


FLUIDIZED-BED GASIFICATION OF COAL-BIOMASS-PLASTICS FOR HYDROGEN PRODUCTION

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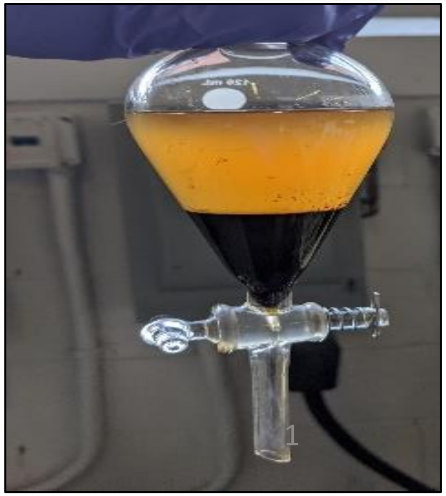


RESEARCH OBJECTIVES

- The **main objective** of this research is to examine the gasification performance of coal, waste plastics, and southern pine mixture in a laboratory-scale fluidized-bed gasifier for the hydrogen production.

- Specific objectives:
  1. coal-plastic-biomass mixture flowability
  2. gasification behavior of the mixtures for hydrogen production
  3. characterization of ash/slag and interaction between slag/ash and refractory materials; and
  4. process model(s) for hydrogen production cost.

OBJECTIVE 1

- This objective is focused on understanding the flow behavior of the mixture at various proportions.

- The **expected outcome** of this objective is that we will be able to understand if three feedstocks can be blended for consistent feeding or not. The study will also highlight the associated challenges (if any) of feeding feedstock blends in the gasifier.

Sample Preparation

Hammer mill at AU

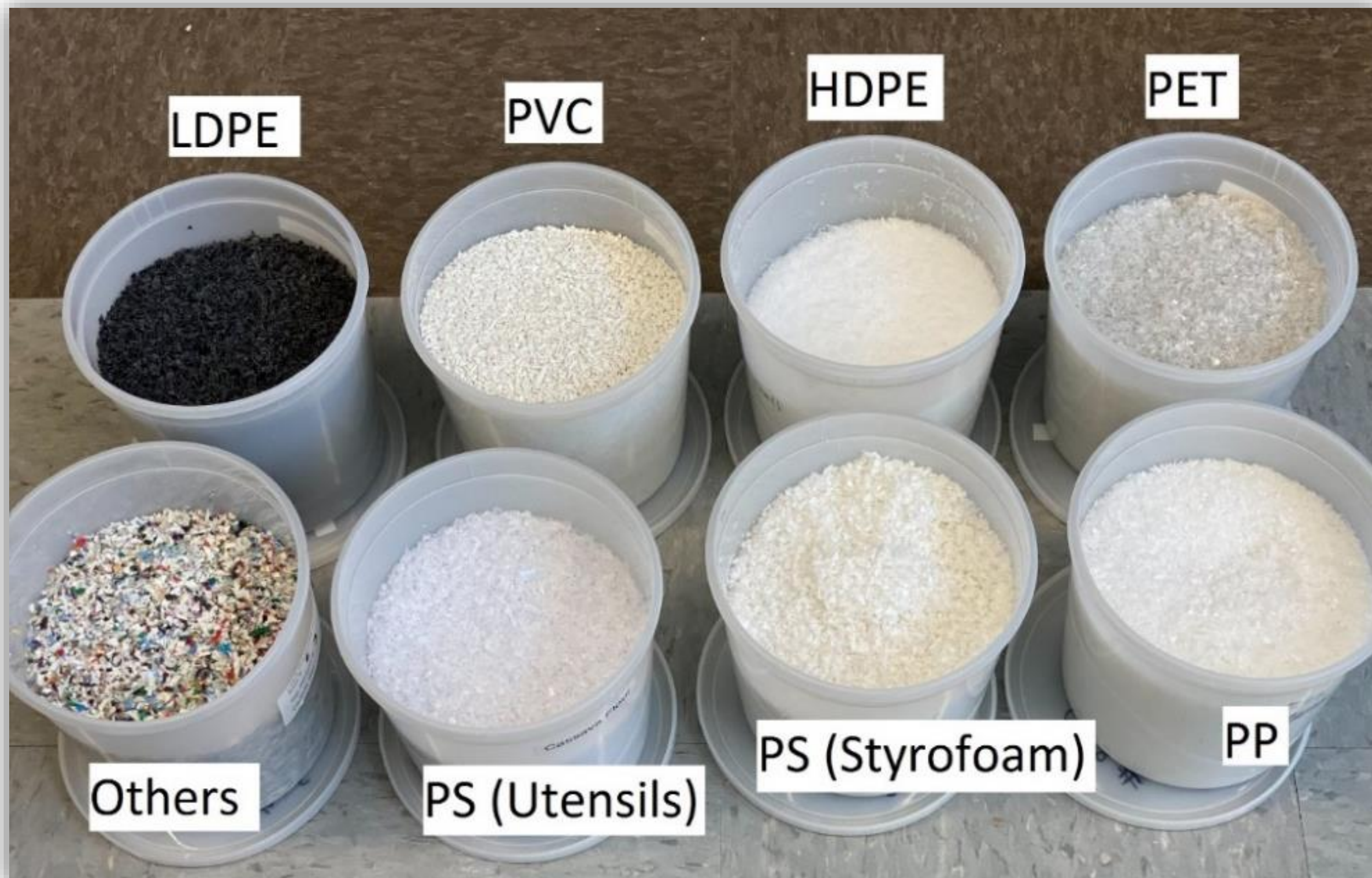
Plastic shredder

Vibratory screen separator

Cryogenic Grinder

Preparation of Plastic Samples

- **The plastic samples were shredded using a plastic shredder, sieved and ground using cryogenic grinder for many analyses.**

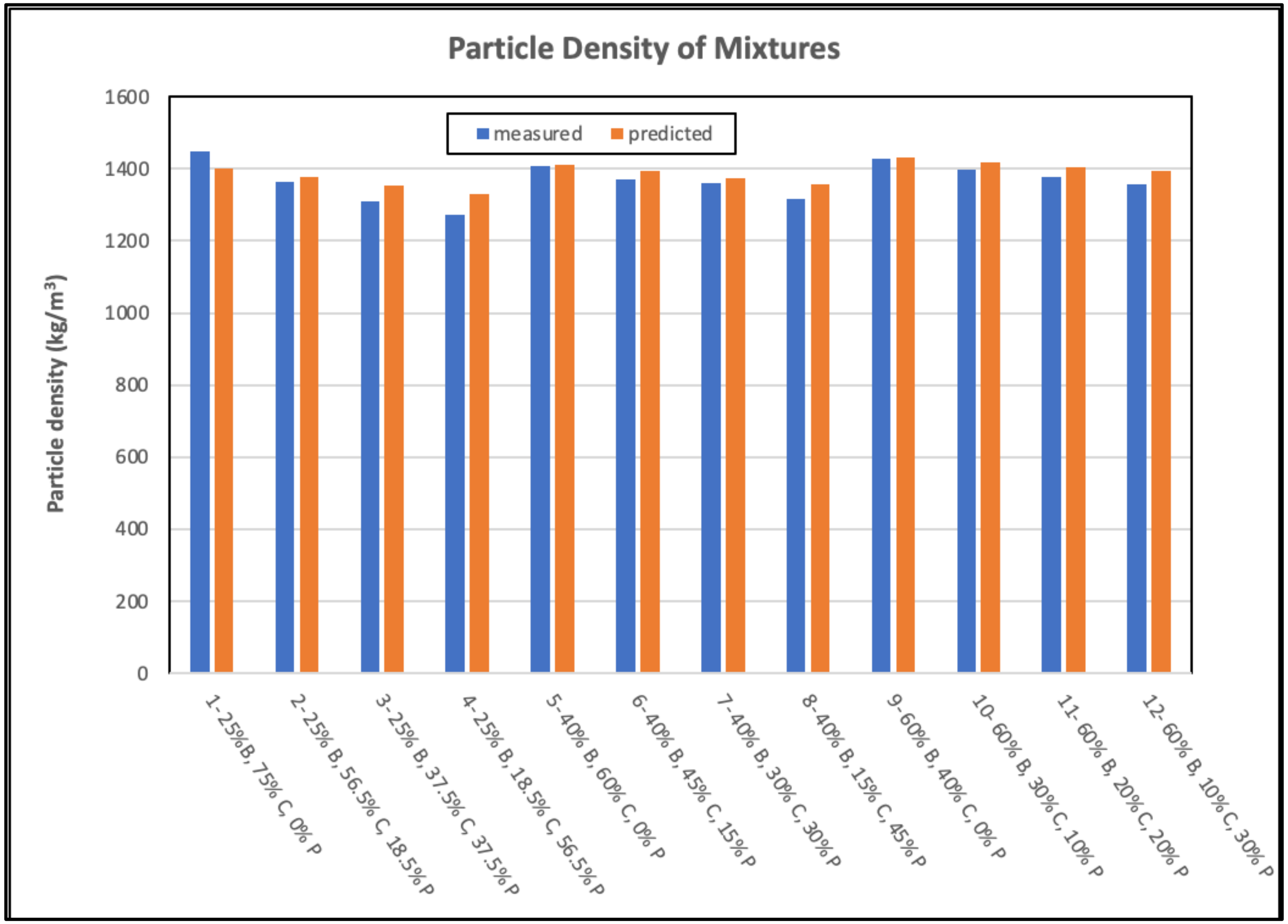


Density[a] and Flowability

Name	Bulk Density, kg/m³	Tap Density, kg/m³	Particle Density, kg/m³	Flowability (Flow Index)
#1 PET	358	458	1369	Easy Flowing
#2 HDPE	323	398	953	Easy Flowing
#3 PVC	596	681	1416	Easy Flowing
#4 LDPE	87	210	1157	Cohesive
#5 PP (Food cups)	308	374	909	Easy Flowing
#6 PS (Styrofoam)	43	53	1026	Cohesive
#6 PS (Cutlery)	421	499	1065	Easy Flowing
#7 Others	471	551	1194	Easy Flowing
Coal (AL Co-Op)	691	1035	1423	Cohesive
Biomass	231	284	1461	Cohesive
Mixed Plastics	475	550	1107	Easy Flowing

[a]Coefficient of variation is less than 5%

PARTICLE DENSITY OF MIXTURES



Particle density of mixtures from samples screened through 2-4 mm sieves

$$\rho_{pm} = \sum_{i=1}^{3} x_i \rho_{pi}$$

Percent relative deviation (%RE)

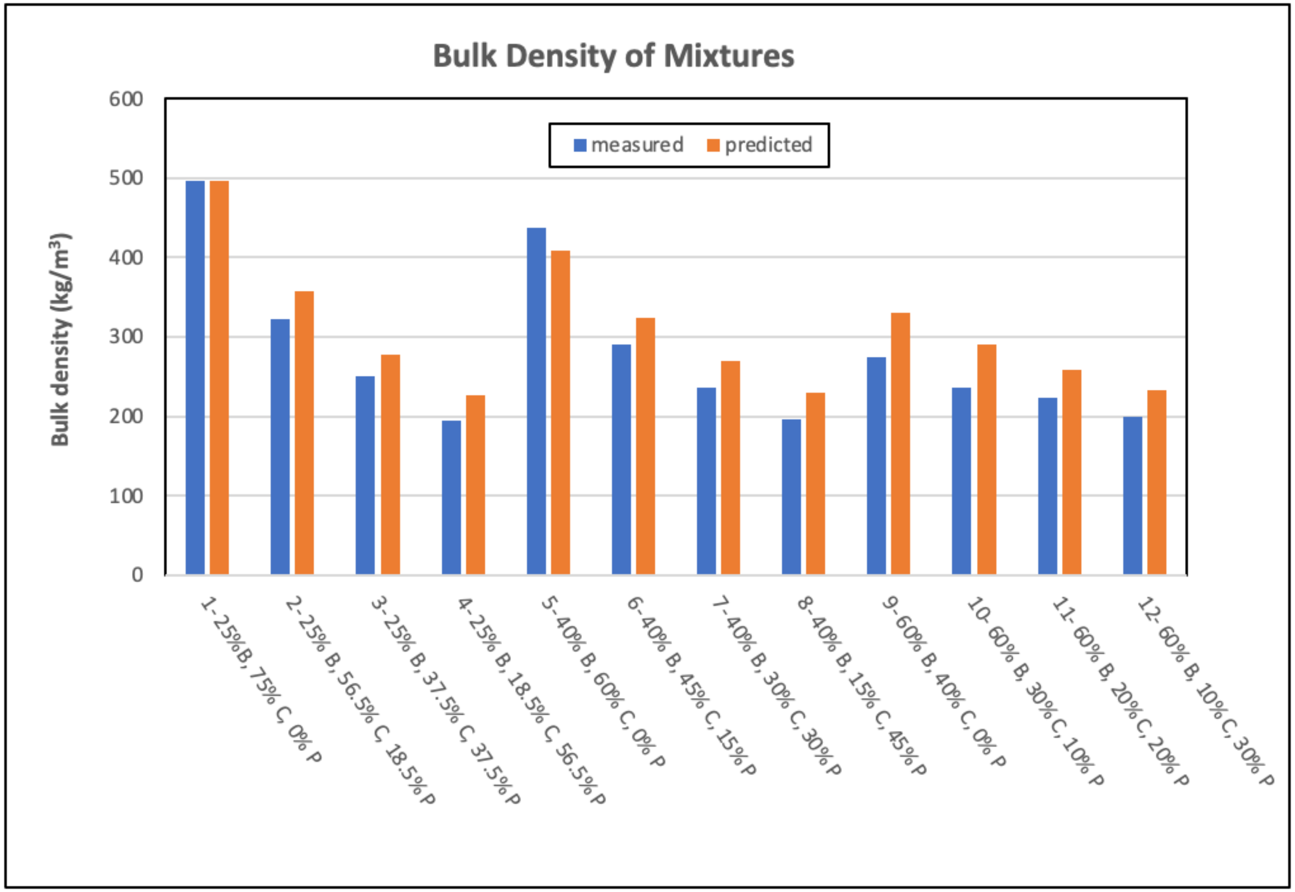
- Average: 1.47%
- Range: -3.44% to 4.55%

$$\%RE = 100x \frac{measured - predicted}{measured}$$

Note:

- *x_i is mass fraction*
- *Density of plastics was obtained from the above equation*
- *ρ_p is particle density (kg/m³)*

Bulk Density of Mixtures



Bulk density of mixtures from samples screened through 2-4 mm sieves

$$\frac{1}{\rho_{bm}} = \sum_{i=1}^{3} \frac{x_i}{\rho_{bi}}$$

Percent relative deviation (%RE)

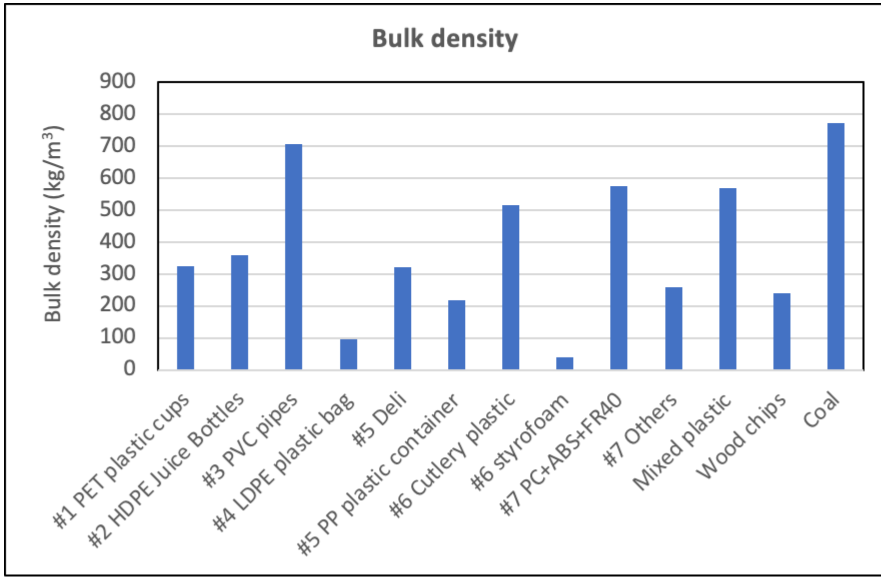
- Average: 12.44%
- Range: -6.57% to 22.69%

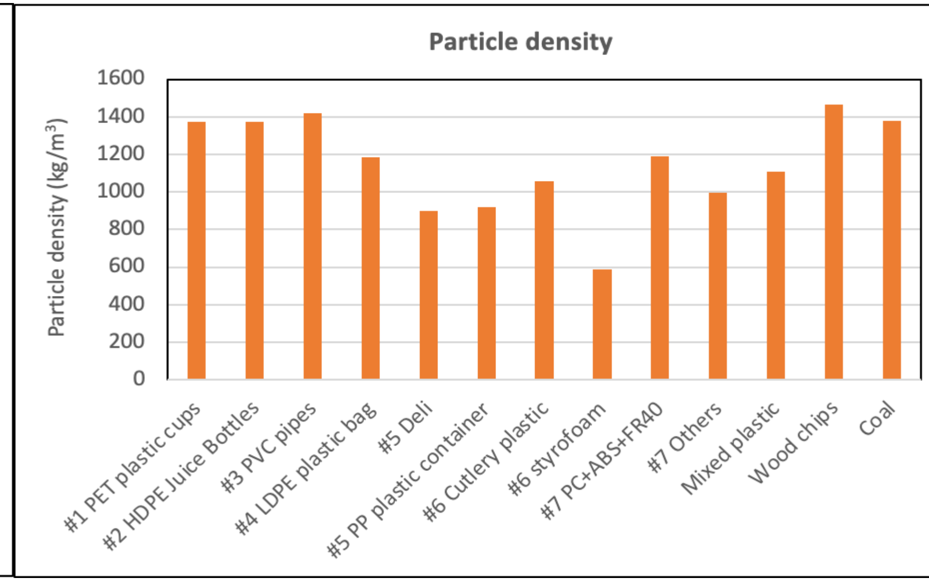
$$\%RE = 100x \frac{measured - predicted}{measured}$$

Note:

- *x_i is volume fraction*
- *Density of plastics was obtained from the above equation*
- *ρ_b is bulk density (kg/m^3)*

Bulk and Particle Density





Densities of plastics in plastic blends used for biomass/coal/plastic mixtures

Segregation Testing

- Developed according to ASTM D6490 Standard
- Apparatus was not suitable for mixtures
- Need samples with less than 300 microns even though standard mentioned maximum particle size limited to 3 mm
- Visual observation show that mixtures will likely not segregate

Objective 2

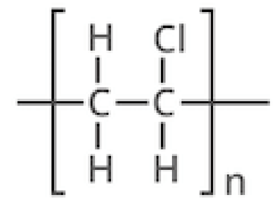
- The objective is focused on feedstock reactivity and laboratory-scale fluidized bed gasification to determine the syngas composition and contaminants under steam and oxygen gasification conditions.

- The **expected outcome** of this is to have better understanding about the <u>reactivity</u> of the mixture and also how <u>syngas composition</u> and contaminants are being impacted by various mixtures.

Proximate Analysis

Component	Ash [d.b., wt.%]	Moisture [w.b., wt.%]	Volatile Matter [d.b., wt.%]
#1 PET	0.38	0.25	94.03
#2 HDPE	0.03	0.13	97.12
#3 PVC	6.20	0.11	88.42
#4 LDPE	**24.32**	0.37	74.66
#5 PP	0.27	0.05	96.21
#6 PS (Utensils)	0.02	0.45	96.35
#6 PS (Styrofoam)	0.08	0.44	98.16
#7 Others	3.09	0.17	94.20
Biomass (Southern pine)	1.51	4.40	76.37
Lignite coal	28.28	0.57	35.44

- **Among the samples, LPDE (#4) and coal samples showed the highest ash content.**



Calorific Value

Component	Plastic Composition in MSW [%]	Heating Value[MJ/kg] (Btu/lbm)
PET	40%	**22.98 (9,880)**
HDPE	18%	**46.31 (19,909)**
PVC	6%	**14.52 (6,242)**
LDPE	18%	**34.52 (14,841)**
PP	2%	**45.36 (19,501)**
Polystyrene (Utensils)	8.40%	**40.87 (17,571)**
Polystyrene (Styrofoam)	3.60%	**41.63 (17,897)**
Other plastics	4%	**35.69 (15,344)**
Mixed plastics		**31.94 (13,731)**
Biomass (Southern Pine)		**18.92 (8,134)**
Coal		**29.95 (12,876)**

❖ **Among all the samples, PVC (#3) has the lowest heating value.**

Ultimate Analysis

Component	N [wt.%]	C [%]	H [%]	S [%]	Cl [%]
#1 PET	N.D.	61.32	4.15	0.16	N.D.
#2 HDPE	N.D.	82.54	14.96	0.08	N.D.
#3 PVC	0.06	**38.86**	5.24	0.59	**43.7**
#4 LDPE	N.D.	67.91	11.40	0.16	0.105
#5 PP	N.D.	82.60	14.96	0.06	N.D.
#7 Others	0.35	73.75	11.02	0.04	0.093
Mixed plastics	0.0	74.68	8.38	0.08	**1.55**
Biomass (Southern pine)	0.01	49.67	8.22	0.03	0.007
Coal	1.57	66.59	4.09	1.16	0.015

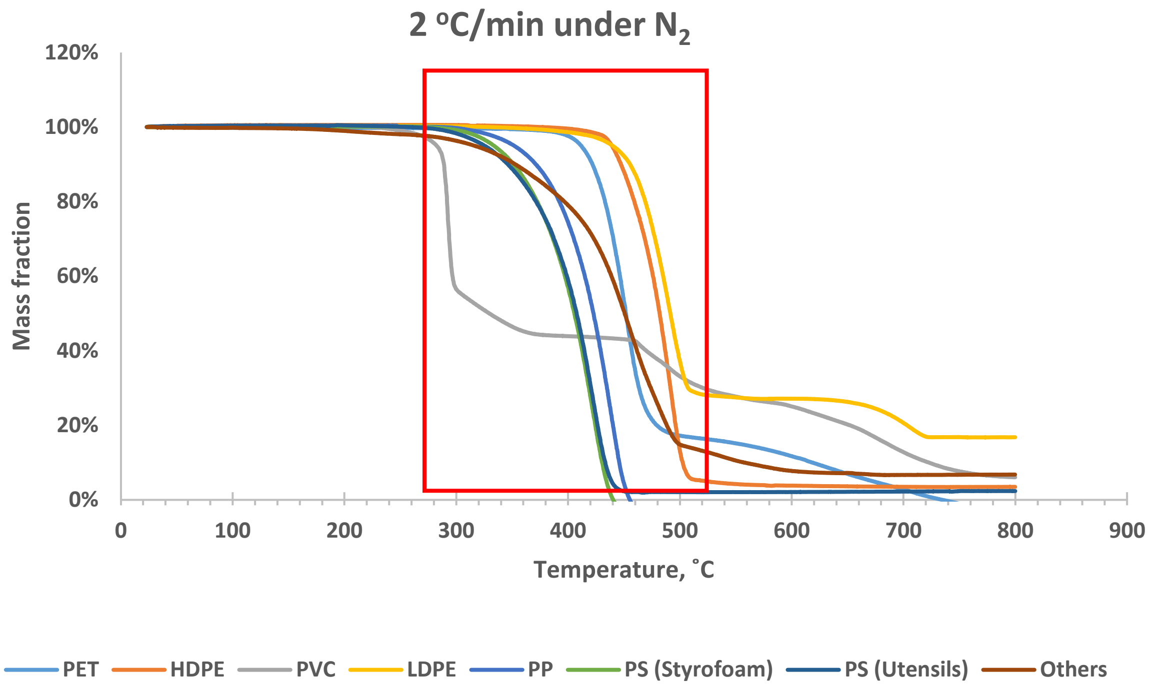
N.D.: Not Determined or Not Detected

Ash Fusion Temp (Reducing Atmosphere)

Component	Initial Temp. °F (°C)	Softening Temp. °F	Hemispherical Temp. °F	Fluid Temp. °F
#3 PVC	2247 (1230)	2390	2422	2460
#4 LDPE	+2700 (1482)	+2700	+2700	+2700
#7 Others	2303 (1261)	2307	2319	2324
Mixed plastics	2610 (1432)	2616	2621	2623
Biomass (Southern pine)	2105 (1151)	2126	2132	2145
Coal	2349 (1287)	2390	2397	2420

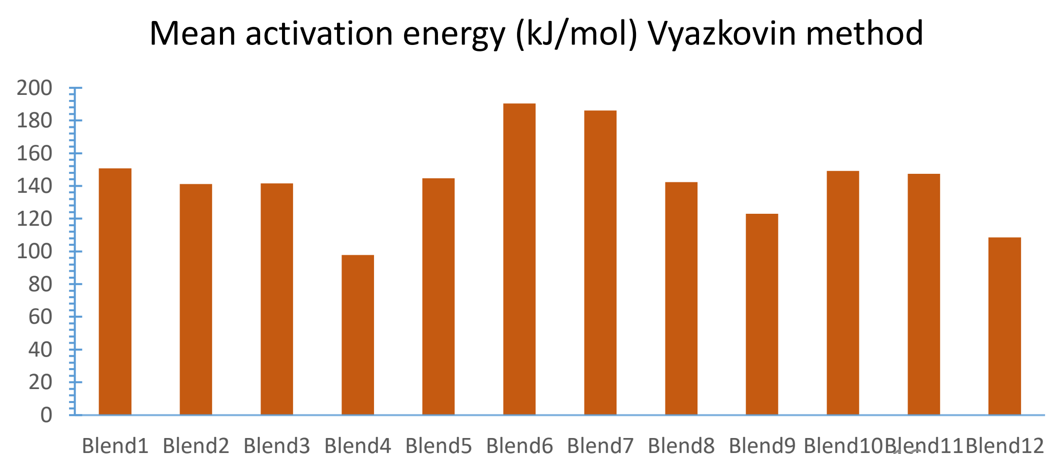
- **Ash fusion temperature is higher than 1150 °C; we do not anticipate of slagging during gasification runs in our set-up.**

TGA & Activation Energy



Distribution based on Energy content			
Blend No.	Coal	Plastics	Biomass
1	75.00%	0.00%	25.00%
2	56.25%	18.75%	25.00%
3	37.50%	37.50%	25.00%
4	18.50%	56.50%	25.00%
5	60.00%	0.00%	40.00%
6	45.00%	15.00%	40.00%
7	30.00%	30.00%	40.00%
8	15.00%	45.00%	40.00%
9	40.00%	0.00%	60.00%
10	30.00%	10.00%	60.00%
11	20.00%	20.00%	60.00%
12	10.00%	30.00%	60.00%

- **Decomposition starts ~280 °C and completes ~ 500 °C.**
- **Blend 4 showed the lowest activation energy.**



EXPERIMENTAL SETUP (GASIFICATION)

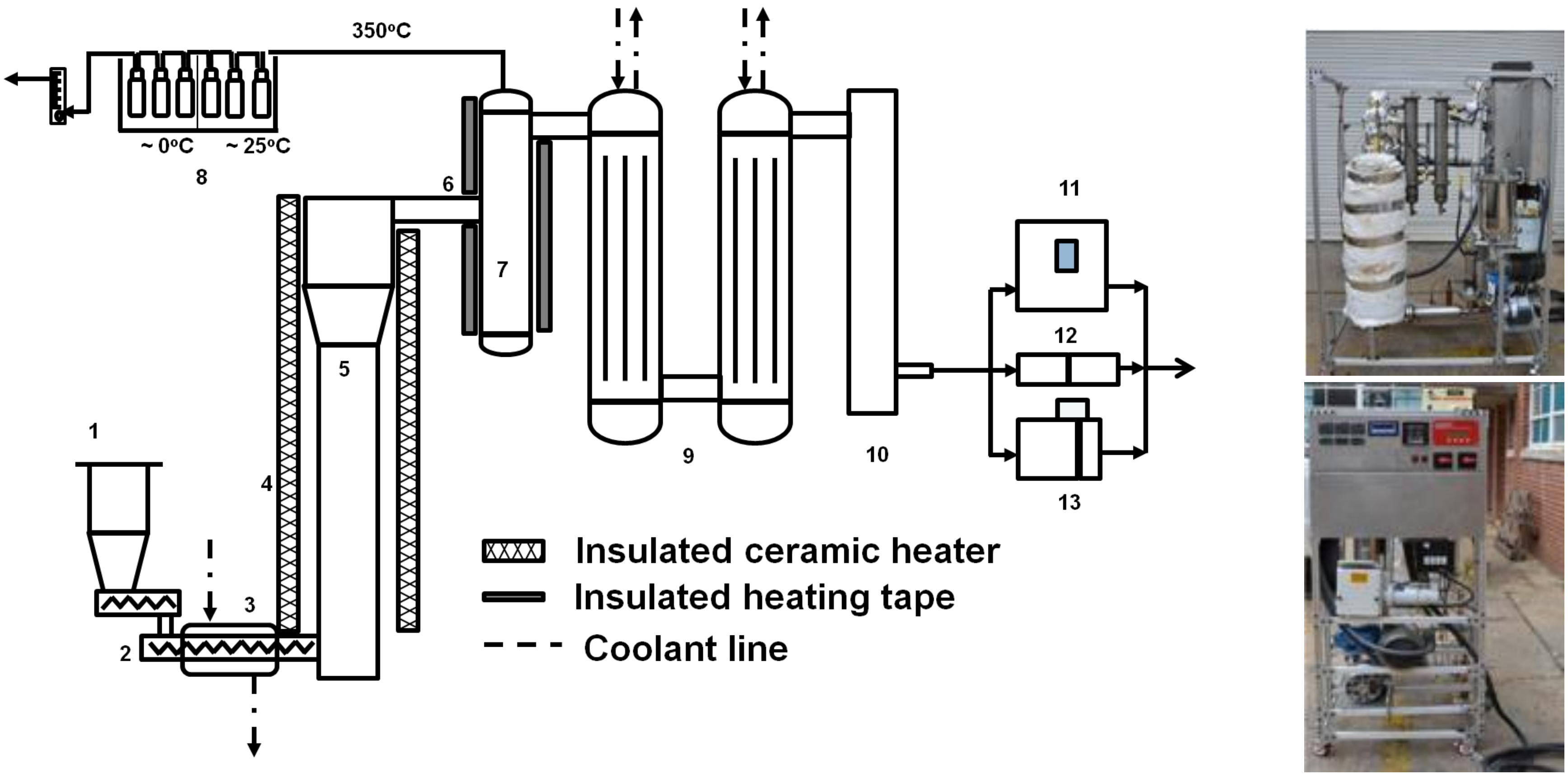


Figure . Experimental setup **1.** Hopper, **2**. injection screw, **3.** heat exchanger, **4.** heaters, **5.** fluidized bed gasifier, **6.** filter heaters, **7.** high temperature filter, **8.** impingers for tar sampling, **9.** condensers, **10.** ESP, **11.** primary gas analyzer, **12.** FTIR gas analyzer and **13.** FPD GC

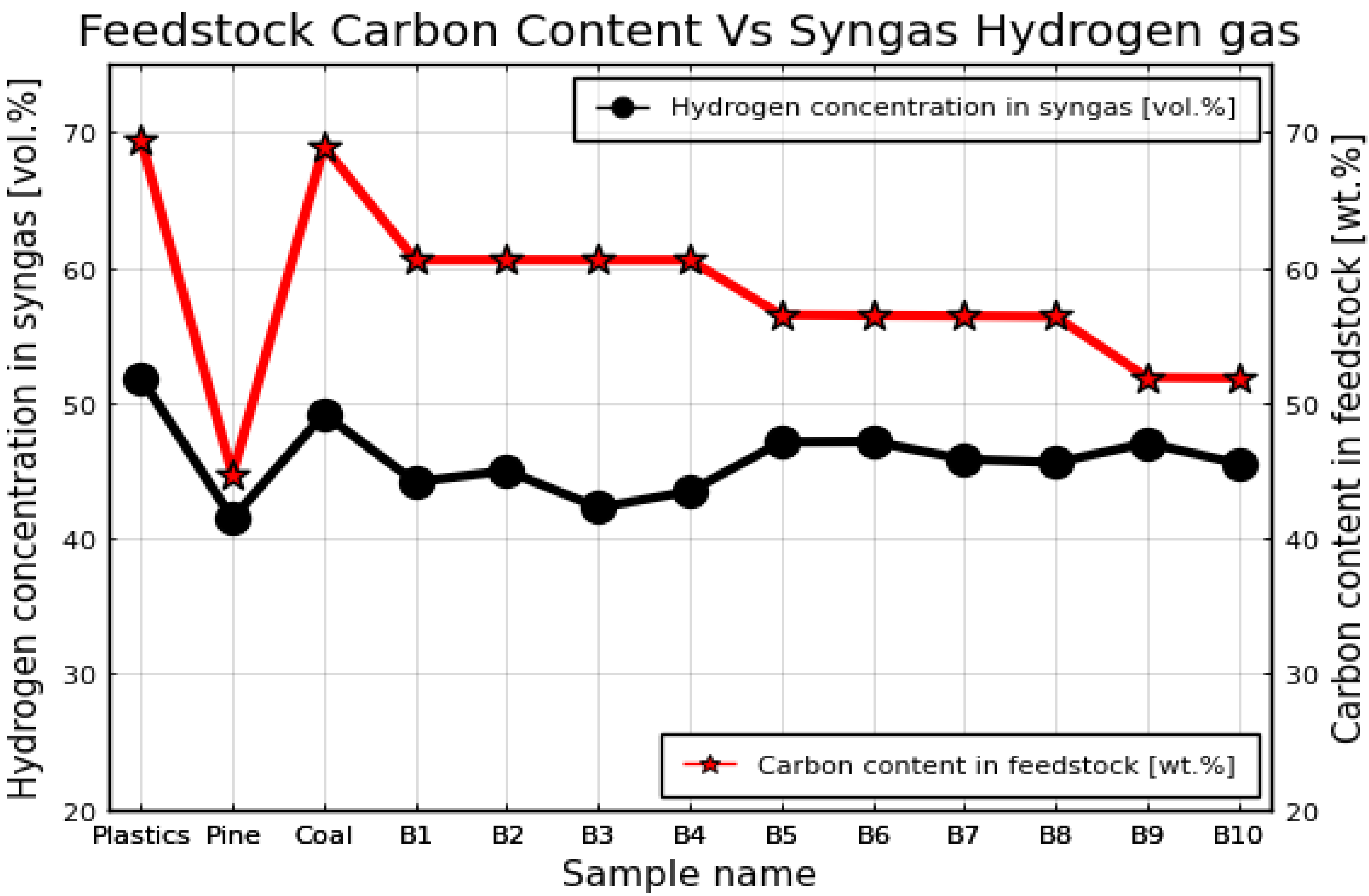
Syngas Composition (Nitrogen Free Basis)

Sample	H_2 (vol.%)	CO (vol.%)	CO_2 (vol.%)	CH4 (vol.%)	C2-C3 (vol.%)	H_2/CO
Plastic	51.86	29.79	12.83	4.62	0.85	1.74
Pine	41.43	31.84	14.47	7.28	4.85	1.30
Coal	49.18	25.26	21.20	4.02	0.32	1.95
Blend1	44.16	28.1	22.16	4.96	0.6	1.57
Blend2	44.99	29.02	19.70	5.71	0.57	1.55
Blend3	42.26	29.02	22.44	5.47	0.75	1.46
Blend4	43.45	28.46	19.46	7.30	1.31	1.53
Blend5	47.11	27.05	19.83	5.81	0.18	1.74
Blend6	47.14	26.75	18.24	7.46	0.37	1.76
Blend7	45.84	29.29	16.17	7.91	0.79	1.57
Blend8	45.60	29.99	16.03	7.62	0.75	1.52
Blend9	47.02	29.52	15.86	7.17	0.41	1.59
Blend10	45.53	30.42	15.99	7.46	0.59	1.50

Gasification Conditions

Bed Temperature (°C)	S/C	ER
920 - 970	3	0.2

FEEDSTOCK C VS HYDROGEN COMPOSITION



Objective 3

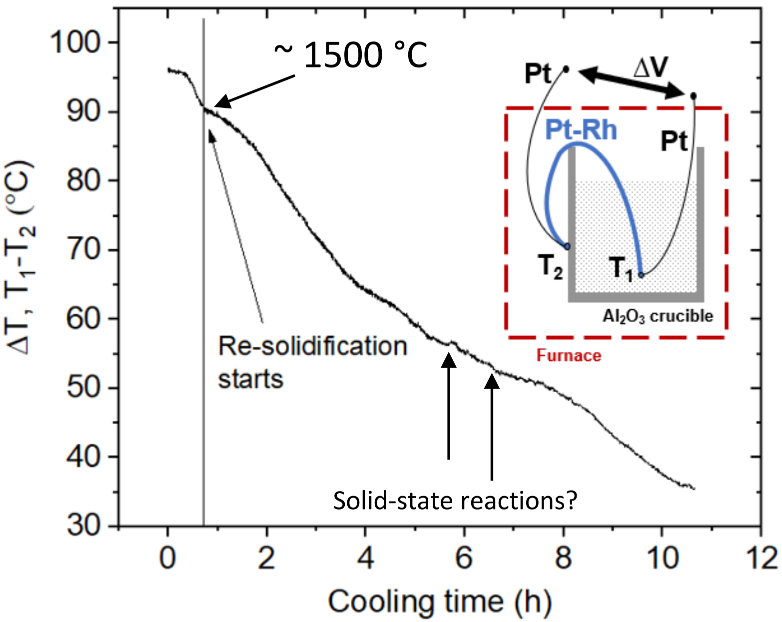
- The goal is to determine the slagging behavior of the mixtures. We will also determine the thermal conductivity of ash/slag, and flow property of slag at various temperatures.

- The **expected outcome** of this study is that we will understand how ash/slag properties are different when the mixture is gasified as compared to individual feedstocks.

Ash Melting and Slag Solidification Kinetics

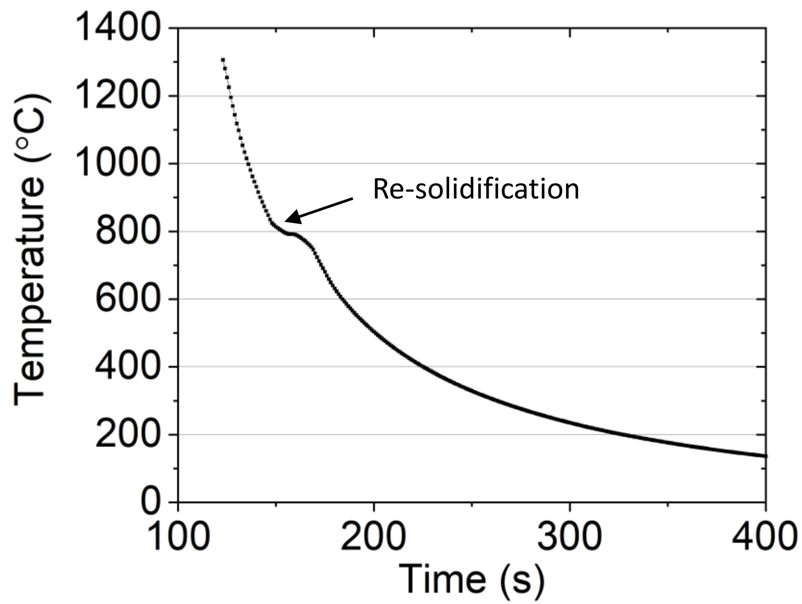
Method 1: Slow cooling.

2.4 °C/min cooling of molten coal slag.



Method 2: quenching (induction heater).

Quenching of molten NaCl in graphite crucible.



Quenching of slag samples in progress.

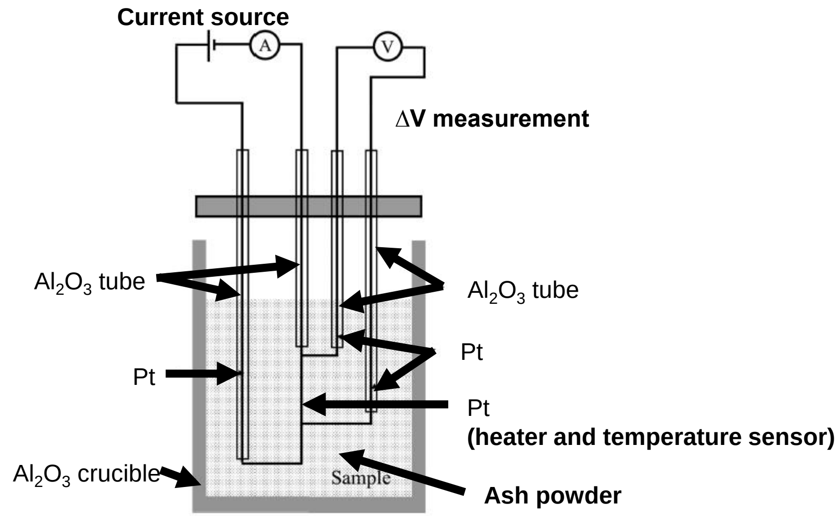
THERMAL CONDUCTIVITY MEASUREMENT

$$\Delta T = \frac{\Delta R}{R_{ref}\beta}$$ β: resistivity temperature coefficient

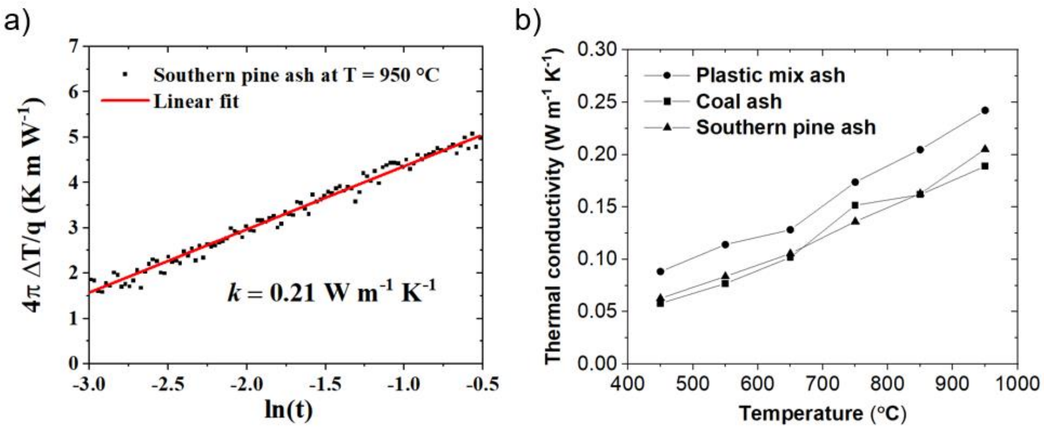
$$k = \frac{\dot{q}}{4\pi}\frac{d(\ln t)}{d(\Delta T)}$$ $\dot{q}$: heat generation rate per length $(= I^2 R_o / L)$

Thermal conductivity ($W\ m^{-1}\ K^{-1}$)

1 ms time inverval for 2 s.



Transient hot wire method
: a line heat source in an infinite medium



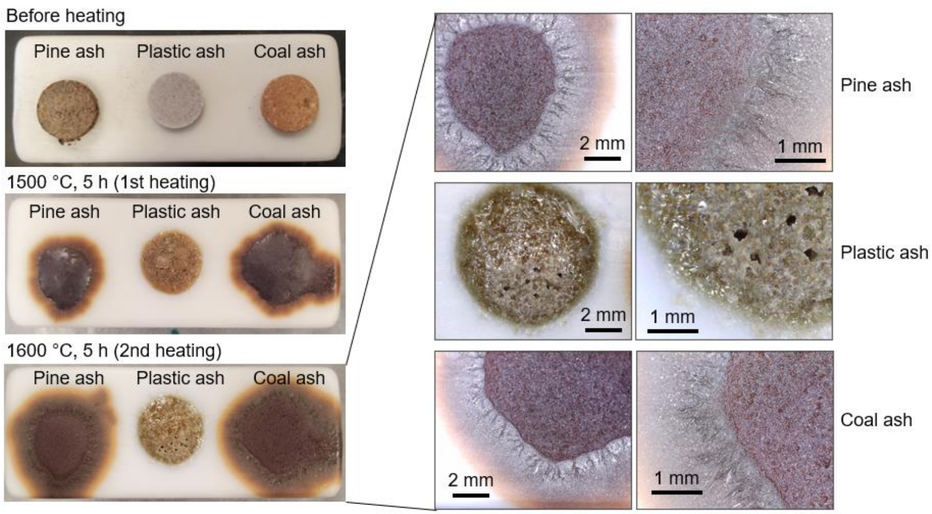
Plastic ash > Southern pine ash ~ Coal ash

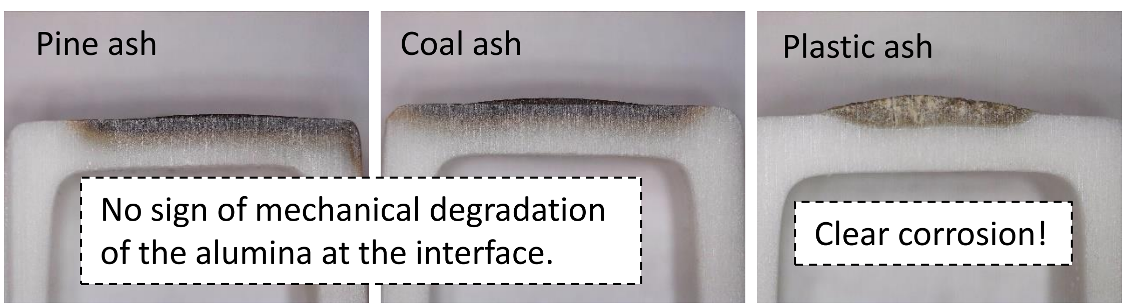
Synthetic molten ash without porosity
: $k \geq 0.5\ W\ m^{-1}\ K^{-1}$ at 950 °C.

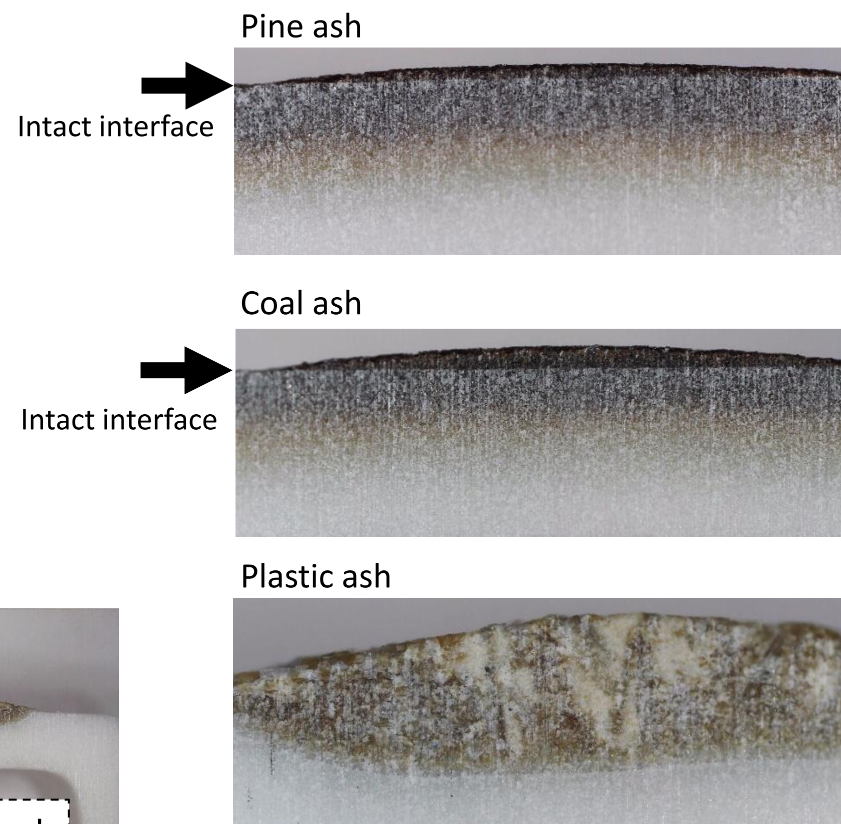
Figure 1. a) The wire temperature rise normalized by heat per wire unit length plotted against logarithmic time. Slope ~ 1/k. b) High temperature thermal conductivity values of three different ashes.

SLAG-REFRACTORY INTERFACE STUDY

Ash melting on the alumina surface.





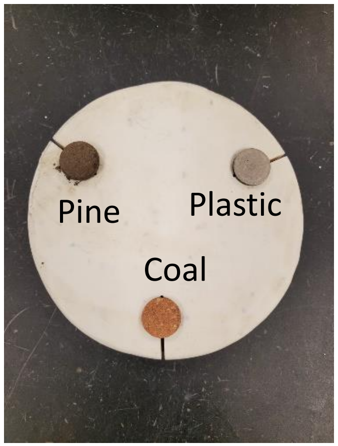


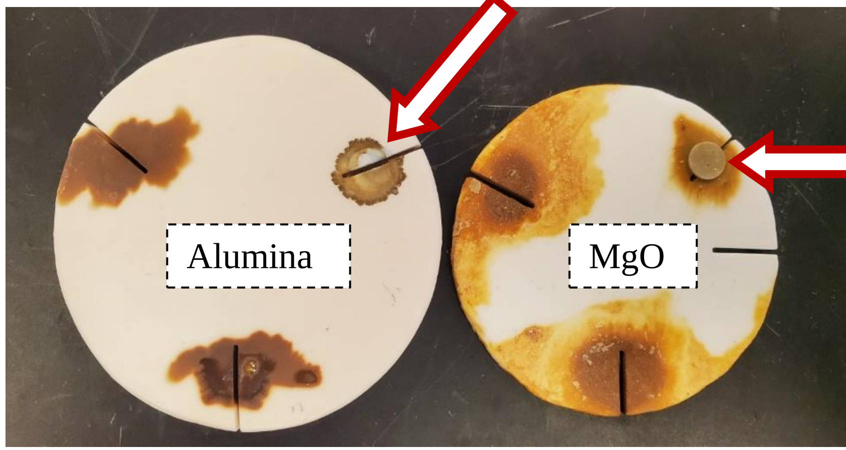
SLAG-REFRACTORY INTERFACE STUDY (CONTD.)

Plastic ash behaves very differently from alumina on MgO and yttria-stabilized zirconia.

1500 °C, 5 h

Corrosion dent already formed prior to gravity-driven slag flow.





“No” melting (plastic ash)

Plastic ash did “not” melt on yttria-stabilized zirconia, either.

All molten slags moved in and filled the 0.5 mm slit on alumina.

MgO-contacted plastic ash disc
YSZ-contacted plastic ash disc

} Both made corrosion dents on alumina (1500 °C, 5 h).

OBJECTIVE 4

- This study will inform researchers about the capital and operating costs of hydrogen production from selected wastes. The model will also compare various technologies that have shown promises for gas cleanup and conditioning with base case.

- The **expected outcome** of this study is that we will able to understand the cost of producing hydrogen and required process units.

Process Modeling- Goals, Approach & Update

- **Develop process models** to determine technologies needed for hydrogen production from coal, biomass and waste plastics gasification

- **Plant Case-based Approach**
  - A base-case plant is developed using the state-of-the-art technologies for gas cleanup, conditioning and hydrogen purification
  - An advanced-case plant is developed using RTI's emerging advanced syngas cleanup and conditioning technologies that provide process and economic benefits over conventional technologies

- **Process Modeling Task Update**
  - Base Plant: Process modeling and cost estimation has been completed
  - Advance Plant: Process modeling and cost estimation will be completed based on the gasifier performance data collected at Auburn University

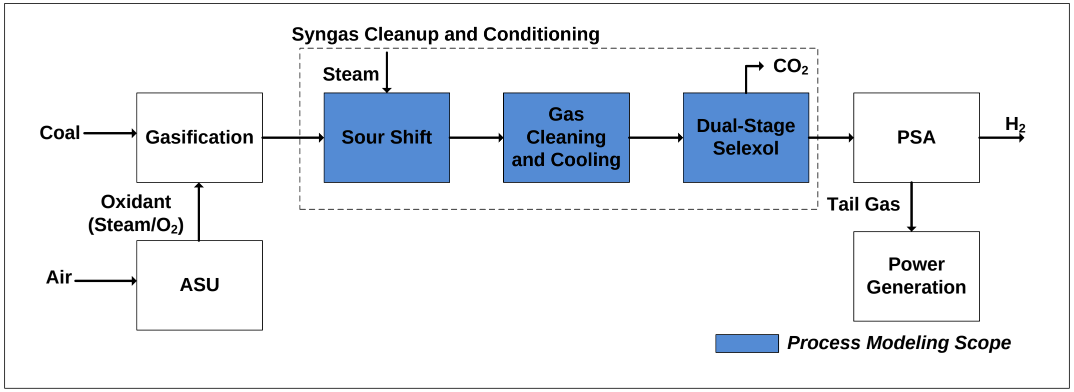
Base Case Plant Performance and Capital Cost Estimation

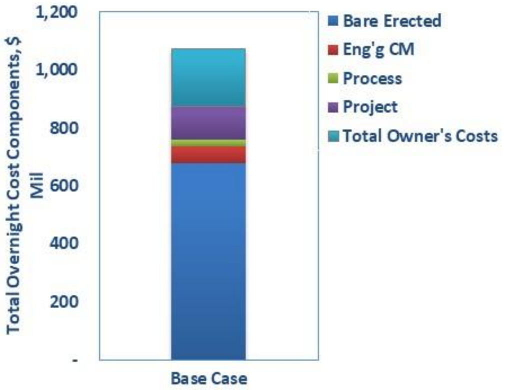
<u>Plant Performance</u>

- Plant Capacity: 2000 tpd of PRB coal is processed in oxygen-blown Shell gasifier.
- Produces 159,548 kg/day of hydrogen.
- Sour WGS process adjusts syngas composition to produce H_2-rich stream and performs COS hydrolysis.
- Gas Cleaning removes contaminants, such as HCl, mercury using disposable sorbent fixed-beds.
- Dual-Stage Selexol® removes acid gases- H_2S in first stage and CO_2 in second stage. 3,338 tons/day of CO_2 is captured. Captured CO_2 is compressed to approximately 2,215 psia and sequestered.
- PSA can achieve >99.99 vol% hydrogen purity.

<u>Capital Cost Estimation</u>

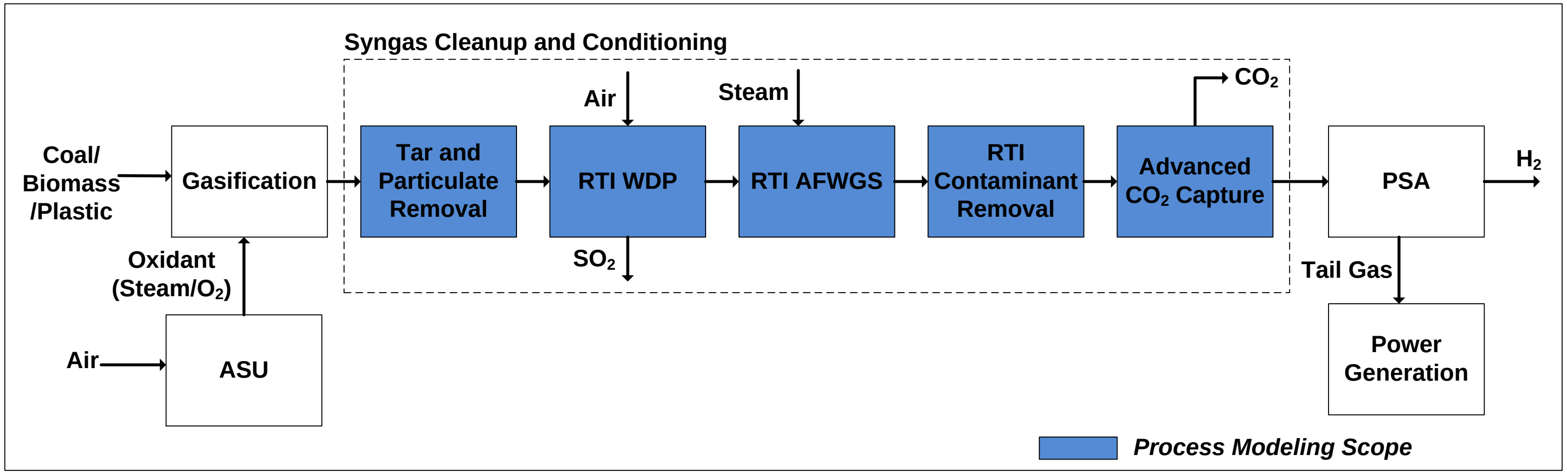
- Total overnight cost for the base plant was estimated to be $1,001 Mil.





Advanced Case Plant using Emerging Technologies

- Advanced Plant processes 2000 tpd of coal/biomass/plastic mixture as feedstock to produce hydrogen.
- Process Models for RTI's Emerging Syngas Cleanup and Conditioning Technologies have been completed
  - RTI's commercially available WDP process uses regenerable ZnO-based sorbent, lowers footprint and capital cost
  - RTI's advanced WGS process lowers steam consumption and provides capex reduction
  - Trace contaminants are removed in modular fixed-bed reactors using efficient adsorbents at elevated temperatures
  - Advanced CO_2 capture technologies using Activated MDEA reduces capital cost



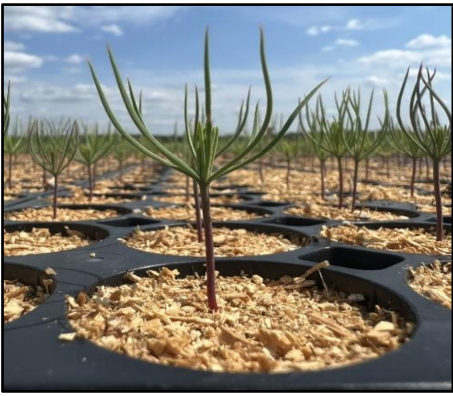
- Gasifier performance data being collected at Auburn University will be incorporated into process models

Emerging Technologies will improve Net Energy Efficiency and lower Cost of Hydrogen Production

PROJECT SCHEDULE

Tasks/Milestones	3 month	6 month	9 month	12 month	15 month	18 month	21 month	24 month	27 month	31 month
	Year 1				Year 2				Year 3	
Obj. 1: Study coal-plastic-biomass mixture flowability										
Task 2: Prepare 3 pure and 12 blended samples for the study	SA, GRA1				M 3					
Task 3: Complete flow properties such as flow index, cohesive strength, Hausner ratio, tap			OF, GRA2							
Task 3: Complete fluidization segregation and sifting segregation measurements.							OF, GRA2			
Obj. 2: Understand gasification behavior of the mixtures										
Task 2: Complete proximate, ultimate, heating value and ash analyses of 15 samples			SA, GRA1		M 2					
Task 4: Complete TGA experiments for 15 samples and calculate activation energy and th				SA, GRA1						
Task 5: Complete gasification of 3 pure samples.				SA, GRA1						M 4
Task 5: Complete gasification of remaining 12 samples.								SA, GRA1		
Obj. 3: Perform thermal property characterization of ash/slag										
Task 6.1 & 6.2: Reliable thermal conductivity data of ash and slag			TSO, GRA3							
Task 6.3: Slag composition-flow characteristics relationship.			TSO, GRA3							
Task 6.4: Identification of the best Cr-free refractory based on Al2O3, ZrO2, and MgO					TSO, GRA3					M 5
Task 6.5: Estimation of the impact of the refractory surface pore structure								TSO, GRA3		
Obj. 4: Develop process models for hydrogen production										
Task 7: A base-case ASPEN process model.										
Task 7: Updated ASPEN process model			PS, RTI		M 6					M 7
								PS, RTI		
Project Management										
Project SOPO and PMP Update		M 1								
Project Kickoff Meeting										
Quarterly Progress Report										
Annual and Final Report										M 8

Note: M = Milestone
SA: Sushil Adhikari
OF: Oladiran Fasina
TSO: Tae-Sik Oh
PS, RTI: Pradeep Sharma, RTI
GRA: Graduate Research Assistance



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THANK YOU!