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

(DE-FE0032043)

Heather Nikolic, Dimitrios Koumoulis, Jian Shi and Kunlei Liu

University of Kentucky

Lexington, KY

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

Overall Goal

To develop and study a coal/biomass/plastic fuel with a surface area <10 m^2/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

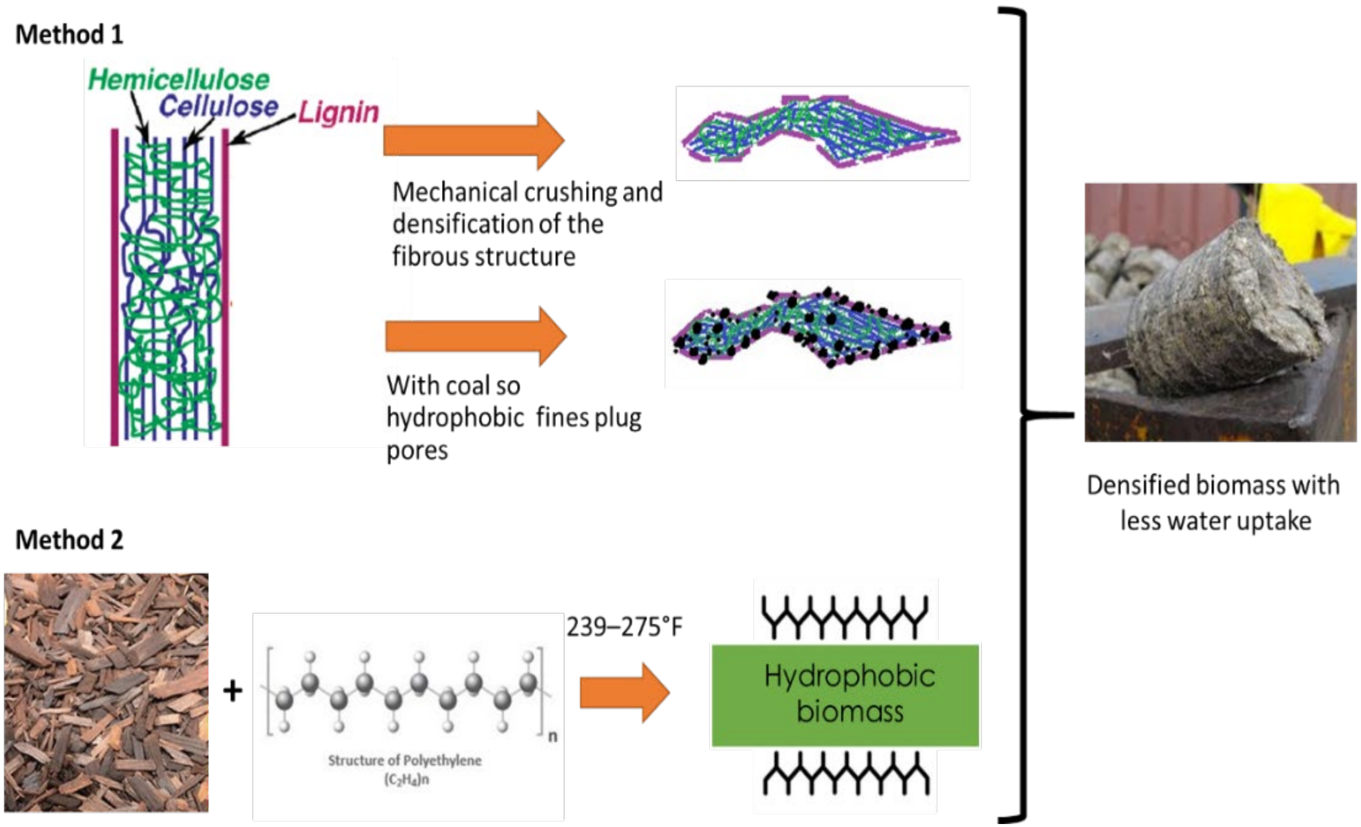
The Challenge: Viscosity of Coal-biomass Slurries

Viscosity: 3240 cp	Viscosity: 3333 cp	Viscosity: 4736 cp	Too thick to measure

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).

Background

Root Cause for Water Uptake and UK Approach

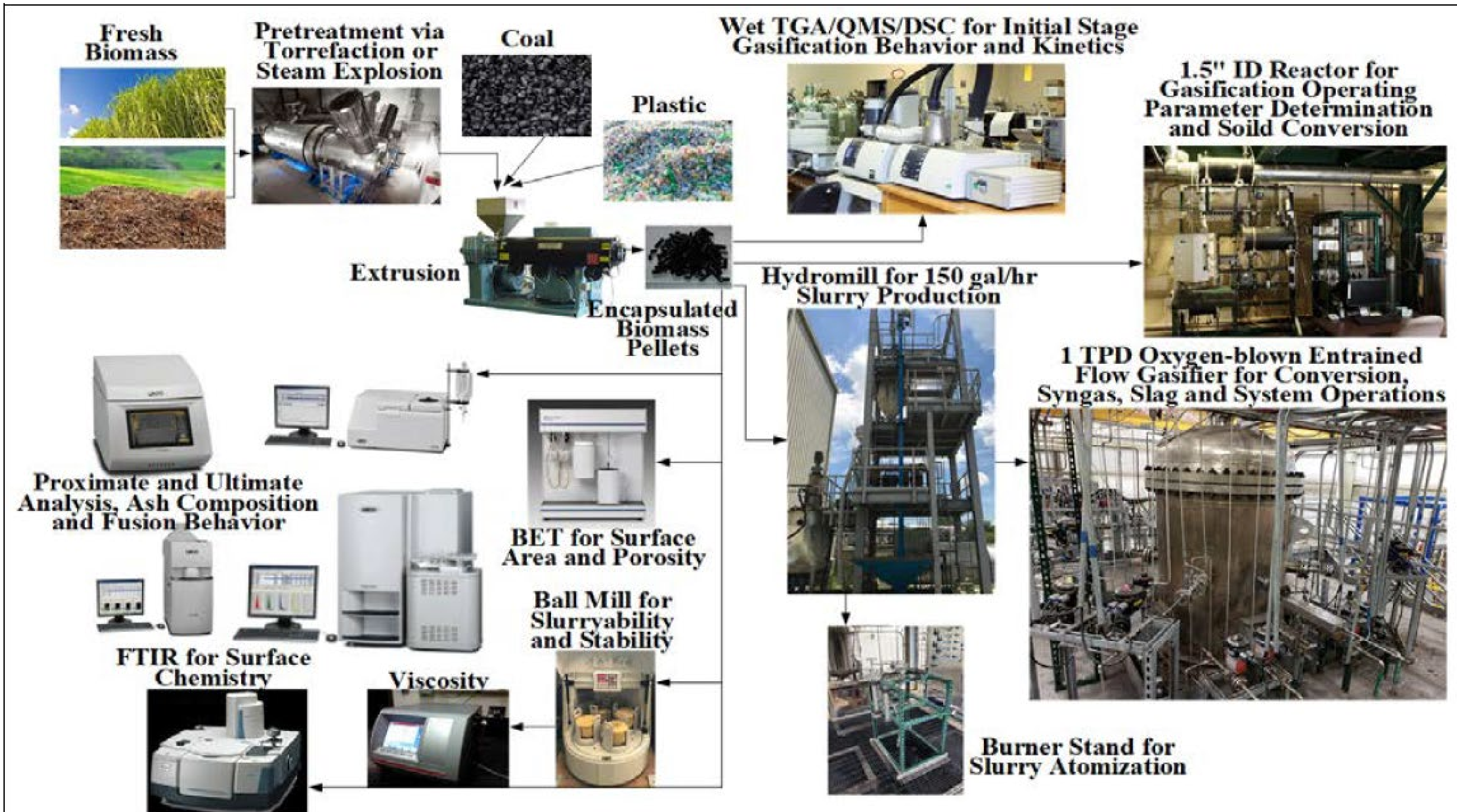


Project Specific Objectives

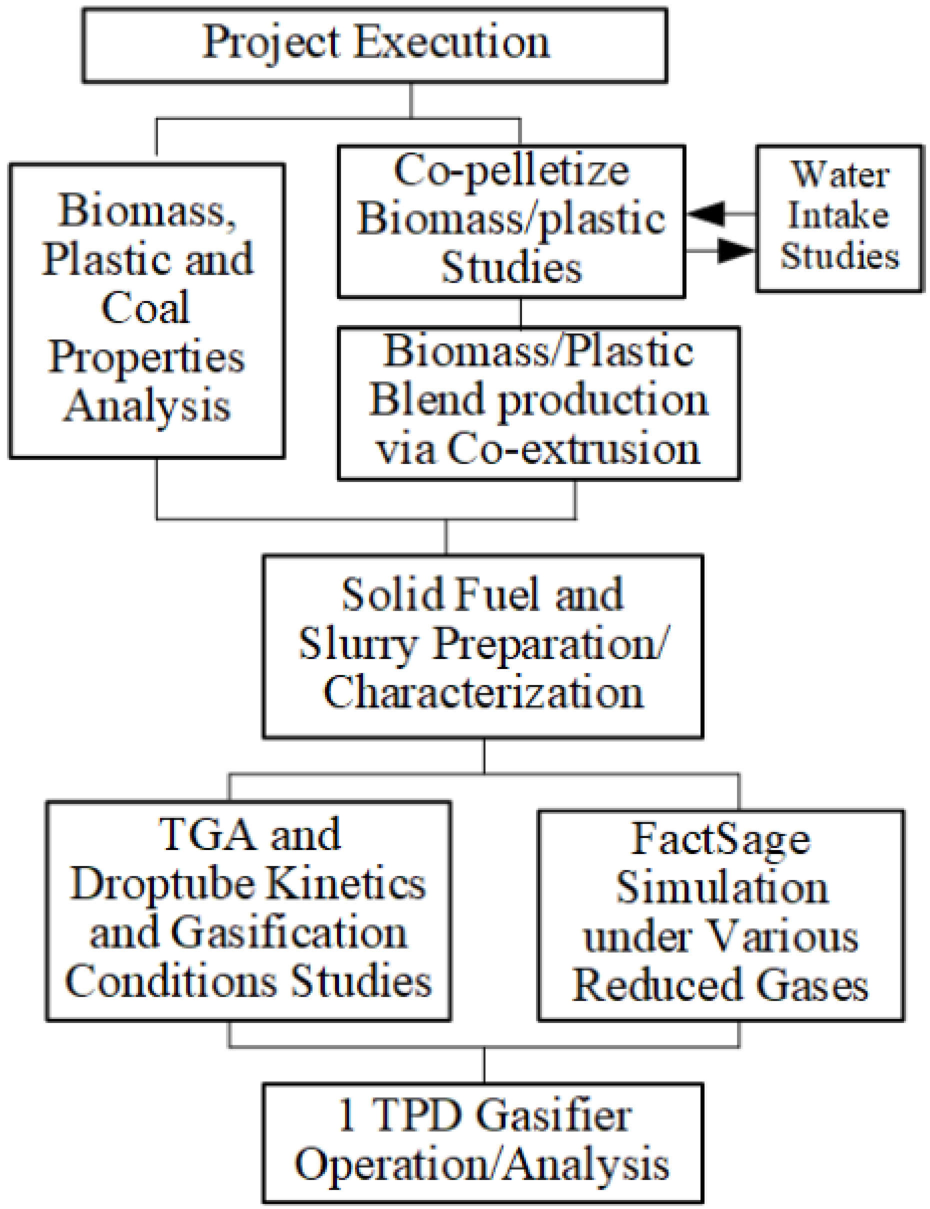
Gasification of coal-plastic-biomass for reducing CO_2 emissions and syngas/H_2 production

- **Demonstration of hydrophobic layer encapsulated biomass production that is suitable for a slurry with solid content with ≥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

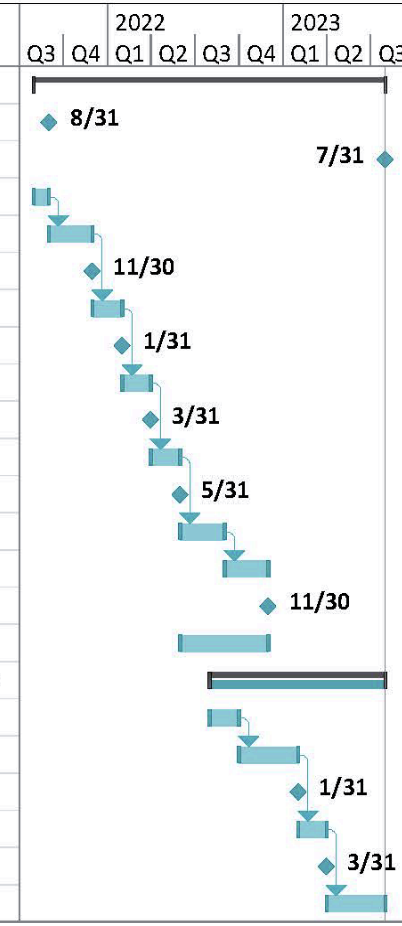


Project Activities and Execution



Schedule

ID	Task Name	Start	Finish	Task Cost
1	**1 Project Management and Planning**	**8/1/21**	**7/31/23**	**$120,090**
2	*1.1 PMP Updated*	*8/31/21*	*8/31/21*	
3	*1.2 Final Project Report Complete*	*7/31/23*	*7/31/23*	
4	**2 Test Plan**	**8/1/21**	**8/31/21**	**$ 19,245**
5	**3 Biomass Property Control Using Plastic**	**9/1/21**	**11/30/21**	**$ 45,286**
6	*3.1 Densified biomass produced with at least 20% improvement of hydrophobicity and density*	*11/30/21*	*11/30/21*	
7	**4 Biomass/Plastic Co-Extrusion for Blended Fuel Production**	**12/1/21**	**1/31/22**	**$ 36,772**
8	*4.1 Plastic encapsulated biomass demonstrated*	*1/31/22*	*1/31/22*	
9	**5 Slurry Preparation and Characterization**	**2/1/22**	**3/31/22**	**$ 85,471**
10	*5.1 Acceptable Coal/biomass/plastic Solid Fuel Slurry Demonstrated*	*3/31/22*	*3/31/22*	
11	**6 Solid Fuel Characterization**	**4/1/22**	**5/31/22**	**$ 19,694**
12	*6.1 Solid Fuel Characterization Complete*	*5/31/22*	*5/31/22*	
13	**7 Blended Fuel Gasification Kinetic Study**	**6/1/22**	**8/31/22**	**$ 35,822**
14	**8 Bench Scale Gasification Study Using 1.5" ID Drop Tube Reactor**	**9/1/22**	**11/30/22**	**$ 21,925**
15	*8.1 Completion of Gasification Kinetic Studies*	*11/30/22*	*11/30/22*	
16	**9 FactSage Simulation**	**6/1/22**	**11/30/22**	**$ 46,596**
17	**10 Gasification on 1 TPD Gasifier**	**8/1/22**	**7/31/23**	**$194,658**
18	**10.1 Operation Plan**	**8/1/22**	**9/30/22**	
19	**10.2 Slurry Preparation**	**10/1/22**	**1/31/23**	
20	*10.2.1 > 600 kg blended solid fuel prepared*	*1/31/23*	*1/31/23*	
21	**10.3 Operation**	**2/1/23**	**3/31/23**	
22	*10.3.1 Gasification Complete on the 1 TPD Entrained Flow Gasifier*	*3/31/23*	*3/31/23*	
23	**10.4 Data Analysis**	**4/1/23**	**7/31/23**	



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

Budget Period 1							
FY2021		FY2022		FY2023		Total	
DOE Funds	Cost Share	DOE Funds	Cost Share	DOE Funds	Cost Share	DOE Funds	Cost Share
$31,030	$26,597	$257,136	$70,130	$211,834	$28,832	$500,000	$125,559
54%	46%	79%	21%	88%	12%	80%	20%

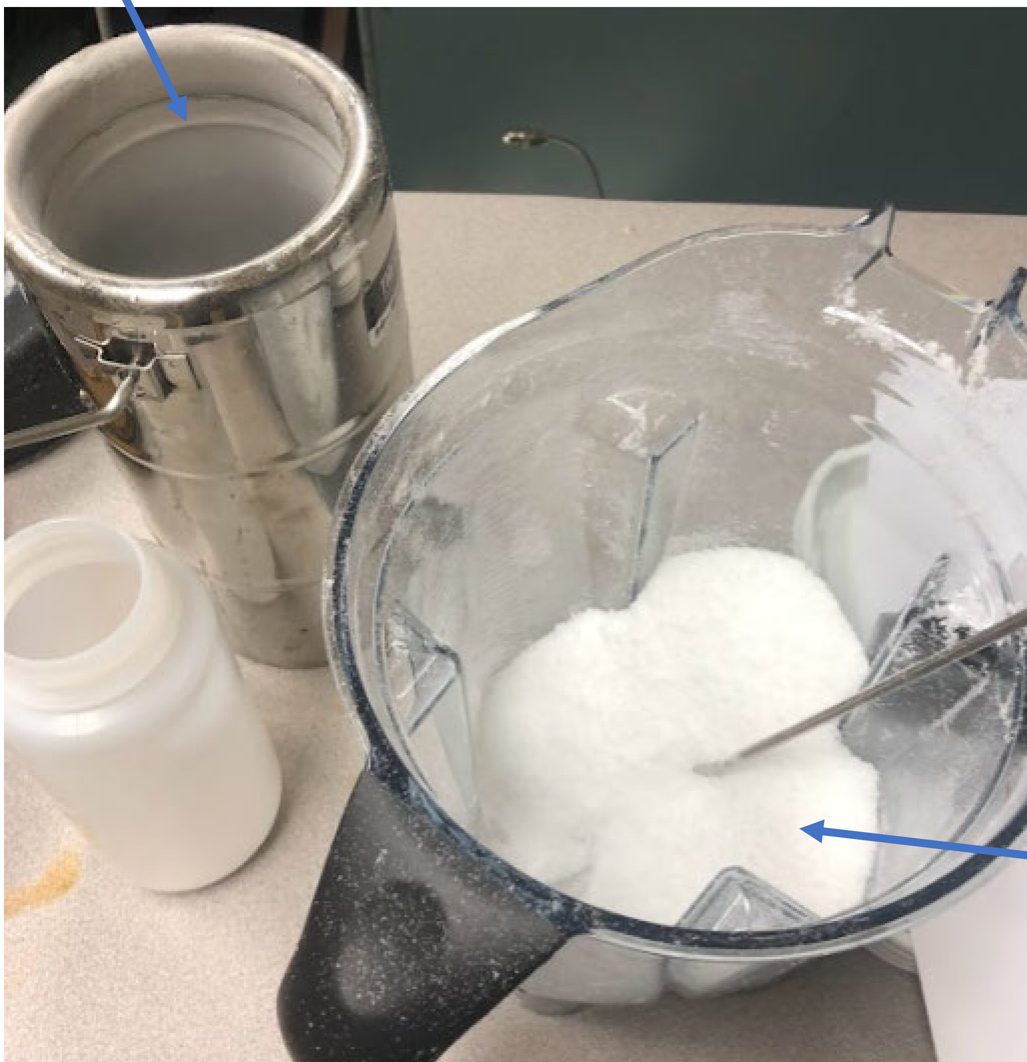
Material Preparation
Vitamix Blender

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



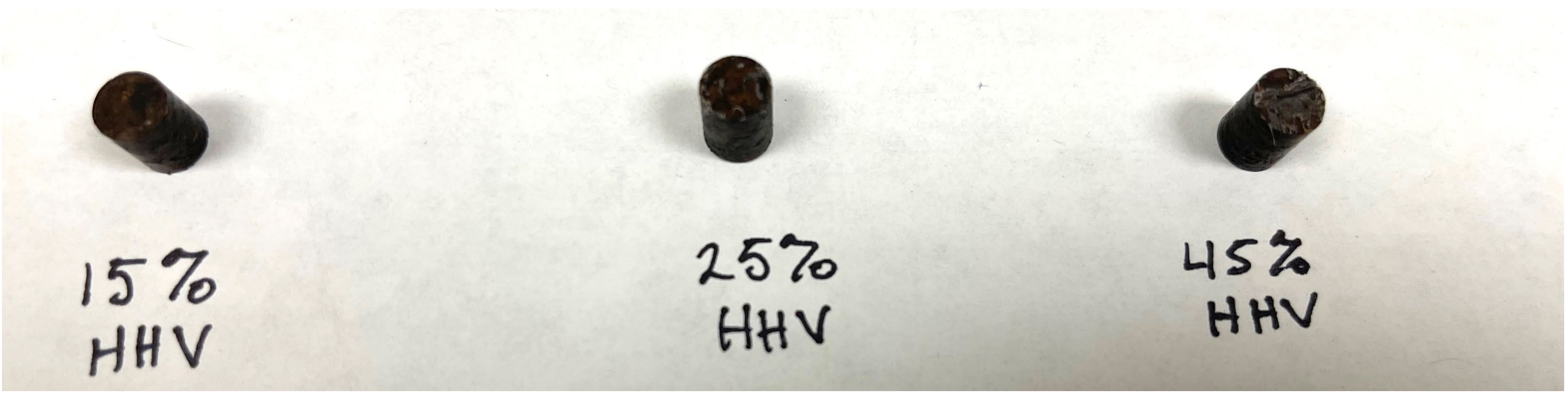
HDPE powder

Summary of Observations

	HDPE @ Freezer Temperature	HDPE with Water	HDPE with Ice and Water	HDPE Submerged in Liquid Nitrogen
Coffee bur grinder	could not break	N/A	N/A	N/A
Vitamix blender	could not break	Barely break	Some break (<10%)	Complete breakdown
Hammer	smashed	N/A	N/A	Smashed
Knife grinder	Size limit 1/16", ~25% of material lost	N/A	N/A	N/A

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

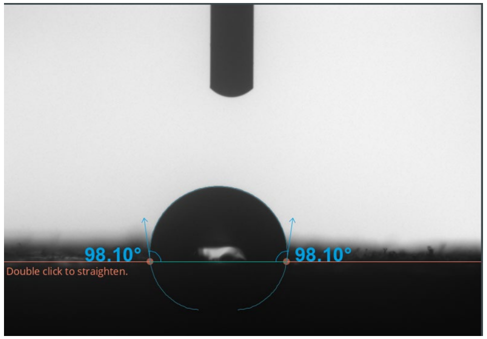
1/8- and 1/16-inch Biomass and Plastic Particle Size Before Pelletizing

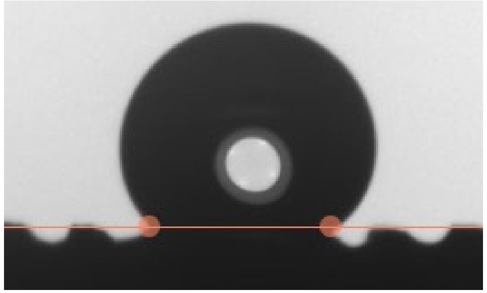
Buehler SimpliMet 1000

Samples Have Hydrophobic Surface

Sample	Component Size (inch)	Component Blend Plastic:Biomass (HHV Basis)	Contact Angle (º)
Plastic Mix	1/8		131.3
HDPE/biomass	1/8	15:85	89.0
PET/biomass	1/8	15:85	109.2
Plastic/biomass	1/8	30:70	98.0
plastic/biomass	1/8	50:50	106.7
Plastic/biomass	1/8	70:30	112.3
HDPE/biomass	1/16	15:85	94.4
PET/biomass	1/16	15:85	99.7
Plastic/biomass	1/16	30:70	110.4
plastic/biomass	1/16	50:50	108.3
Plastic/biomass	1/16	70:30	109.6

(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

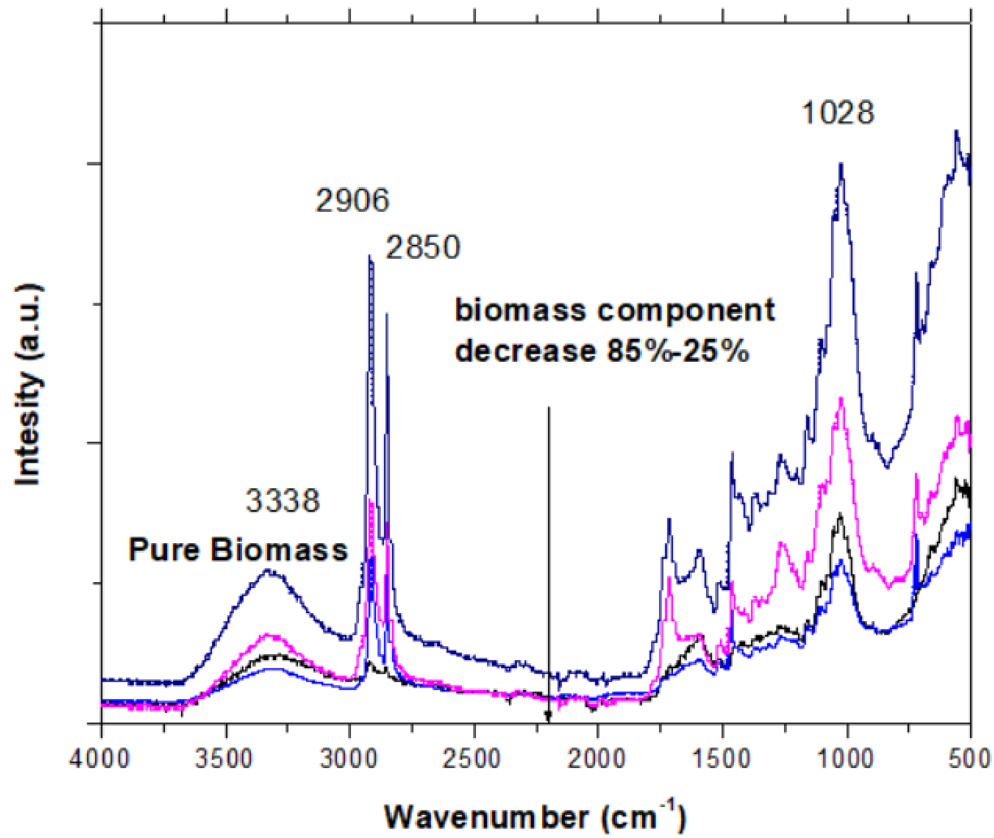
Sample	Component Size (inch)	Component Blend Plastic:Biomass (HHV Basis)	Water Uptake (wt %, Based on Mass of Biomass) Immersion Time (h)				
			2	4	6	8	24
Plastic Mix	1/8	100:0	1.2	1.8	2.2	2.3	3
Biomass	1/8	0:100	113	115	120	125	148
HDPE/Biomass	1/8	15:85	2.7	5.0	4.7	4.9	5.5
PET/Biomass	1/8	15:85	-	-	-	-	-
HDPE/Biomass	1/16	15:85	1.0	3.0	2.3	3.6	9.1
PET/Biomass	1/16	15:85	4.9	5.8	5.5	6.5	8.1

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

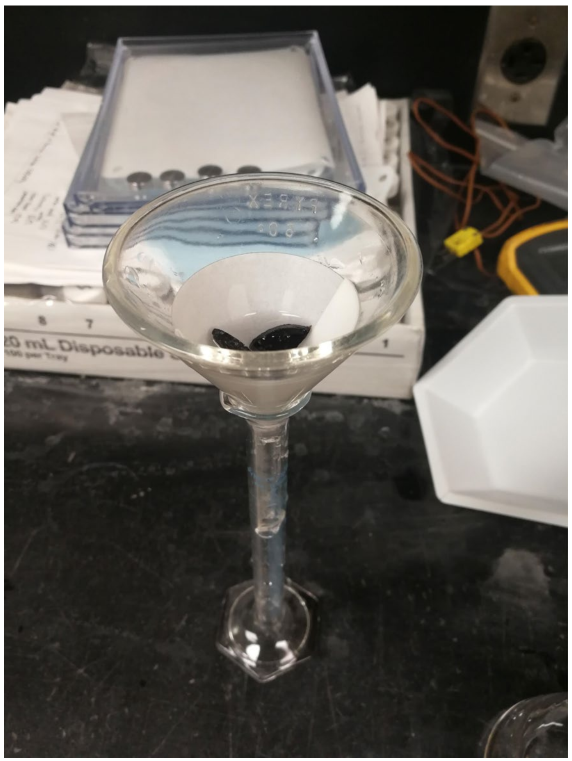
Sample	Component Size (inch)	Component Blend Plastic:Biomass (HHV Basis)	Bulk Density (g/cm³)
Plastic Mix	1/8		1.45
Biomass	~1.5		0.15-0.35
HDPE/Biomass	1/8	15:85	0.88
PET/Biomass	1/8	15:85	0.95
Plastic/Biomass	1/8	30:70	0.96
Plastic/Biomass	1/8	50:50	0.96
Plastic/Biomass	1/8	70:30	1.23
HDPE/Biomass	1/16	15:85	0.81
PET/Biomass	1/16	15:85	0.90
Plastic/Biomass	1/16	30:70	0.91
Plastic/Biomass	1/16	50:50	1.01
Plastic/Biomass	1/16	70:30	1.15

Decrease of Biomass Peak Intensity with Decrease of Biomass Component



O-H (water) stretch: 3338 cm^{-1}, C-O stretch: 1028cm^{-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

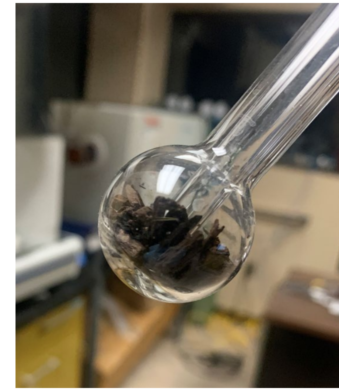
1) measure saturated paper and funnel for tare mass
sample saturated in funnel for immersed time
2) water discharged from the bottom of the funnel
3) measured the mass of funnel/paper/sample

Water Uptake (% Total Mass) of MWP/Biomass 70:30 (HHV Basis) Pellets Prepared with <1/16-inch Particles Submerged in Water						
Immersion Time (hr)		**2**	**4**	**6**	**8**	**24**
Paper Towel Method	**1**	**2.3**	**4.3**	**5.7**	**6.3**	**8.8**
Filter Paper Method	**1**	**4.6**	**6.3**	**7.5**	**9.3**	**10.4**
Filter Paper Method	**2**	**4.8**	**6.4**	**7.4**	**9.8**	**10.6**
Filter Paper Method	**3**	**5.0**	**6.7**	**7.9**	**9.2**	**10.6**

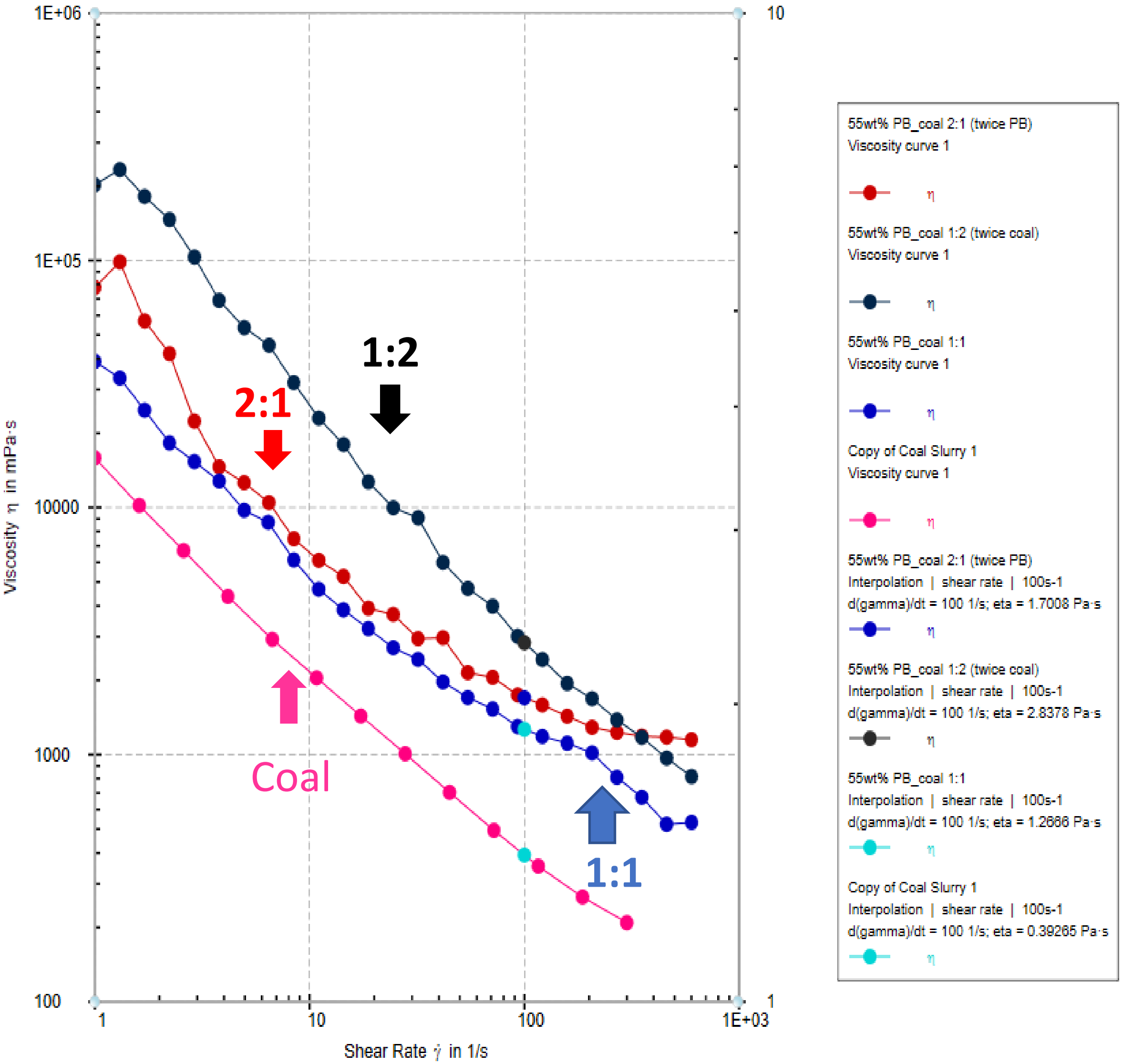
BET Surface Area Measurements

Sample	BET Surface Area (m^2/g)	
Biomass	0.5401	1/8” Particles
Blended Pellet	0.2452	MWP/Biomass, 15% Biomass (HHV Basis), Pellet made with 1/8" Particles
Reground Pellet	0.4068	Pellet Reground with Mortar and Pestle, MWP/Biomass, 15% Biomass (HHV Basis), Pellet made with 1/8" Particles

Notes:
System error of BET method is 10 m^2/g
Degassing at 104 ºC for 600 min
BET surface area calculated at relative pressure of 0.23



Slurryability of Blend Fuel



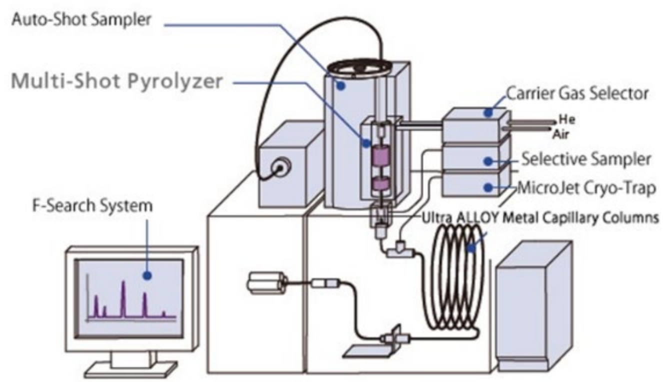
Anton Paar GmbH Rheometer

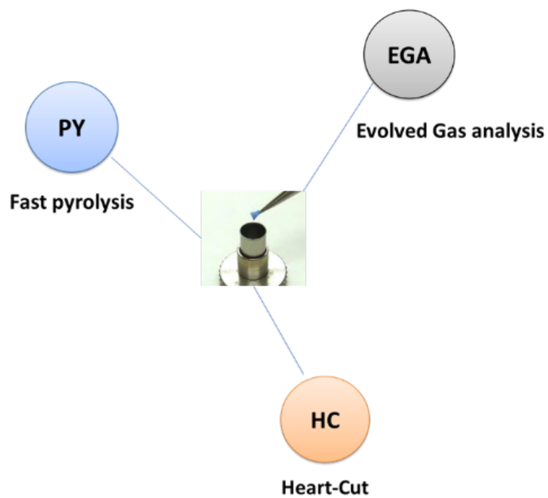
Sample (55 wt% Solid Fuel)	Viscosity @100s^{-1} mPa.s	PB:Coal Ratio
Coal	0.393	-
PB:Coal	1.266	1:1
PB:Coal	2.838	1:2
PB:Coal	1.701	2:1

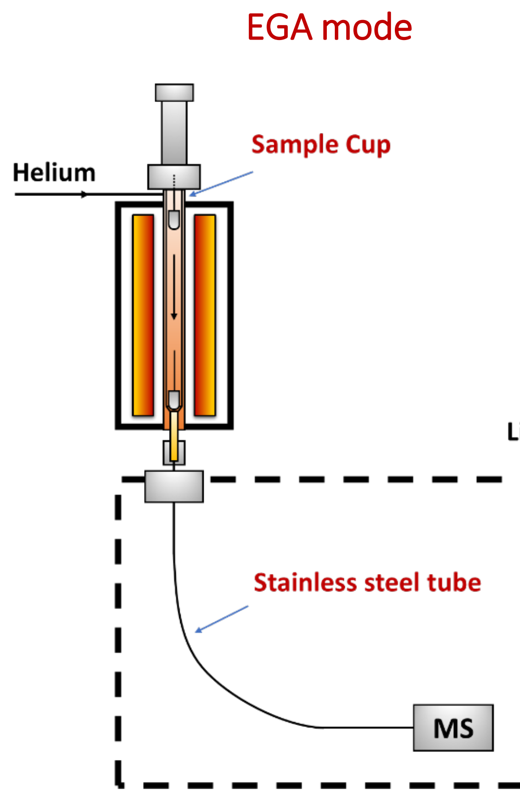
Notes:

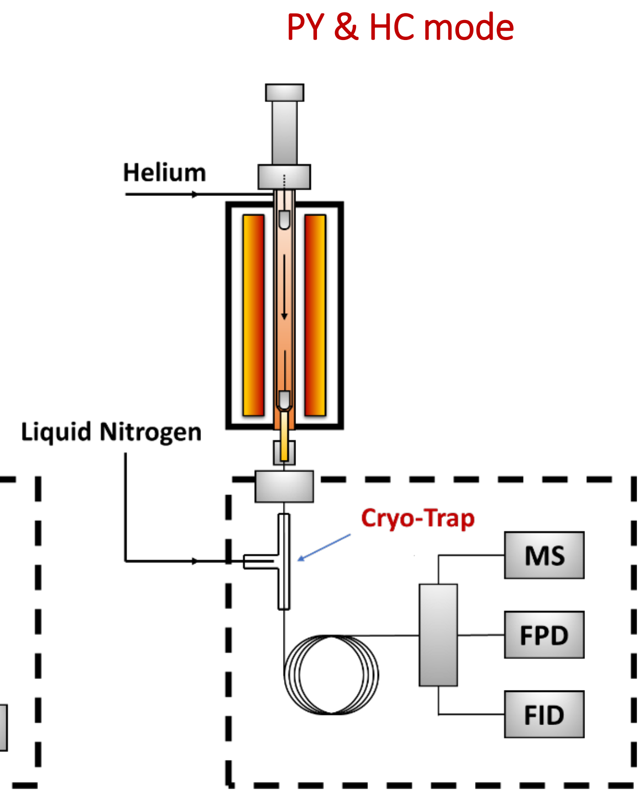
- Plastics:Biomass (PB) 50:50 (50% biomass) used
- PB had particle size < 1680 microns
- High amount of coal reacts with the PB and forms clusters – enhances viscosity (particle agglomeration)
- High amount of PB in the slurry contains a high amount of plastic particles that precipitate, and phase separation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

Analytical Pyrolysis GC/MS







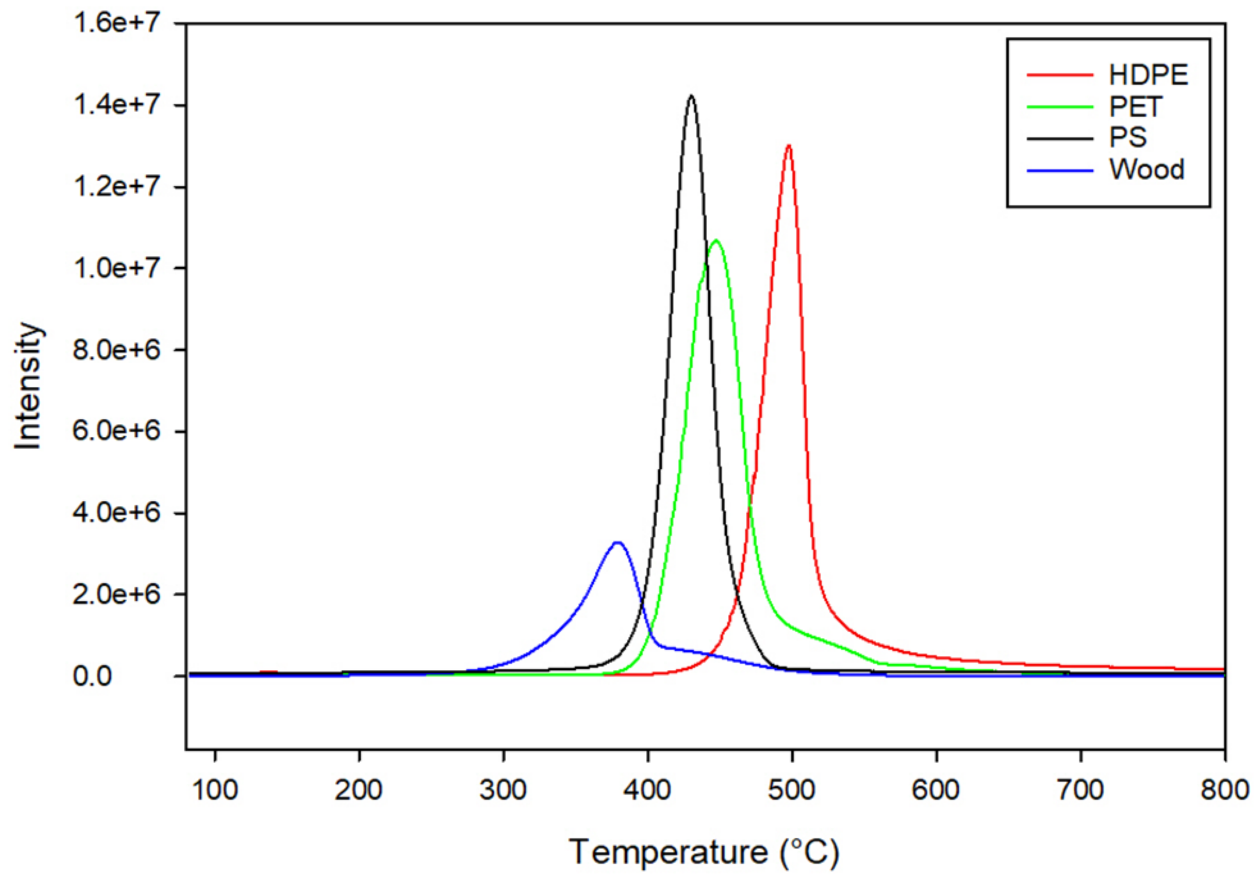


<u>Add-on capacities</u>

- Cryo-trap for heart-cut mode
- Gas selector for reactive gases, such as air, O_2, H_2, etc.
- FPD detector for sub ppm level volatile sulphur and phosphorus compounds

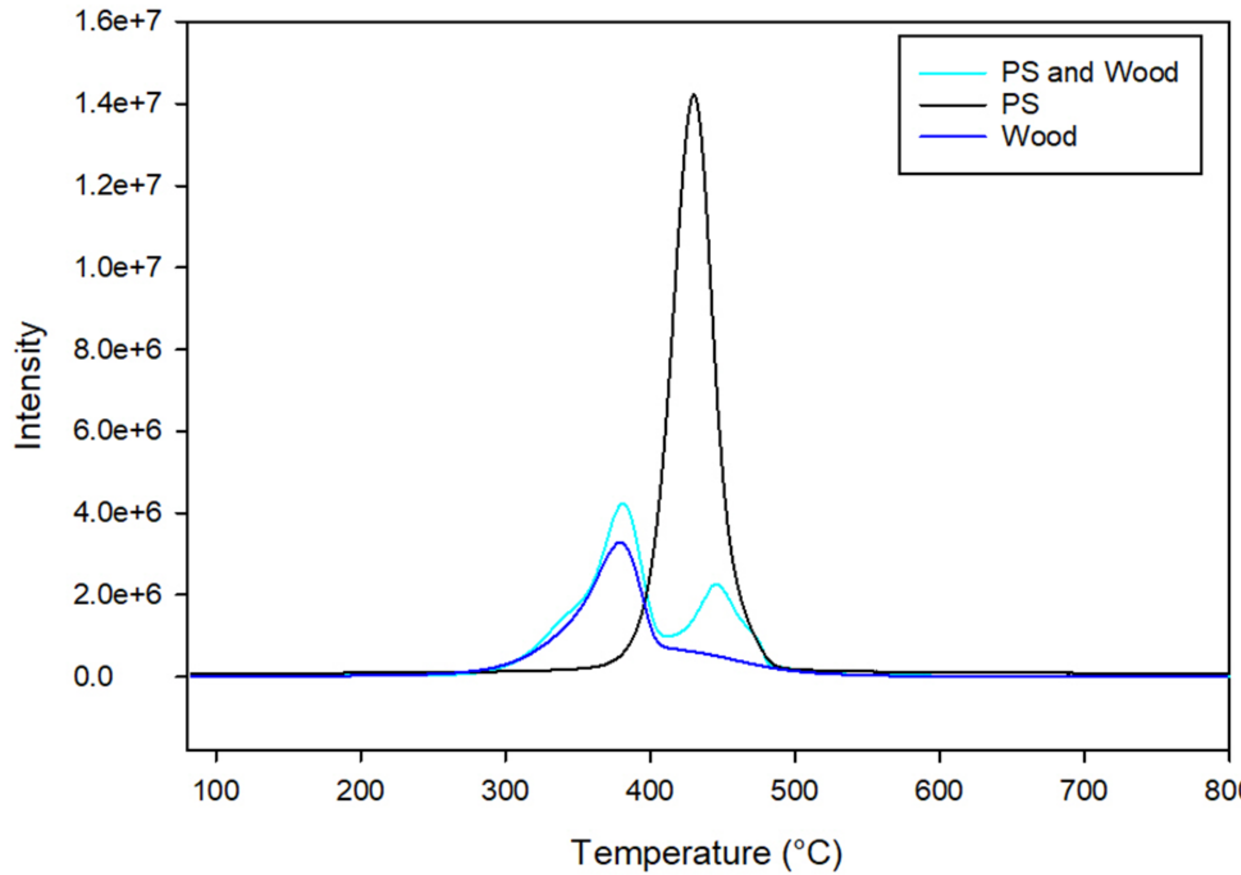
Plastic and Wood Separate EGA

- HDPE
  - 497 °C
  - 1.30e+7
- PET
  - 447 °C
  - 1.06e+7
- PS
  - 430 °C
  - 1.42e+7
- Wood
  - 379 °C
  - 3.29e+6



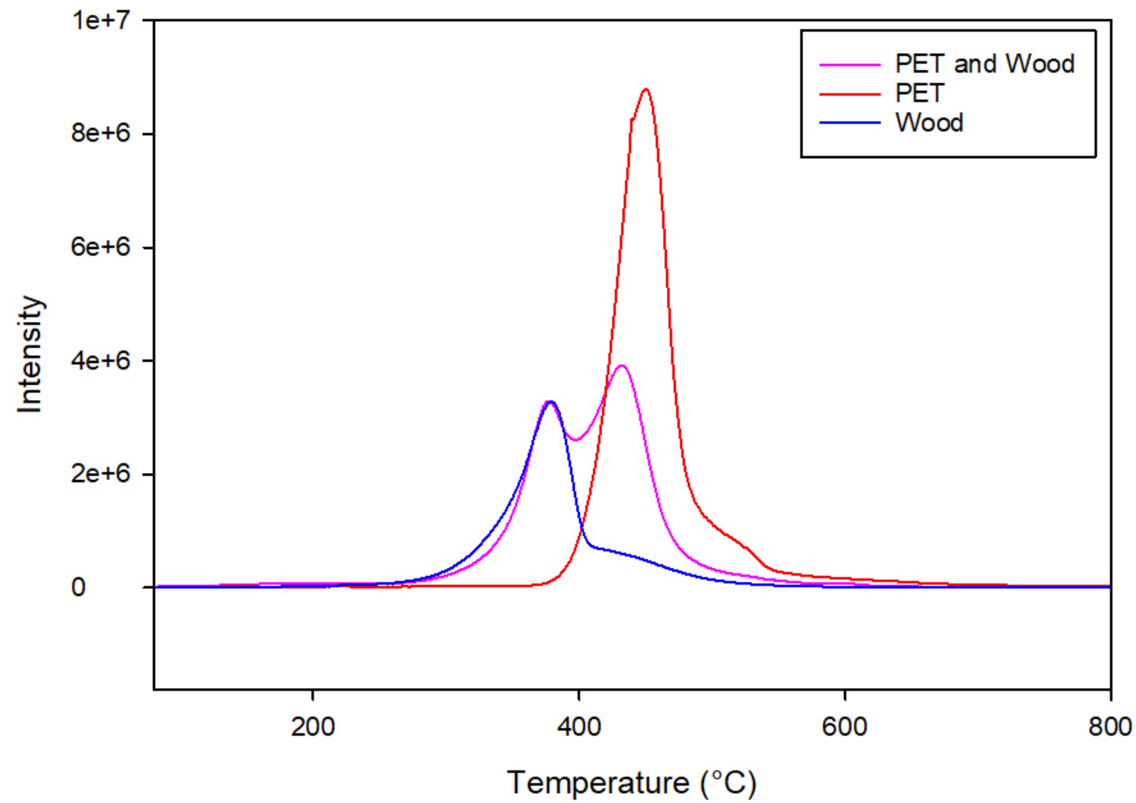
Polystyrene (PS) and Wood EGA

- 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



Milestones & Success Criteria

Task	Milestone Title & Description	Planned Completion Date	Actual Completion Date
1.1	PMP Updated	7/21/21	7/14/2021
3.0	Densified biomass produced with at least 20% improvement of hydrophobicity and density	11/30/21	12/17/2021
4.0	Plastic encapsulated biomass demonstrated	1/31/22	12/17/2021
5.0	Acceptable Coal/biomass/plastic Solid Fuel Slurry Demonstrated	3/31/22	2/22/2022
6.0	Solid Fuel Characterization Complete	5/31/22	
8.0	Completion of Gasification Kinetic Studies	11/30/22	
10.2	> 600 kg blended solid fuel prepared	1/31/23	
10.3	Gasification Complete on the 1 TPD Entrained Flow Gasifier	3/31/23	
1	Final Project Report Complete	7/31/23	

Planned Completion Date	Actual Completion Date	Success Criterion
3/31/22	2/22/2022	Demonstration of blended solid fuel slurry with 60 wt% solids and comparable heat value to 100 % coal water slurry.
11/30/22		Collection of gasification kinetic data and identification of preliminary operating conditions.
7/31/23		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.

Acknowledgements

U.S. DOE-NETL

Andrew C. O'Connell

University of Kentucky

Ryan Kalinoski, Jameson Hunter, Hanjing Tian, and Pengfei He

Wabash Valley Resources, LLC

Dan Williams, Rory Chambers and Brad Stone