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

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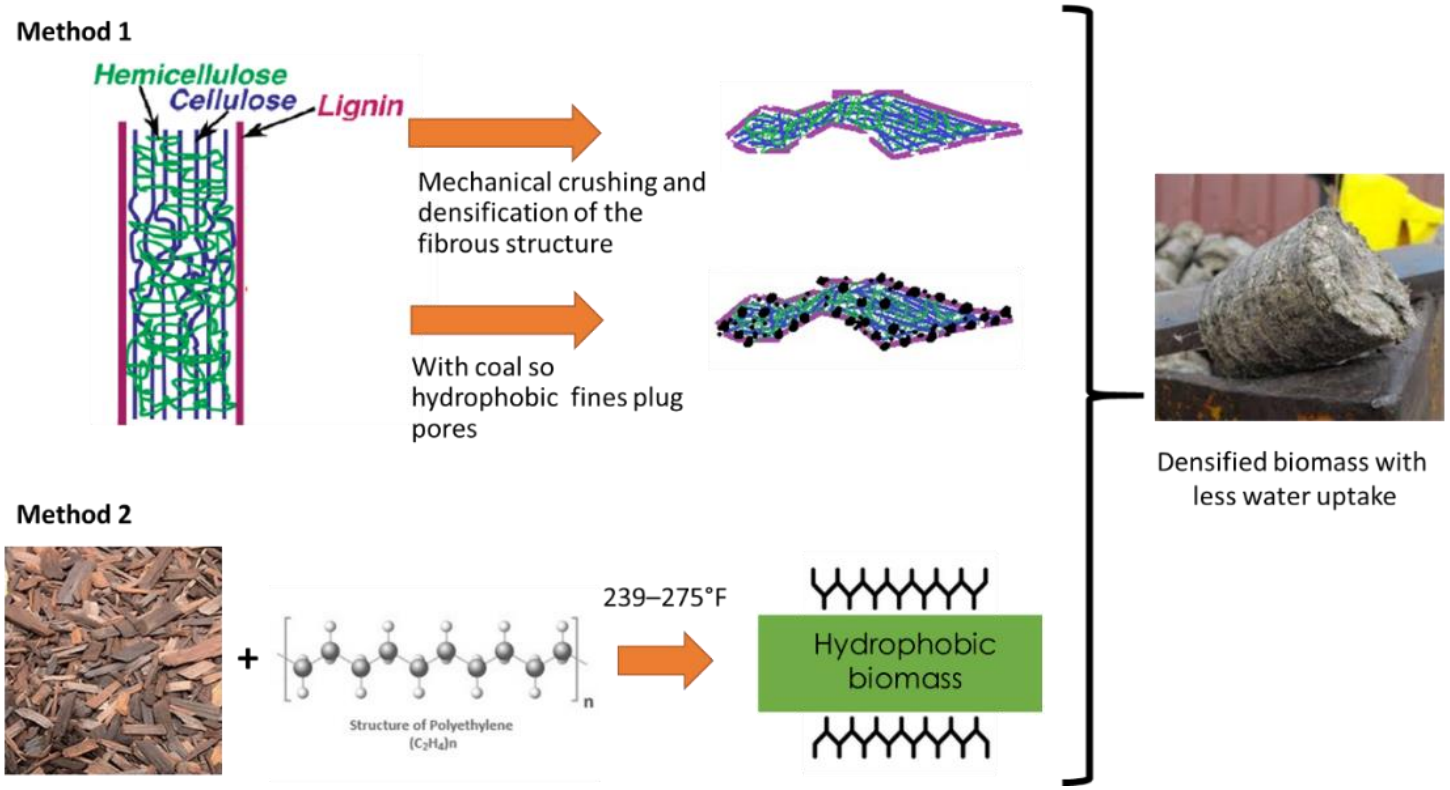
Overall Goal

Develop and study a biomass-plastic fuel that is suitable for oxygen blown entrained flow co-gasification with carbon-negative emissions

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

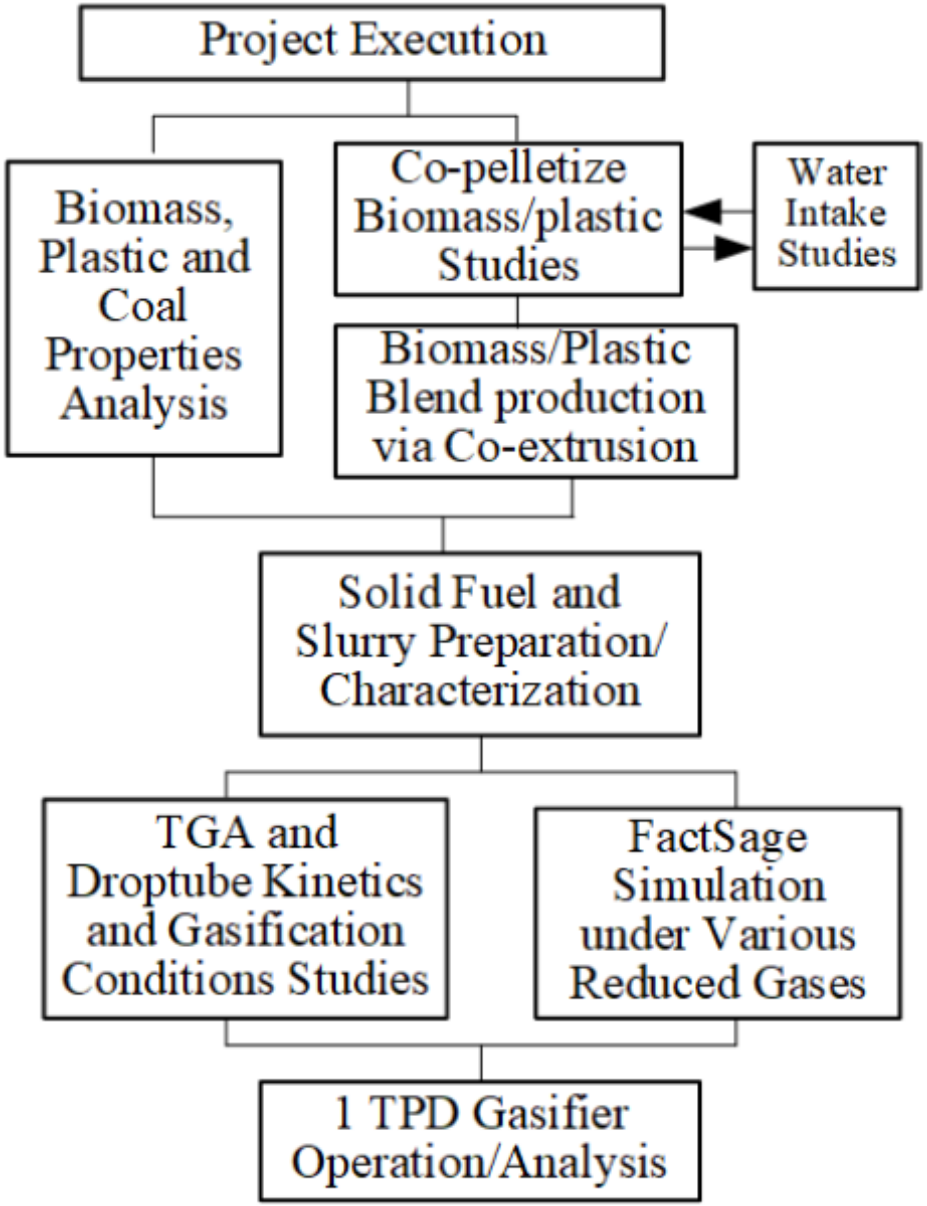
5% torrefied wood added to coal-water slurry increased the viscosity beyond the limits of slurry pump

Our Approach



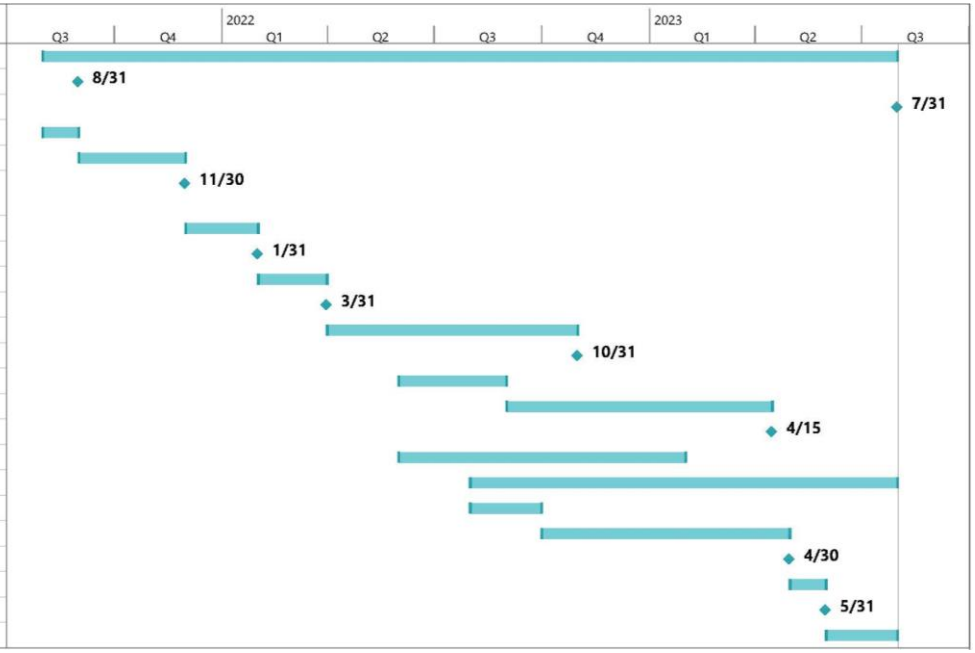
Material	Bulk Density (kg /m^3	Heating Value (Btu/lb)	Heating Value (GJ/m)	BET Surface Area (m^2/g)	Porosity (%)	Pore Volume. (cm^3/g)	Average Pore Size (nm)
IL #6 Coal	670-920[5]	11,666-13,125[6]	28-31	<29[7]	--	<0.01[8 9]	0.6-1[6]
Torrefied Pine Wood	150-350[10 11]	9,203-10,340[5]	18-20	>40[12 13]	~65[12]	~0.1[14]	30-100[14]
Steam Exploded Pine Wood	40-200[15 16]	8,000-9,800[17 18]	3-14	65-130[19]	~80[18]	0.3-1.1[20]	500-1000[21]

Project Execution



Project Schedule and Cost

Task Name	Start	Finish
1.0 Project Management and Planning	**8/1/21**	**7/31/23**
1.1 PMP Updated	*8/31/21*	*8/31/21*
1.2 Final Project Report Complete	*7/31/23*	*7/31/23*
2.0 Test Plan	**8/1/21**	**8/31/21**
3.0 Biomass Property Control using Plastic	**9/1/21**	**11/30/21**
3.1 Densified biomass product with at least 20% improvement of hydrophobicity and density	*11/30/21*	*11/30/21*
4.0 Biomass/Plastic Co-extrusion for Blended Fuel Production	**12/1/21**	**1/31/22**
4.1 Plastic encapsulated biomass demonstrated	*1/31/22*	*1/31/22*
5.0 Slurry Preparation and Characterization	**2/1/22**	**3/31/22**
5.1 Acceptable coal/biomass/plastic solid fuel slurry demonstrated	*3/31/22*	*3/31/22*
6.0 Solid Fuel Characterization	**4/1/22**	**10/31/22**
6.1 Solid fuel characterization complete	10/31/22	10/31/22
7.0 Blended Fuel Gasification Kinetic Study	**6/1/22**	**8/31/22**
8.0 Bench Scale Gasification Study Using 1.5" ID Drop Tube Reactor	**9/1/22**	**4/15/23**
8.1 Completion of gasification kinetic studies	*4/15/23*	*4/15/23*
9.0 FactSage Simulation	**6/1/22**	**1/31/23**
10.0 Gasification on 1 TPD Gasifier	**8/1/22**	**7/31/23**
10.1 Operation Plan	**8/1/22**	**9/30/22**
10.2 Slurry Preparation	**10/1/22**	**4/30/23**
10.2.1 >600 kg blended solid fuel prepared	*4/30/23*	*4/30/23*
10.3 Operation	**5/1/23**	**5/31/23**
10.3.1 Gasification complete on the 1 TPD entrained flow gasifier	*5/31/23*	*5/31/23*
10.4 Data Analysis	**6/1/23**	**7/31/23**

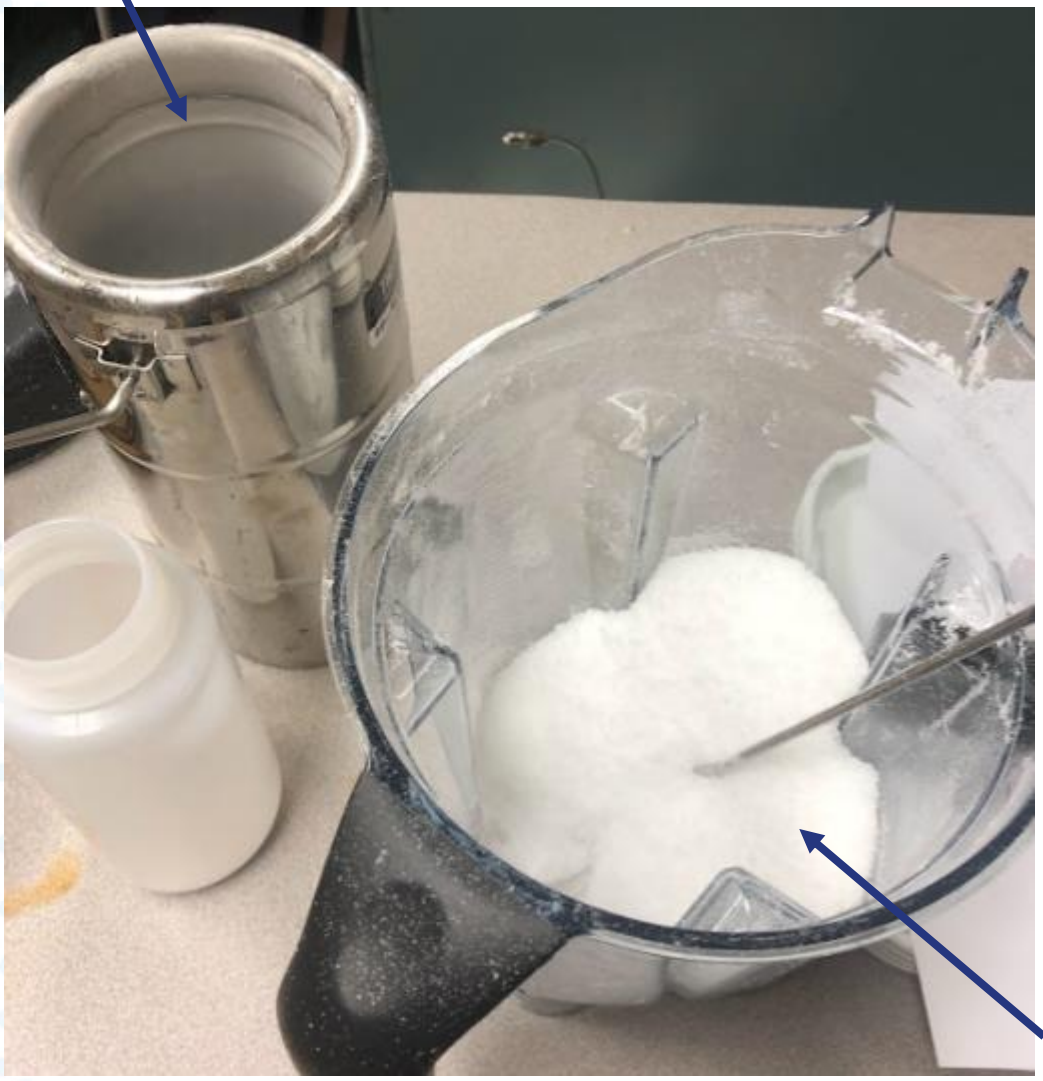


Budget Period 1							
FY2021		**FY2022**		**FY2023**		**Total**	
DOE Funds	**Cost Share**	**DOE Funds**	**Cost Share**	**DOE Funds**	**Cost Share**	**DOE Funds**	**Cost Share**
$31,030	$26,597	$257,136	$70,130	$211,834	$28,832	$500,000	$125,559
54%	46%	79%	21%	88%	12%	80%	20%

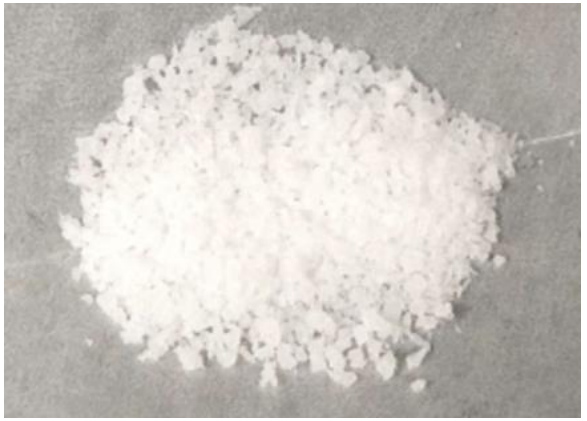
Lab-scale Proof of Concept Studies

Liquid N_2

Cryogenic Milling



Biomass-HDPE Pellets



HDPE powder

Pellet Bulk Density

Sample	Component Size (inch)	Component Blend Plastic:Biomass (HHV Basis)	Bulk Density (g/cm^3)
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

Densities increase with addition of plastic

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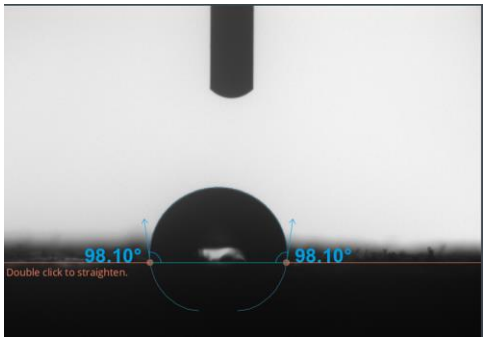
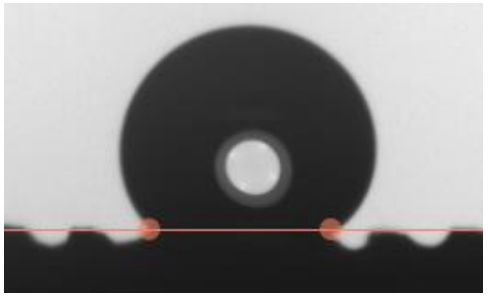
Hydrophobic Surface

Water droplet contact angle measurements

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





Most blends of biomass and plastic have contact angles greater than 90° to signify hydrophobicity

Water Uptake

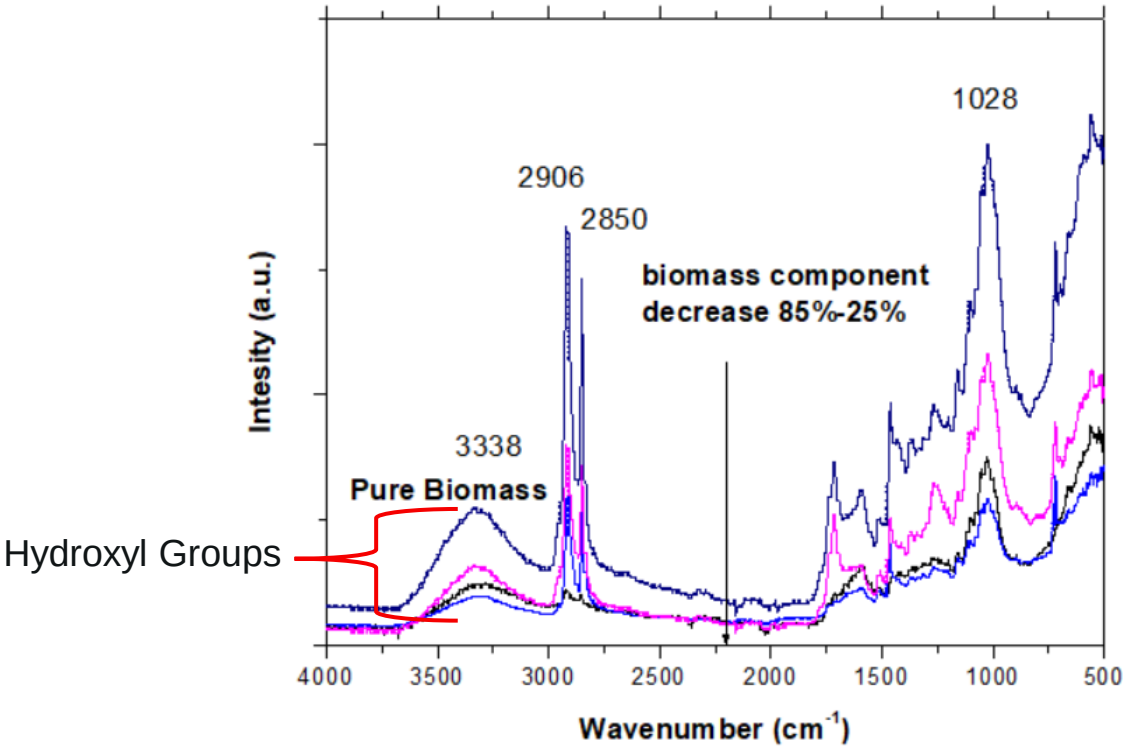
Less than 10% in mass for the plastic blends after 8 hours of submersion

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

The addition of plastic to the biomass significantly reduces the amount of water uptake

Surface Chemistry

ATR FTIR



The addition of plastic reduces the area of the peak associated with hydroxyl groups

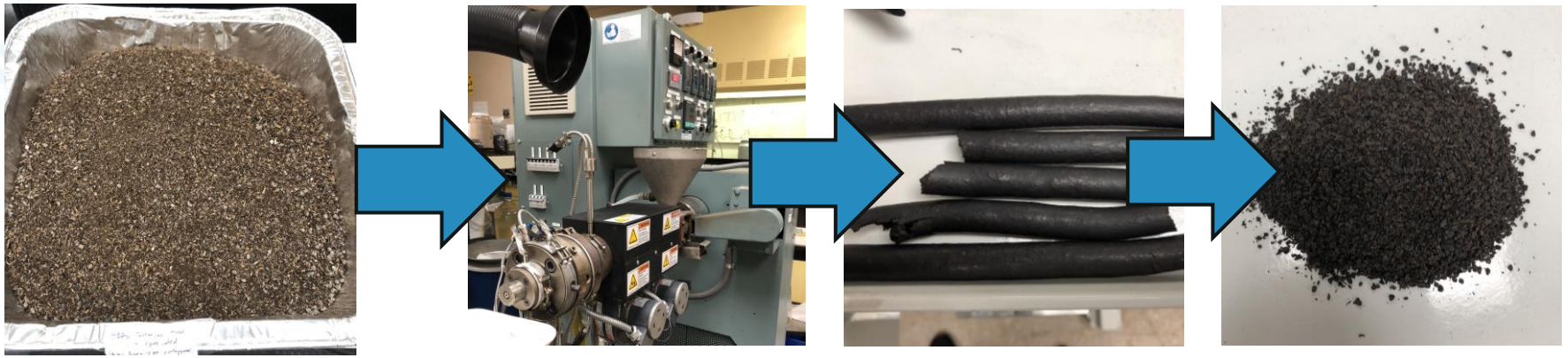
Solid Fuel Characterization

Heating value and ash composition

Sample	BTU/Lb	%Ash	%Carbon	%Volatile Matter	%Fixed Carbon
HDPE:TW 1:4	9604	1.14	53.91	72.58	20.15
Coal	11487	11.59	66.48	36.69	48.4

Biomass-plastic blend has a heating value close to coal and significantly lower ash and fixed carbon.

Large Quantity Production -
Plastic Biomass Co-extrusion



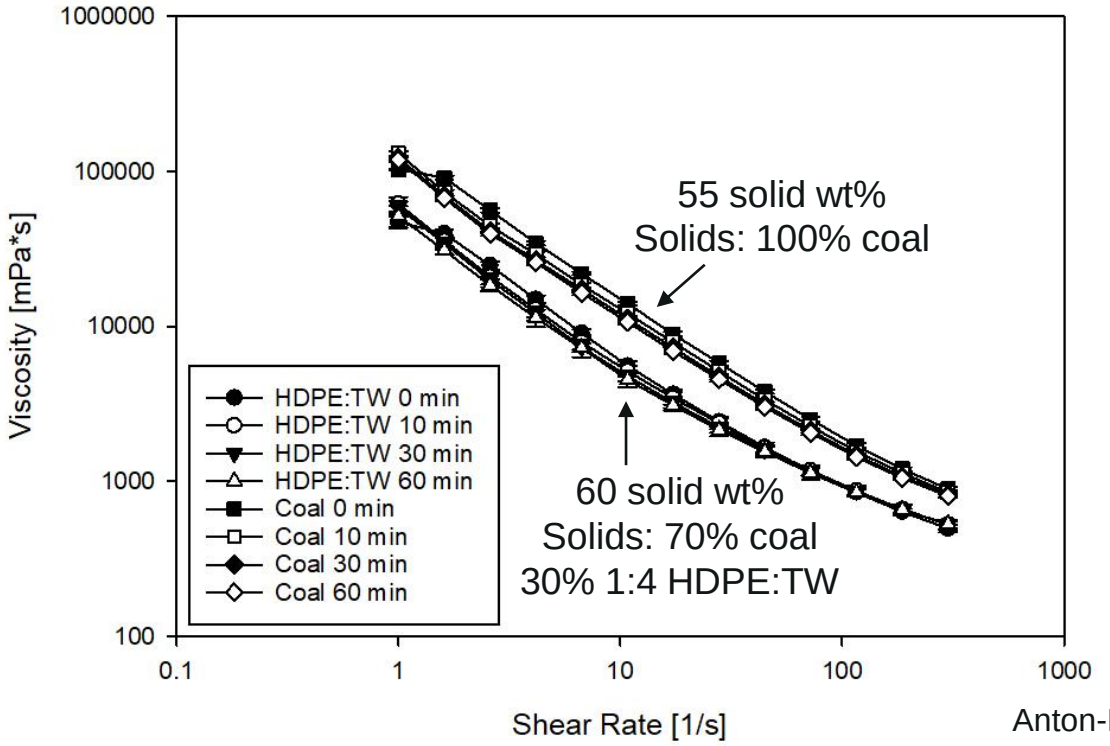
HDPE:Torrefied wood (1:4 ratio)

Extruder

The bulk of material for the 1 TPD gasification will be produced by the Polymers Center in Charlotte, NC

Slurry Characterization

Goal: Lower viscosity than coal-water slurry at similar weight percents

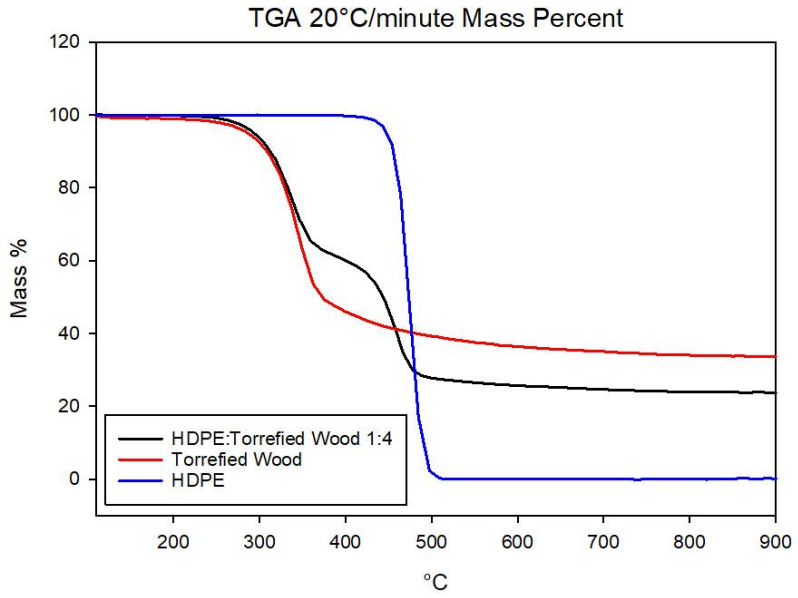


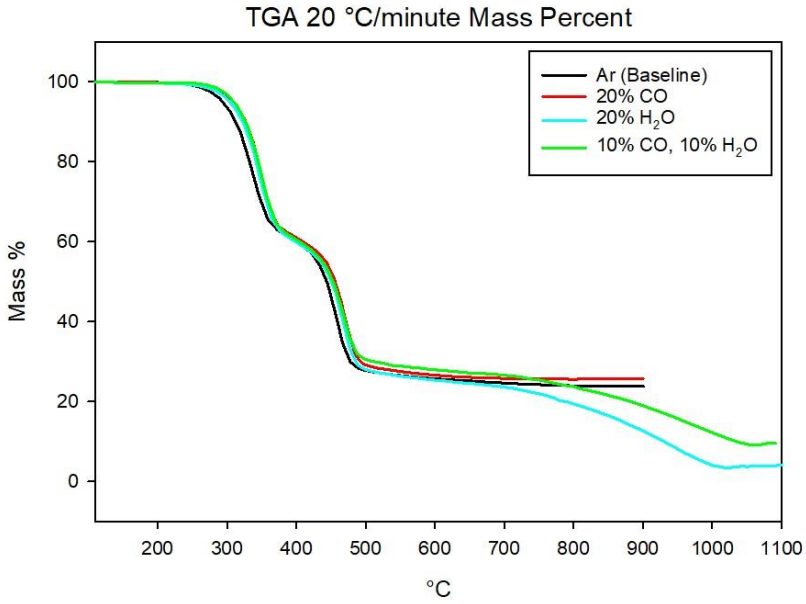
Anton-Paar GmbH Rheometer

Inclusion of plastic biomass blend decreased the viscosity of the slurry with a higher solid wt%

Blended Fuel Kinetics

Thermogravimetric Analysis

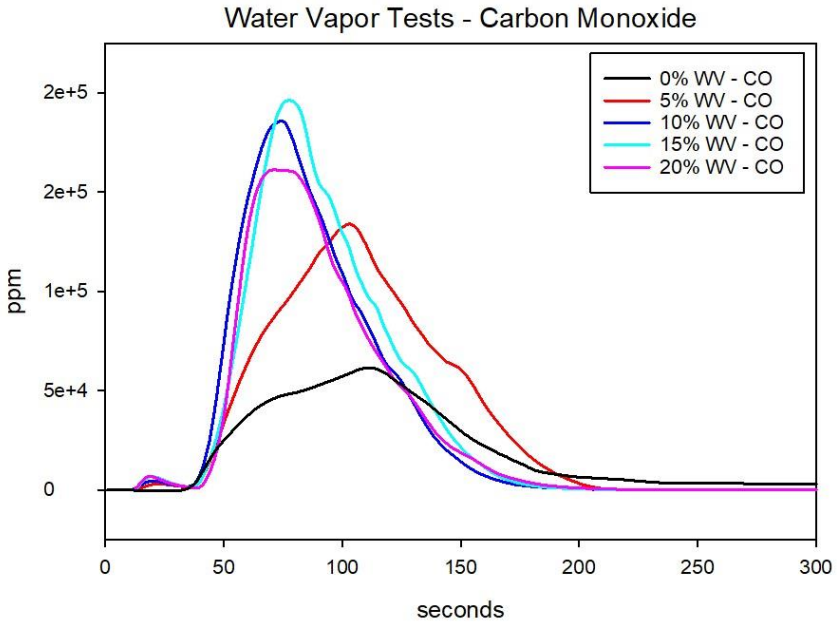




Biomass and plastic have two distinct thermal decomposition points. These are maintained when blended. Altering the gas environment during decomposition causes slight shifts in these peaks.

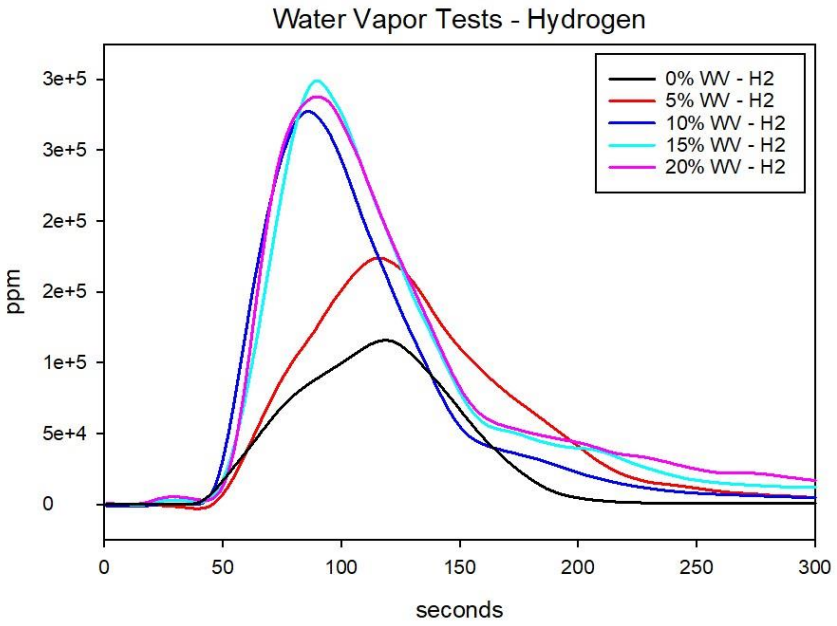
Bench Scale Gasification

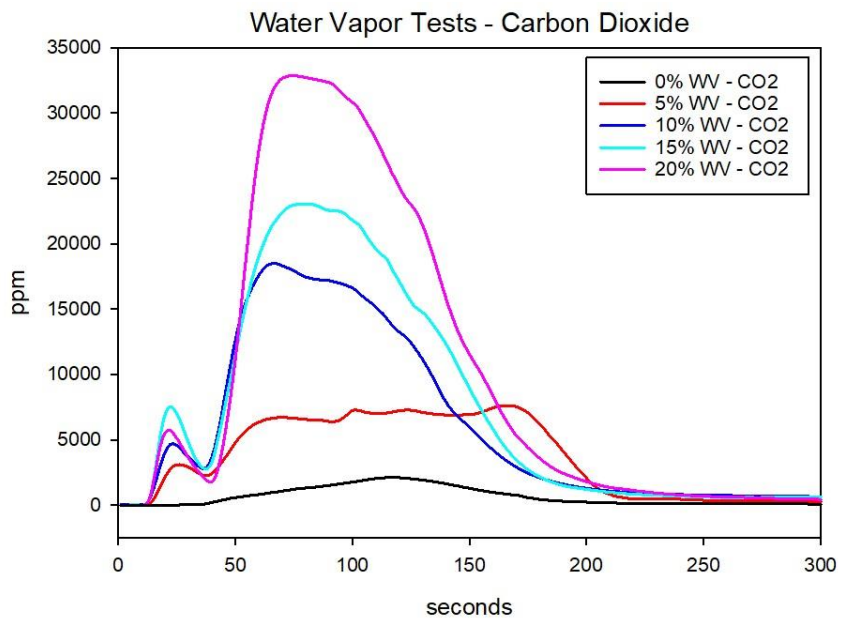
Drop tube furnace



Blended fuel is dropped into the reactor at 1100 °C
Gas environments include increasing concentrations of water vapor in mostly nitrogen.

The Moisture on Gasification

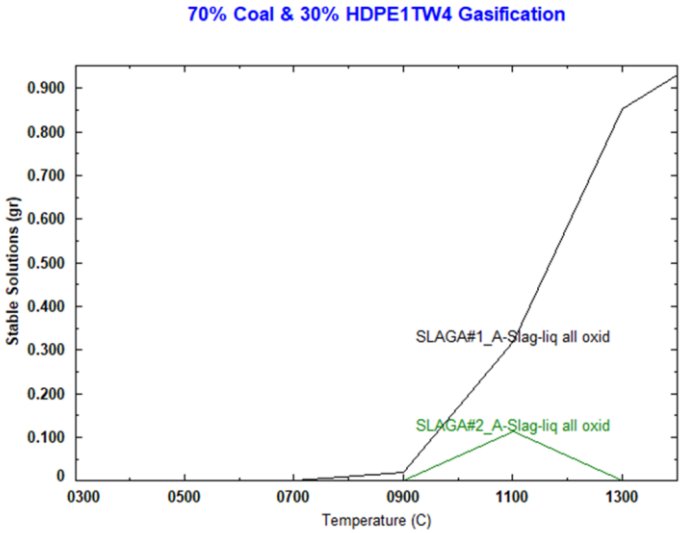




An optimal gas environmental: 15% Water vapor produces the most CO and H_2 with less CO_2 production than 20% water vapor

FactSage Simulation

Slag composition



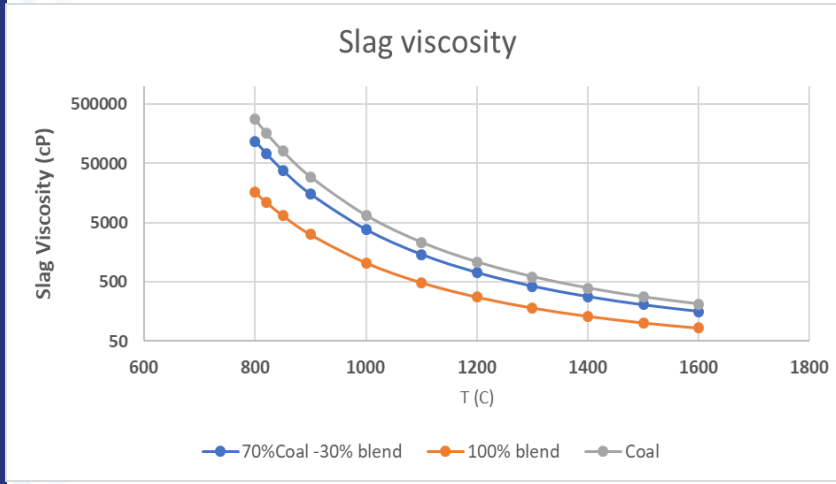
Co-gasification of coal and biomass-plastic blend produce two distinct slags

Ash fusion temperature using two different methods

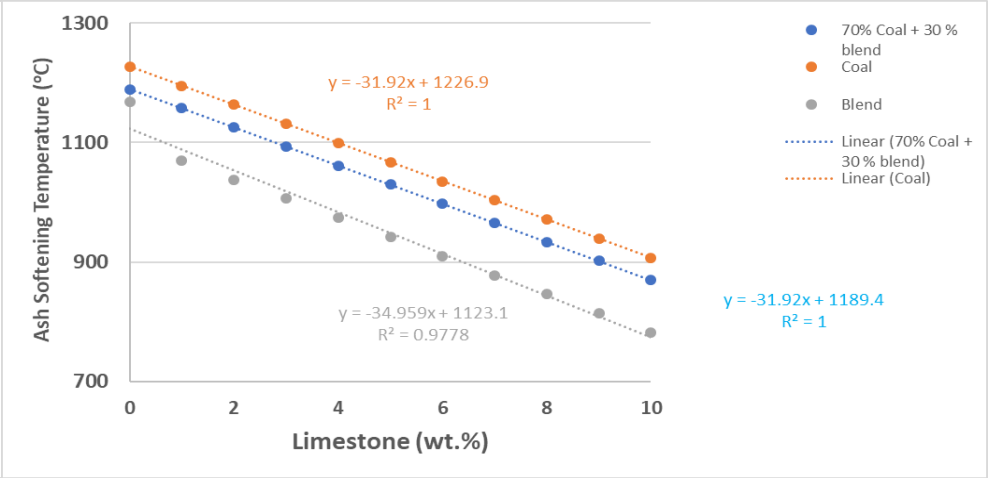
Fuel	FT (Aijun Dai)	FT (Vincent)
Coal	1229.97 °C	1257.46 °C
BFNC	1213.18 °C	1275.88 °C

FactSage Simulation

Slag viscosity



Watt *et al.* model for the "high-T slag viscosity prediction"



Yin *et al.* model for the "Ash Softening Temperature (AST) prediction"

- **w/o limestone**
  - Anorthite
  - Hematite
- **2 wt% limestone**
  - Hematite
  - Anorthite
- **4 wt% limestone**
  - Hematite
- **6 wt% limestone**
  - $CaSO_4$
  - $K_2Ca_2(SO_4)_3$
- **9 wt% limestone**
  - Rankinite
  - Gehlenite
  - $K_2Ca_2(SO_4)_3$
  - $CaTiO_3$

Pilot Scale Gasification

1 TPD entrained flow gasifier

Testing of co-gasification of coal and the biomass-plastic blend will be conducted later this year

Milestones and Success Criteria

Task	Milestone	Completion Date
1.1	PMP Updated	7/14/21
3.0	Densified biomass produced with at least 20% improvement of hydrophobicity and density	12/17/21
4.0	Plastic encapsulated biomass demonstrated	12/17/21
5.0	Acceptable Coal/biomass/plastic Solid Fuel Slurry Demonstrated	2/22/22
6.0	Solid Fuel Characterization Complete	11/15/22
8.0	Completion of Gasification Kinetic Studies	
10.2	> 600 kg blended solid fuel prepared	
10.3	Gasification Complete on the 1 TPD Entrained Flow Gasifier	
1	Final Project Report Complete	

Comple-tion Date	Success Criterion
3/31/22	Demonstration of blended solid fuel slurry with 60 wt% solids and comparable heat value to 100 % coal water slurry.
	Collection of gasification kinetic data and identification of preliminary operating conditions.
	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.

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