Report on Co-utilization of Coal and Mixed Scrap Plastics via Syngas Production with Carbon Capture, Utilization, and Storage

March 24, 2022

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Acknowledgements

Overview

• Introduction

• Co-gasification as a Potential Solution

• Carbon Capture Utilization and Sequestration

• State-of-the-Art and Future Steps
Introduction
Stage-Setting and Goals

Plastic Waste + Coal → Co-gasification + Carbon Capture Utilization & Sequestration (CCUS) → Syngas
Introduction

Problem Description

- Growth in plastics continues with packaging as a significant and growing contributor
- We have made progress, but plastic is still seen as a waste product and not a valuable resource

Most Plastic waste is still landfilled

Plastics Waste Management: 1960-2018

Click on legend items below to customize items displayed in the chart
- Recycled
- Composted
- Combustion with Energy Recovery
- Landfilled
Introduction

Problem Description

• Need a fundamental conceptual shift from “plastics are waste” to “plastics are valuable resource”

• Progression from linear to circular typically happens in stages

• The US currently recycles only 8.7% of plastics
• Primary recycling can only be done with clean scrap
• Secondary recycling is limited to single polymer plastics and is energy intensive
• Tertiary recycling uses gasification and other processes to create syngas – more complicated but creates higher value products
• Quaternary recovers energy from the plastic by incineration – potential emissions issues
Global Strategies for Plastic Waste

- EU, Japan have stringent restrictions on PSW disposal and advocate circular plastics economy.
- EU directive to reduce use of single-use plastics and their landfilling.
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Co-Gasification as a Potential Solution

**Background**

**Gasification**
- Chemical recycling treatment technology
- Pure plastic feedstock
- High calorific value, low moisture, low ash content of plastics desirable
- Operational problems that chokes equipment

**Co-gasification**
- Chemical recycling treatment technology
- Mixed, various feedstock options
- Control product gas specification by blending plastics with other carbonaceous feedstock
- Emerging versatile technology
Co-Gasification as a Potential Solution

Technology Description

- Plastic waste can be added to mature technologies such as coal (and/or biomass) gasification without major changes to the process.
- Co-gasification has been studied by researchers at the laboratory and pilot scales for the utilization of wastes with coal and biomass.
- Main operations involved:

  - Drying of wet feedstock
  - Pyrolysis of dry feedstock
  - Oxidation
    - Char
    - Volatiles
  - Reduction
    - Product Synthesis Gas/Syngas
      - Tar
      - Ashes
Co-Gasification as a Potential Solution

Versatile Syngas Product

Syngas is a fundamental building block for versatile applications.

[Diagram showing the processes and products of syngas, including power generation, hydrogen production, methanol synthesis, and Fischer-Tropsch reactions.]

USEA-10

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Process versatility and potential synergies with different feedstock combinations has encouraged the study of plastic waste co-gasification.
Co-Gasification

Process Parameters

Process parameter conditions drive product yield and gasification performance.
Co-Gasification

Gasifier Types

Co-gasification of coal and biomass has been sufficiently demonstrated globally using all three types.

<table>
<thead>
<tr>
<th>Gasifiers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Bed Gasifier</td>
</tr>
<tr>
<td>Fluidized Bed Gasifier</td>
</tr>
<tr>
<td>Entrained Flow Gasifier</td>
</tr>
</tbody>
</table>

- Simple design
- Primarily used for small-scale applications
- Low tar formation typical
- Widely used for plastic gasification
- Suitable for large-scale applications
- Require mixed uniform size feed
- Can handle varying moisture content
- Suitable for large-scale applications
- Short residence time and small particle size typical
Co-Gasification
Effect of Feedstock Blends

Example investigation of the effect of feedstock blends on performance metrics such as gas composition and undesirable tar content.
Co-Gasification

Key Research Findings

- In general, a high $\text{H}_2$ content and heating value, low char yield and tar content, and high gas yield is desirable.

- Optimal process considerations typically depend on the use of the exit gas (product synthesis gas).

- The H/C ratios in plastics and lignite played an important role in the synergistic effect in co-gasification.

<table>
<thead>
<tr>
<th>Feedstock/Blend Ratio</th>
<th>Gasifier Type</th>
<th>Temperature</th>
<th>Catalyst/Bed Material</th>
<th>Gasifying Agent</th>
<th>Syngas Quality</th>
<th>Co-Gasification Performance</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal (60 wt.%), biomass (20 wt.%), plastic (20 wt.%)</td>
<td>Air gasified bubbling fluidized bed (BFB) reactor</td>
<td>850°C</td>
<td>Silica sand with dolomite catalyst</td>
<td>Air</td>
<td>$\text{H}_2$: 7–15% CO: 10–20% CO$_2$: 14–23% CH$_4$: 2–10%</td>
<td>Gas yield: 3 m³/kg feedstock Tar: &lt; 0.5 g/Nm³</td>
<td>(Aznar et al., 2006)</td>
</tr>
<tr>
<td>Coal (60 wt.%), pine (20 wt.%), PE plastic (20 wt.%)</td>
<td>Fluidized bed</td>
<td>850-900°C (890°C)</td>
<td>Air/Steam</td>
<td></td>
<td></td>
<td></td>
<td>(Pinto et al., 2003)</td>
</tr>
<tr>
<td>Coal, PE plastic</td>
<td>Dual fluidized bed</td>
<td>850°C</td>
<td>Olivine bed material</td>
<td>Steam</td>
<td>$\text{H}_2$: 40.4–49.4 vol% CO: 20.3–29.5 vol% CO$_2$: 3.6–12.9 vol% CH$_4$: 4.4–15.6 vol%</td>
<td>Tar: 0.8-11.2 g/Nm³</td>
<td>(Kern et al., 2013)</td>
</tr>
<tr>
<td>Coal, plastics, wood</td>
<td>BFB</td>
<td>850°C</td>
<td>Quartz sand bed material</td>
<td>Oxygen-enriched air</td>
<td>$\text{H}_2$: 13.8 vol% CO: 19.3 vol% CO$_2$: 16.3 vol% CH$_4$: 6.0 vol%</td>
<td>Tar: 13.5–21.8 g/Nm³</td>
<td>(Mastellone, Zaccariello, &amp; Arena, 2010)</td>
</tr>
</tbody>
</table>
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Carbon Capture Utilization and Sequestration

Plastics co-gasification facilities would release significant amounts of CO$_2$.

CCUS = Economic Benefit + Environmental Benefit

Coupling a CCUS system enables CO$_2$ removal and redirects it either to a process that utilizes the CO$_2$ or into permanent geologic storage.

**CO$_2$ Capture:**
- Pre-combustion
- Post-combustion
- Oxy-combustion

**CO$_2$ Transport:**
- Pipeline
- Truck
- Rail
- Ship

**CO$_2$ Storage:**
- Saline Formations
- Depleted oil and gas reservoirs
- Un-mineable coal seams
Carbon Capture Utilization and Sequestration

Well-established commercial implementation of flue gas capture and geologic storage spans multiple decades.
Carbon Capture Utilization and Sequestration

Numerous established and emerging technologies could provide additional pathways to new products using the CO₂ captured from plastics co-gasification.
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Abundance of plastic waste – Only 8.7% recycled in 2018

States with coal reserves can use plastic waste for co-gasification

Co-gasification resulting in a versatile product syngas

Coupling co-gasification with a CCUS to reduce GHG emissions
State-of-the-Art and Future Steps

Technical Challenges

• Feedstock preparation and post-processing cleanup operations.

• More complex due to combination of multiple feedstocks
State-of-the-Art and Future Steps

Non-Technical Challenges

- Policy Gaps for plastic recycling
- Landfills in U.S.
  - 1,269 facilities in 2018
  - Cheaper than most countries
- Social behavior and awareness
  - Plastic considered a waste
State-of-the-Art and Future Steps

Existing Facilities

Operational facilities around the world with plastics feedstock component

<table>
<thead>
<tr>
<th>Company</th>
<th>Project Name, Location</th>
<th>Status</th>
<th>Plant Capacity</th>
<th>Feedstock</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sierra Energy</td>
<td>FastOx Pathfinder, Fort Hunter Liggett, California, USA</td>
<td>Operational since 2018</td>
<td>10 tonnes per day gasifier capacity</td>
<td>MSW and biomass</td>
<td>Electricity and Fischer-Tropsch Diesel (FTD)</td>
</tr>
<tr>
<td>Fulcrum</td>
<td>Sierra Biofuels Plant, Reno, Nevada, USA</td>
<td>Construction completed in July 2021; full operations in Q4 2021</td>
<td>480 tonnes per day</td>
<td>MSW</td>
<td>Synthetic crude for transportation fuels</td>
</tr>
<tr>
<td>JGC Group</td>
<td>Showa Denko plant, Kawasaki, Japan</td>
<td>Operational since 2003</td>
<td>192 tonnes per day</td>
<td>Plastic waste</td>
<td>Syngas for chemical products like ammonia</td>
</tr>
<tr>
<td>Enerkem</td>
<td>Enerkem Alberta Biofuels, Edmonton, Alberta, Canada</td>
<td>Operational since 2017</td>
<td>274 tonnes per day (dry)</td>
<td>MSW</td>
<td>Ethanol</td>
</tr>
</tbody>
</table>

MSW- Municipal Solid Waste
State-of-the-Art and Future Steps

Ongoing Research Efforts – DOE/NREL

Auburn University (Auburn, AL)
Fluidized Bed Gasification of Coal-Biomass-Plastics for Hydrogen Production

Electric Power Research Institute, Inc. (Palo Alto, CA)
Performance Testing of a Moving-Bed Gasifier Using Coal, Biomass, and Waste Plastic Blends to Generate White Hydrogen

University of Kentucky Research Foundation (Lexington, KY)
Development and Characterization of Densified Biomass-Plastic Blend for Entrained Flow Gasification

University of Utah (Salt Lake City, UT)
Enabling Entrained Flow Gasification of Blends of Coal, Biomass and Plastics

Adapted from National Energy Technical Laboratory (NETL), 2019
DOE’s Office of Fossil Energy and Carbon Management
State-of-the-Art and Future Steps

Policy Framework

Policy framework drivers that support commercialization

• Reframe landfill policies
• Awareness at the City/Municipality-level on PSW management
• Federal/state initiatives can promote use of chemical recycling technologies for PSW
• Government, Coal and Plastic Industry consortiums can promote value recovery; evaluate the use of recyclcates instead of virgin plastic
Summary Findings

Untapped Potential in the U.S.

Utilize plastic waste for supplementing syngas production via co-gasification

Plastic waste a revenue source

Co-gasification of plastic waste and coal

Value proposition for utilization of coal while managing plastic waste

CO₂ storage potential

Gaps in Policy Framework

Leverage established CCUS technology for reduced environmental impacts

Reduce single-use plastics and avoid landfilling
Battelle

It can be done