrolysis, Naphtha, Mechanical recycling losses
- Dissolution, Plastic polymer, MP
- Pyrolysis, Naphtha, MP

End-point values do not represent the same parameters
Mechanical recycling would be best, but practically very difficult for mixed plastic (MP) (i.e. multilayer)

Three evaluated AR technologies outperform WTE in terms of CO$_2$eq emissions for MP that cannot currently be mechanically recycled.

Pyrolysis performs similarly to gasification (within its range of error). Integration of projected future process efficiency gains further reduces CO$_2$eq emissions.

**Mixed plastics processed with AR technologies are preferred**
Analysis Example: One AR, different material

Co-gasification technology (plastic + coal)

Many input feedstocks:
- Post-consumer polyester carpet fiber
- Pre-consumer cross-linked polyethylene scrap
- Postindustrial cellulose acetate plastic scrap

All produce the same output intermediates:
- Syngas (→ further intermediates and products)

Coleman, 2020

Figure 3. Summary of relative carbon footprints of Eastman syngas from scenarios studied

Commercial weighted avg of CRT feedstocks for 2020 operating plan

Optimized supply chain of feedstock sourced within 500 miles

The ‘best’ material is closest proximity to technology
Refining industry is essential for providing the world’s platform chemicals and transportation fuel.

Refiners are exploring waste plastic pyrolysis-oil (py-oil) & biogenic feeds for co-processing in FCC.

**Catalytic cracking (FCC) can process pyrolysis oils from plastics**
Infrastructure Integration Challenges Exist

- FCC → production of transportation fuels and commodity chemicals
- FCC units process a variety of gasoil feedstock with varying contaminant levels
- As a result, the use of renewable and recyclable py- or crude oils (PYOIL/RCO) such as the pyrolysis oil obtained from waste biomass and plastics is explored

**Bio-based pyrolysis oils present challenges:**
- **High oxygen content**
- **Metals → catalyst fouling**
**Plastics:**
- Olefin/Paraffin ratio increases with increasing temperature

**Biomass:**
- Increasing temperature, decreases variety of oxygenated compounds.
**FCC catalyst selection determines product mix**

Catalyst A yields for conventional gasoil

BASF catalyst designed for transportation fuel production – Catalyst A

BASF catalyst designed for C₃-C₄ chemicals production – Catalyst B

Catalyst formulation can be tailored to provide desired products

- Cracking of polyethylene derived pyoil = higher yields of C₃-C₄ species, compared to the conventional gasoil cracking
- Catalyst A yields increased fuel; Catalyst B yields increased olefins

Can achieve ~50% of plastic recycling with existing technology!
Summary

• Advance Recycling (AR) technologies and processes must be evaluated on a specific “use-case”

  A single value does not accurately reflect the wide range of results

  Ranges within a given study may not have the same parameters for the maximum & minimum

• Choice of end-point is important (waste, produce, fuel, etc)

  Other environmental impact areas are dominated by beneficial results but are quite uneven

• Goal of AR must be chemical precursors to truly be considered recycling

  Fuel production is OK, but fossil CO₂ is eventually emitted

• Current infrastructure exists for large commercial scale deployment now

  Feedstock consistency and supply must be robust

Focus now must be on capturing plastic to supply technologies

A specific LCA must be done for the system of interest
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