Development and Characterization of Densified Biomass-plastic Blend for Entrained Flow Gasification

(DE-FE0032043)

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https://caer.uky.edu/co2capture/
Overall Goal

To develop and study a coal/biomass/plastic fuel with a surface area <10 $\text{m}^2/\text{gram}$ that is suitable for oxygen-blown entrained flow gasification with slurry feed.

Outline

• Background
• Objective
• Approach
• Project Details
Background

DOE believes that advances in co-gasification of coal, biomass, and waste plastics for polygeneration facilities and hydrogen production can lead to a viable technology for low-carbon energy.

- Provide co-generation with electric power and/or heat
- Reduce GHG (CO$_2$) emissions
- Plastic wastes offer high calorific heating value
- Biomass feedstocks are available and sourced
- Social justice and economic development for coal production region
Background

The Challenge: Viscosity of Coal-biomass Slurries

Only \(~5\) wt\% of biomass (torrefied pinewood) was successfully added to the coal slurry before reaching the upper limit for a slurry pump (\(~4800\) cp).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Viscosity (cp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal only</td>
<td>3240</td>
</tr>
<tr>
<td>1% Torrefied Biomass</td>
<td>3333</td>
</tr>
<tr>
<td>5% Torrefied Biomass</td>
<td>4736</td>
</tr>
<tr>
<td>10% Torrefied Biomass</td>
<td>Too thick to measure</td>
</tr>
</tbody>
</table>
Background

Root Cause for Water Uptake and UK Approach

Method 1
- Hemicellulose
- Cellulose
- Lignin

Mechanical crushing and densification of the fibrous structure

With coal so hydrophobic fines plug pores

Densified biomass with less water uptake

Method 2

239–275°F

Hydrophobic biomass

Structure of Polyethylene (\(\text{C}_2\text{H}_4\text{n}\))
Project Specific Objectives

Gasification of coal-plastic-biomass for reducing CO$_2$ emissions and syngas/H$_2$ production

- Demonstration of hydrophobic layer encapsulated biomass production that is suitable for a slurry with solid content with $\geq$60 wt% of blended coal/biomass/plastic fuel.
- Completion of lab-scale kinetic and gasification studies on the blended coal/biomass/plastic fuel.
- Demonstration of practical operations in the commercially relevant, UK CAER 1 TPD entrained flow gasifier.
Technical Approach
Project Activities and Execution

- Project Execution
  - Biomass, Plastic and Coal Properties Analysis
  - Co-pelletize Biomass/plastic Studies
  - Water Intake Studies
  - Biomass/Plastic Blend production via Co-extrusion
  - Solid Fuel and Slurry Preparation/Characterization
    - TGA and Droptube Kinetics and Gasification Conditions Studies
    - FactSage Simulation under Various Reduced Gases
  - 1 TPD Gasifier Operation/Analysis
## Schedule

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Start</th>
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<th>2022 Q3</th>
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<td>3 Biomass Property Control Using Plastic</td>
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<td>10 Gasiﬁcation on 1 TPD Gasﬁer</td>
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<td>1/31/23</td>
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<td>3/31/23</td>
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<td>10.4 Data Analysis</td>
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</tbody>
</table>
Project Team and Budget

Team:
- UK ME and CAER – plastic-biomass blend preparation, gasification using drop tube and pilot-scale gasifier
- UK BAE – blend fuel characteristic and gasification using TGA and cost-share
- Wabash Valley Resources – cost-share

<table>
<thead>
<tr>
<th></th>
<th>FY2021</th>
<th>FY2022</th>
<th>FY2023</th>
<th>Total</th>
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<tr>
<td>DOE Funds</td>
<td>$31,030</td>
<td>$257,136</td>
<td>$211,834</td>
<td>$500,000</td>
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<td>Cost Share</td>
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<td>$70,130</td>
<td>$28,832</td>
<td>$125,559</td>
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<tr>
<td></td>
<td>54%</td>
<td>79%</td>
<td>88%</td>
<td>80%</td>
</tr>
</tbody>
</table>


Material Preparation
Vitamix Blender

Plastic pellets can be broken down to a size that can go through the mesh size of 16, 12, and 8. Amount less than 10% of total.

Most plastic pellets remain the original size. Blender motor overheats.
Material Preparation
Cryogenic Milling

Liquid N2

HDPE powder
# Summary of Observations

<table>
<thead>
<tr>
<th></th>
<th>HDPE @ Freezer Temperature</th>
<th>HDPE with Water</th>
<th>HDPE with Ice and Water</th>
<th>HDPE Submerged in Liquid Nitrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coffee bur grinder</td>
<td>could not break</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Vitamix blender</td>
<td>could not break</td>
<td>Barely break</td>
<td>Some break (&lt;10%)</td>
<td>Complete breakdown</td>
</tr>
<tr>
<td>Hammer</td>
<td>smashed</td>
<td>N/A</td>
<td>N/A</td>
<td>Smashed</td>
</tr>
<tr>
<td>Knife grinder</td>
<td>Size limit 1/16”, ~25% of material lost</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Biomass Property Control Using Plastic

- **Materials**: torrefied wood mixed with either PET plastic or mixed plastic
- **Process**: Pellets were formed with 0.3 g sample in a 6.35 mm diameter die at 260°C with 1 ton of pressure for 1 minute
Impact of Initial Material Dimensions

1/8- and 1/16-inch Biomass and Plastic Particle Size Before Pelletizing

Buehler SimpliMet 1000
Samples Have Hydrophobic Surface

<table>
<thead>
<tr>
<th>Sample</th>
<th>Component Size (inch)</th>
<th>Component Blend Plastic:Biomass (HHV Basis)</th>
<th>Contact Angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic Mix</td>
<td>1/8</td>
<td></td>
<td>131.3</td>
</tr>
<tr>
<td>HDPE/biomass</td>
<td>1/8</td>
<td>15:85</td>
<td>89.0</td>
</tr>
<tr>
<td>PET/biomass</td>
<td>1/8</td>
<td>15:85</td>
<td>109.2</td>
</tr>
<tr>
<td>Plastic/biomass</td>
<td>1/8</td>
<td>30:70</td>
<td>98.0</td>
</tr>
<tr>
<td>plastic/biomass</td>
<td>1/8</td>
<td>50:50</td>
<td>98.0</td>
</tr>
<tr>
<td>Plastic/biomass</td>
<td>1/8</td>
<td>70:30</td>
<td>112.3</td>
</tr>
<tr>
<td>HDPE/biomass</td>
<td>1/16</td>
<td>15:85</td>
<td>94.4</td>
</tr>
<tr>
<td>PET/biomass</td>
<td>1/16</td>
<td>15:85</td>
<td>99.7</td>
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<tr>
<td>Plastic/biomass</td>
<td>1/16</td>
<td>30:70</td>
<td>110.4</td>
</tr>
<tr>
<td>plastic/biomass</td>
<td>1/16</td>
<td>50:50</td>
<td>108.3</td>
</tr>
<tr>
<td>Plastic/biomass</td>
<td>1/16</td>
<td>70:30</td>
<td>109.6</td>
</tr>
</tbody>
</table>

(Biomass contact angle not available due to uneven surface.)

15:85 HDPE/biomass observed with contact angle <90º
Greater plastic component may be necessary for plastic/biomass blends
Less than 10% Water Uptake Observed after 8 Hours

<table>
<thead>
<tr>
<th>Sample</th>
<th>Component Size (inch)</th>
<th>Component Blend Plastic:Biomass (HHV Basis)</th>
<th>Water Uptake (wt %, Based on Mass of Biomass) Immersion Time (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic Mix</td>
<td>1/8</td>
<td>100:0</td>
<td>1.2 1.8 2.2 2.3 3</td>
</tr>
<tr>
<td>Biomass</td>
<td>1/8</td>
<td>0:100</td>
<td>113 115 120 125 148</td>
</tr>
<tr>
<td>HDPE/Biomass</td>
<td>1/8</td>
<td>15:85</td>
<td>2.7 5.0 4.7 4.9 5.5</td>
</tr>
<tr>
<td>PET/Biomass</td>
<td>1/8</td>
<td>15:85</td>
<td>-    -    -    -    -</td>
</tr>
<tr>
<td>HDPE/Biomass</td>
<td>1/16</td>
<td>15:85</td>
<td>1.0 3.0 2.3 3.6 9.1</td>
</tr>
<tr>
<td>PET/Biomass</td>
<td>1/16</td>
<td>15:85</td>
<td>4.9 5.8 5.5 6.5 8.1</td>
</tr>
</tbody>
</table>

Breakage observed in the 1/8” PET and 1/16” HDPE, indicating a greater plastic component may be needed for increased mechanical strength.
## Bulk Density for Plastic/Biomass Blends

<table>
<thead>
<tr>
<th>Sample</th>
<th>Component Size (inch)</th>
<th>Component Blend Plastic:Biomass (HHV Basis)</th>
<th>Bulk Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic Mix</td>
<td>1/8</td>
<td></td>
<td>1.45</td>
</tr>
<tr>
<td>Biomass</td>
<td>~1.5</td>
<td></td>
<td>0.15-0.35</td>
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<tr>
<td>HDPE/Biomass</td>
<td>1/8</td>
<td>15:85</td>
<td>0.88</td>
</tr>
<tr>
<td>PET/Biomass</td>
<td>1/8</td>
<td>15:85</td>
<td>0.95</td>
</tr>
<tr>
<td>Plastic/Biomass</td>
<td>1/8</td>
<td>30:70</td>
<td>0.96</td>
</tr>
<tr>
<td>Plastic/Biomass</td>
<td>1/8</td>
<td>50:50</td>
<td>0.96</td>
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<tr>
<td>Plastic/Biomass</td>
<td>1/8</td>
<td>70:30</td>
<td>1.23</td>
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<tr>
<td>HDPE/Biomass</td>
<td>1/16</td>
<td>15:85</td>
<td>0.81</td>
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<td>PET/Biomass</td>
<td>1/16</td>
<td>15:85</td>
<td>0.90</td>
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<tr>
<td>Plastic/Biomass</td>
<td>1/16</td>
<td>30:70</td>
<td>0.91</td>
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<tr>
<td>Plastic/Biomass</td>
<td>1/16</td>
<td>50:50</td>
<td>1.01</td>
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<tr>
<td>Plastic/Biomass</td>
<td>1/16</td>
<td>70:30</td>
<td>1.15</td>
</tr>
</tbody>
</table>
Decrease of Biomass Peak Intensity with Decrease of Biomass Component

O-H (water) stretch: 3338 cm\(^{-1}\), C-O stretch: 1028 cm\(^{-1}\)
2906-2850 cm\(^{-1}\): aliphatic symmetric and asymmetric -CH\(_2\)- stretching
Repeatable Method Developed for Water Uptake Measurements of Ground Material

Modified ASTM D2980-04

1) measure saturated paper and funnel for tare mass sample saturated in funnel for immersed time
2) water discharged from the bottom of the funnel
3) measured the mass of funnel/paper/sample

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<th>4</th>
<th>6</th>
<th>8</th>
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<td>6.7</td>
<td>7.9</td>
<td>9.2</td>
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</table>

Water Uptake (% Total Mass) of MWP/Biomass 70:30 (HHV Basis) Pellets Prepared with <1/16-inch Particles Submerged in Water
## BET Surface Area Measurements

<table>
<thead>
<tr>
<th>Sample</th>
<th>BET Surface Area (m²/g)</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Biomass</td>
<td>0.5401</td>
<td>1/8” Particles</td>
</tr>
<tr>
<td>Blended Pellet</td>
<td>0.2452</td>
<td>MWP/Biomass, 15% Biomass (HHV Basis), Pellet made with 1/8&quot; Particles</td>
</tr>
<tr>
<td>Reground Pellet</td>
<td>0.4068</td>
<td>Pellet Reground with Mortar and Pestle, MWP/Biomass, 15% Biomass (HHV Basis), Pellet made with 1/8&quot; Particles</td>
</tr>
</tbody>
</table>

**Notes:**
- System error of BET method is 10 m²/g
- Degassing at 104 ºC for 600 min
- BET surface area calculated at relative pressure of 0.23
Slurryability of Blend Fuel

Notes:
• Plastics:Biomass (PB) 50:50 (50% biomass) used
• PB had particle size < 1680 microns
• High amount of coal reacts with the PB and forms clusters – enhances viscosity (particle agglomeration)
• High amount of PB in the slurry contains a high amount of plastic particles that precipitate, and phase separation increases

<table>
<thead>
<tr>
<th>Sample (55 wt% Solid Fuel)</th>
<th>Viscosity @100s(^{-1}) mPa.s</th>
<th>PB:Coal Ratio</th>
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<tr>
<td>Coal</td>
<td>0.393</td>
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<tr>
<td>PB:Coal</td>
<td>1.266</td>
<td>1:1</td>
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<tr>
<td>PB:Coal</td>
<td>2.838</td>
<td>1:2</td>
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<tr>
<td>PB:Coal</td>
<td>1.701</td>
<td>2:1</td>
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Sample

Anton Paar GmbH Rheometer
Analytical Pyrolysis GC/MS

Add-on capacities
- Cryo-trap for heart-cut mode
- Gas selector for reactive gases, such as air, O₂, H₂, etc.
- FPD detector for sub ppm level volatile sulphur and phosphorus compounds
Plastic and Wood Separate EGA

- **HDPE**
  - 497 °C
  - 1.30e+7
- **PET**
  - 447 °C
  - 1.06e+7
- **PS**
  - 430 °C
  - 1.42e+7
- **Wood**
  - 379 °C
  - 3.29e+6
Polystyrene (PS) and Wood EGA

- **PS and Wood**
  - Peak 1
    - 381 °C
    - 4.23e+6
  - Peak 2
    - 446 °C
    - 2.27e+6
Polyethylene Terephthalate (PET) and Wood EGA

• PET and Wood
  • Peak 1
    • 377 °C
    • 3.29e+6
  • Peak 2
    • 432 °C
    • 3.92e+6

![Graph showing EGA results for PET and Wood]
## Milestones & Success Criteria

<table>
<thead>
<tr>
<th>Task</th>
<th>Milestone Title &amp; Description</th>
<th>Planned Completion Date</th>
<th>Actual Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>PMP Updated</td>
<td>7/21/2021</td>
<td>7/14/2021</td>
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<tr>
<td>3.0</td>
<td>Densified biomass produced with at least 20% improvement of hydrophobicity and density</td>
<td>11/30/21</td>
<td>12/17/2021</td>
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<tr>
<td>4.0</td>
<td>Plastic encapsulated biomass demonstrated</td>
<td>1/31/22</td>
<td>12/17/2021</td>
</tr>
<tr>
<td>5.0</td>
<td>Acceptable Coal/biomass/plastic Solid Fuel Slurry Demonstrated</td>
<td>3/31/22</td>
<td>2/22/2022</td>
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<tr>
<td>6.0</td>
<td>Solid Fuel Characterization Complete</td>
<td>5/31/22</td>
<td></td>
</tr>
<tr>
<td>8.0</td>
<td>Completion of Gasification Kinetic Studies</td>
<td>11/30/22</td>
<td></td>
</tr>
<tr>
<td>10.2</td>
<td>&gt; 600 kg blended solid fuel prepared</td>
<td>1/31/23</td>
<td></td>
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<td>10.3</td>
<td>Gasification Complete on the 1 TPD Entrained Flow Gasifier</td>
<td>3/31/23</td>
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<td>1</td>
<td>Final Project Report Complete</td>
<td>7/31/23</td>
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<thead>
<tr>
<th>Planned Completion Date</th>
<th>Actual Completion Date</th>
<th>Success Criterion</th>
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<tbody>
<tr>
<td>3/31/22</td>
<td>2/22/2022</td>
<td>Demonstration of blended solid fuel slurry with 60 wt% solids and comparable heat value to 100 % coal water slurry.</td>
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<tr>
<td>11/30/22</td>
<td></td>
<td>Collection of gasification kinetic data and identification of preliminary operating conditions.</td>
</tr>
<tr>
<td>7/31/23</td>
<td></td>
<td>Demonstrated gasification of the blended solid fuel in the UK CAER entrained flow gasifier with dataset detailing optimum operating conditions and characterization of slag phase formation and solidification.</td>
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</tbody>
</table>
Acknowledgements

U.S. DOE-NETL
Andrew C. O'Connell

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