


Fluidized-Bed Gasification of Coal-Biomass-Plastics For Hydrogen Production

FOA Number: DE-FOA-0002376

Award No: DEFE0032041

Sushil Adhikari, Tae-Sik Oh, Oladiran Fasina, Haley Mason, Ashish Bhattarai and Ayden Kemp

Auburn University

David C. Dayton and Pradeepkumar Sharma

RTI International


AUBURN
UNIVERSITY

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.

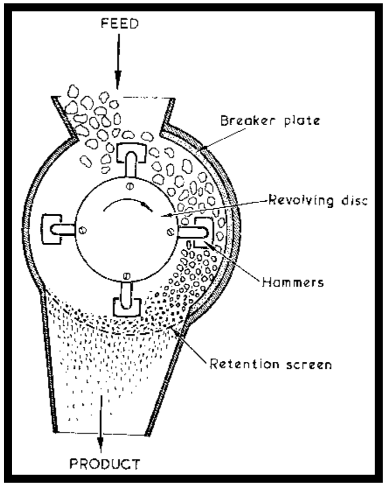
OBJECTIVE 1

- 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.

Biomass Sample Preparation

The hammer mill at Auburn University



A typical hammer mill

Vibratory screen separator

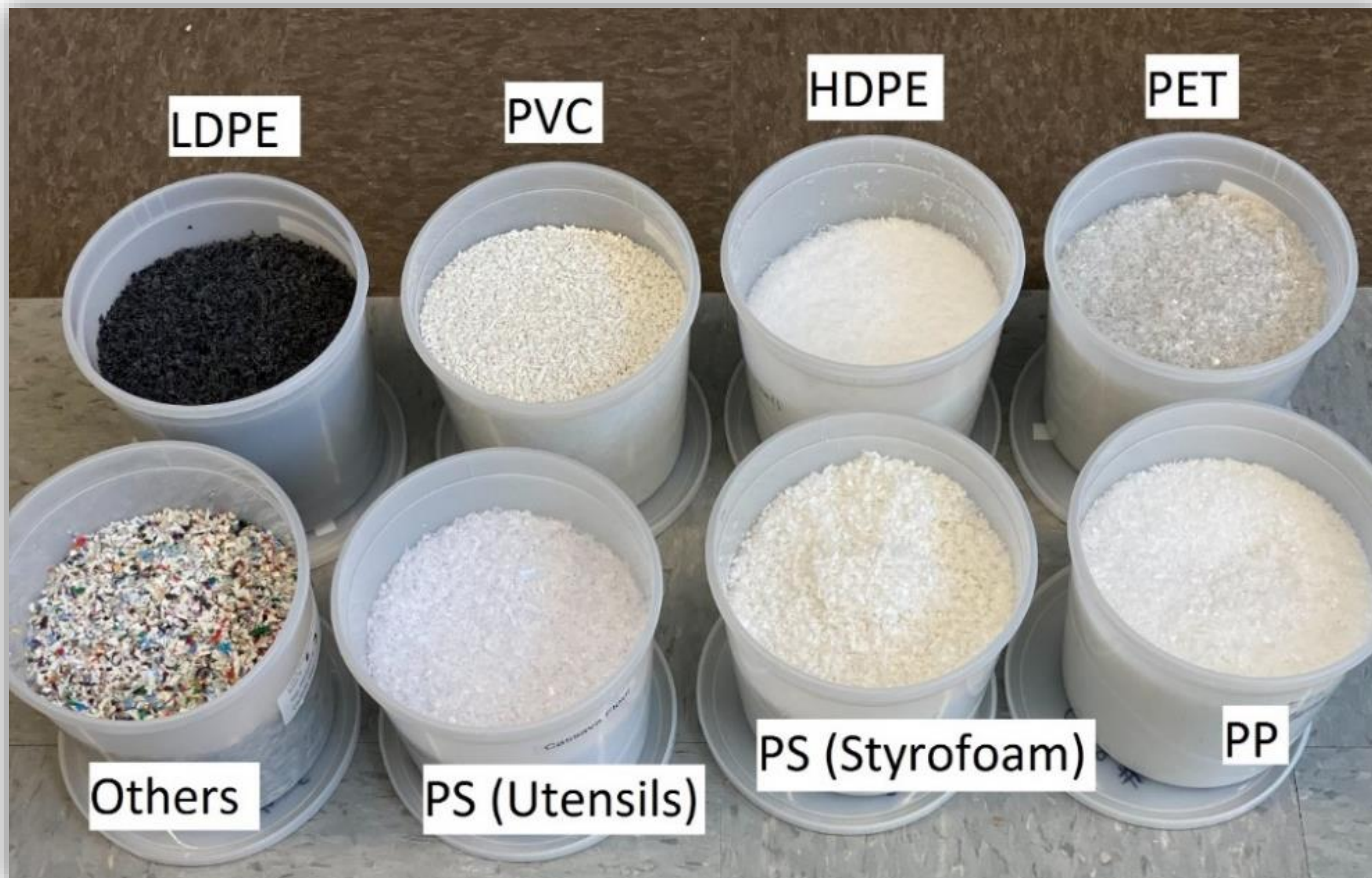
PLASTICS SHREDDING

HDPE #2

LDPE #4
(Granulated)

PREPARATION OF PLASTIC SAMPLES

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



Physical and Flow Characterization

Physical Characterization

- Bulk density
- Particle density
- Particle size distribution
- Flow index
- Cohesive strength
- Hausner ratio

DENSITY[a] AND FLOWABILITY

Name	Bulk Density, kg/m^3	Tap Density, kg/m^3	Particle Density, kg/m^3	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%

OBJECTIVE 2

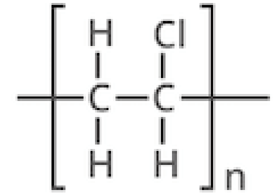
- We will perform feedstock reactivity and laboratory-scale fluidized bed gasification to determine the syngas composition and contaminants under steam and oxygen gasification conditions.

- The **expected outcome** of this is to have better understanding about the reactivity of the mixture and also how syngas composition 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

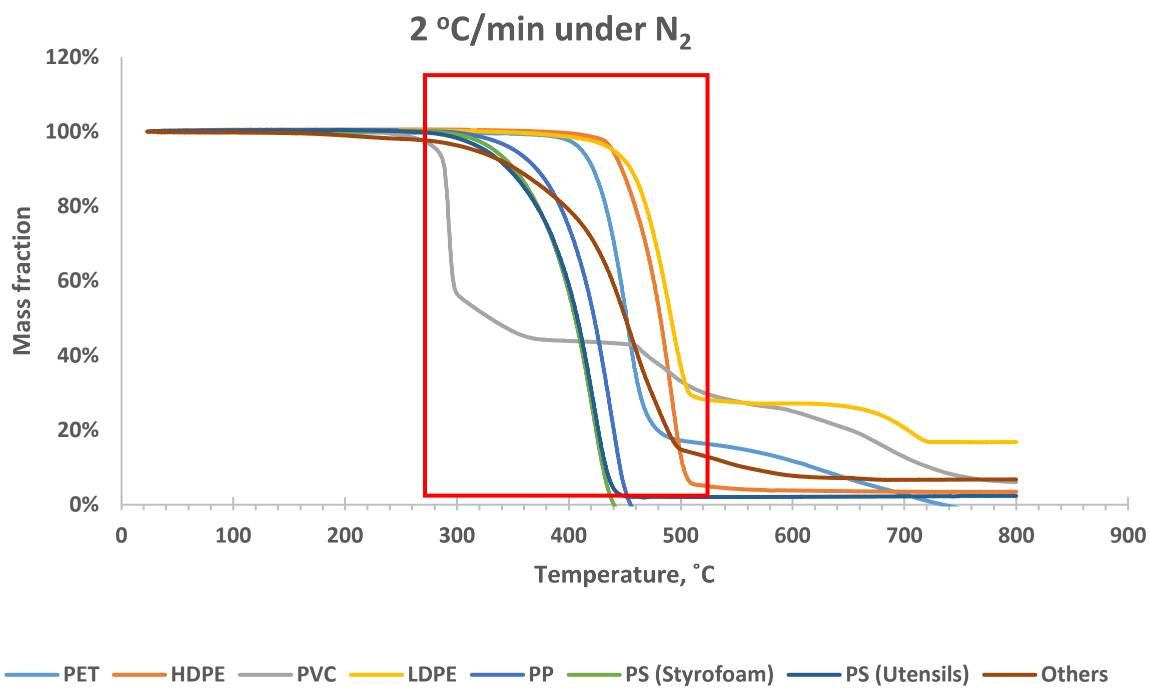
N.D.: Not Determined or Not Detected

Ash Fusion Temp (Reducing Atmosphere)

Component	Initial Temp. ^oF (^oC)	Softening Temp. ^oF	Hemispherical Temp. ^oF	Fluid Temp. ^oF
#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

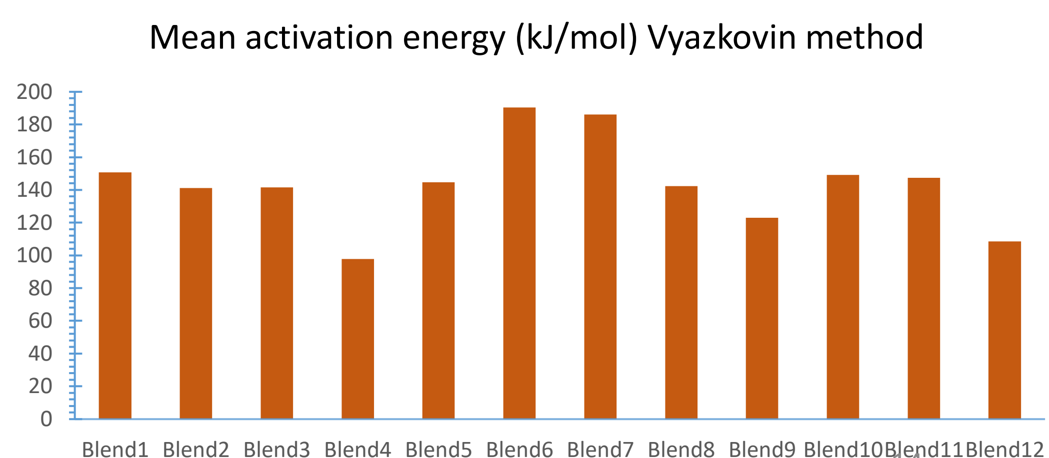
❖ **Ash fusion temperature is higher than 1150 ^oC; we do not anticipate of slagging during gasification runs in our set-up.**

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)

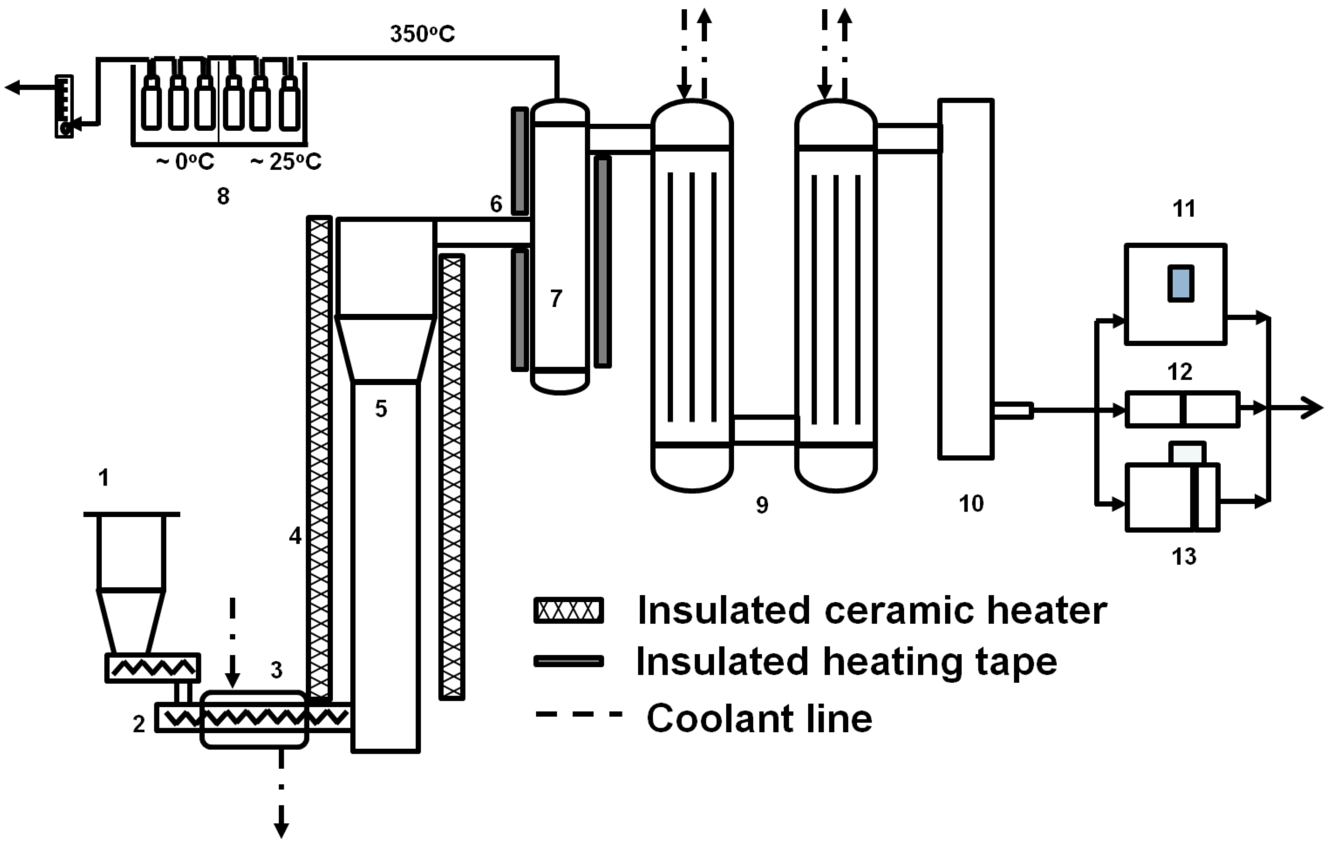


Figure . Experimental setup **1.** Hopper, **2**. injection screw, **3.** heat exchanger, **4.** heaters, **5.** fluidized bed gasifier, **6.** filter heaters, **7.** high temperature filter, **8.** impingers for tar sampling, **9.** condensers, **10.** ESP, **11.** primary gas analyzer, **12.** FTIR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

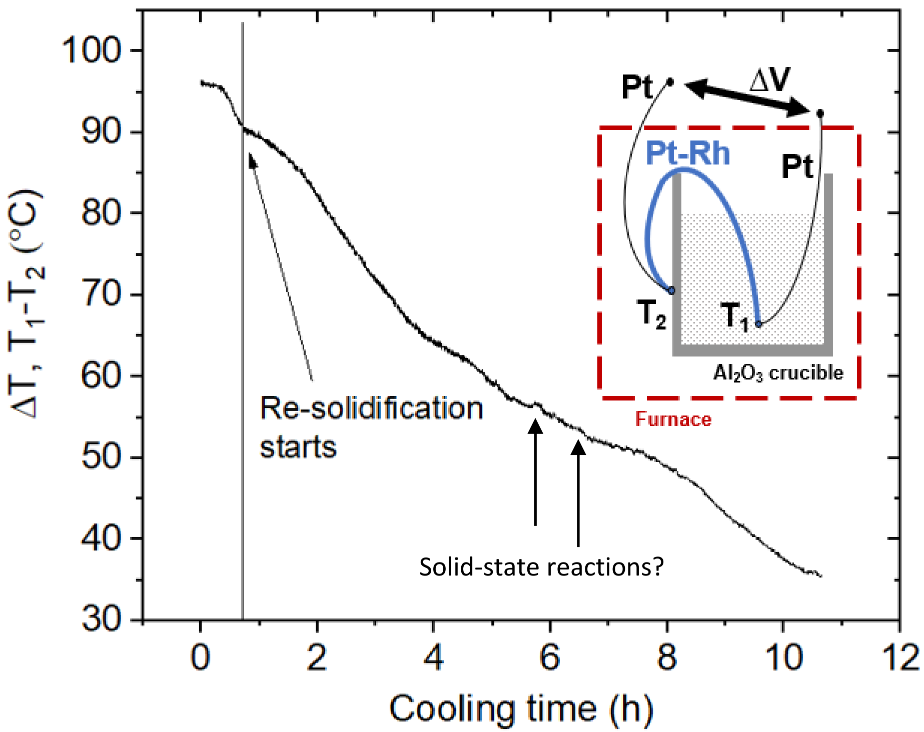
Objective 3

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

- 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

Coal slag re-solidification kinetics



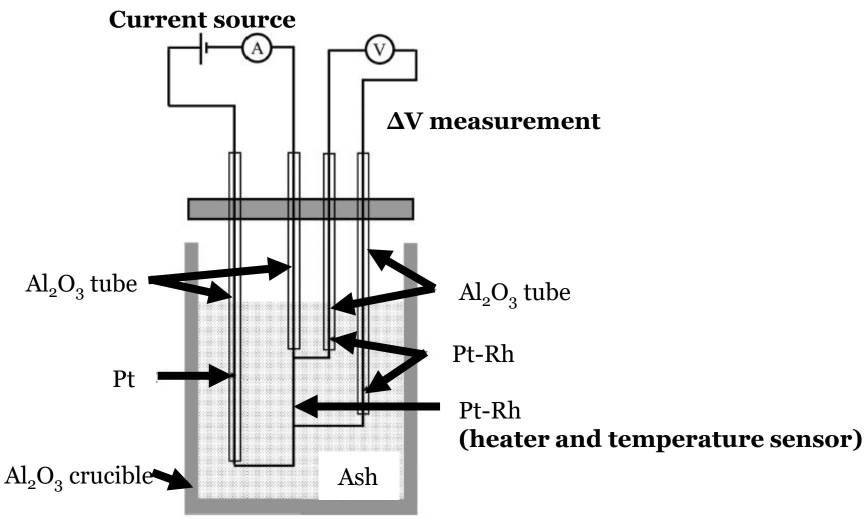
+ 2.4 °C/min cooling from 1600 °C (furnace T).

+ Temperature difference ($T_1 - T_2$) was measured using a differential thermocouple.

+ Re-solidification starts at 40 min (~1500 °C).

+ We will add a separate TC to measure T_2. With the improved setup, we will confirm the low temperature peak(s).

THERMAL CONDUCTIVITY MEASUREMENT (800 ~ 1400 °C)



$$\Delta T = \frac{\Delta R}{R_{ref}\beta}$$

β: resistivity temperature coefficient

$$k = \frac{\dot{q}}{4\pi}\frac{d(\ln t)}{d(\Delta T)}$$

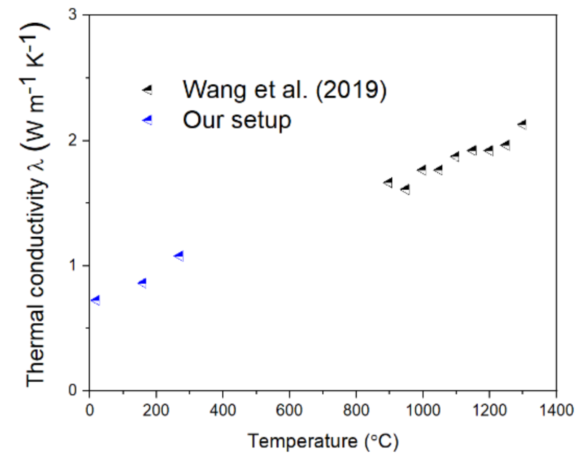
$\dot{q}$: heat generation rate per length $(= I^2 R_o/L)$

Thermal conductivity (W m⁻¹ K⁻¹)

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

An electrical furnace will set the measurement temperature first.
A sudden current flow will heat up the wire. Its resistance will change.

Benchmark sample
: Water at room temperature (~ 0.6 W m^{-1} K^{-1})

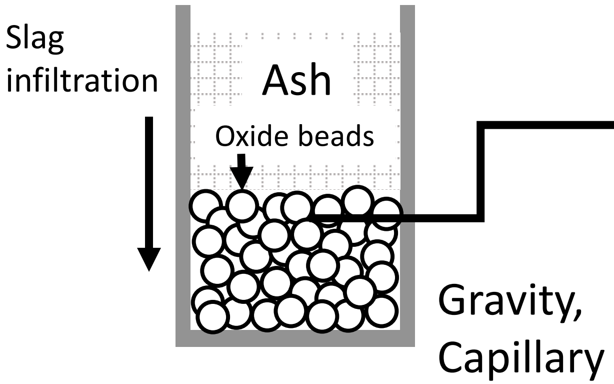


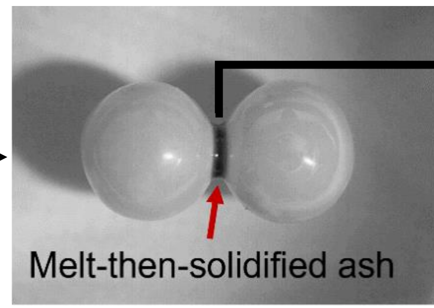
Synthetic ash/slag ➡ Real ash/slag from mixed feedstock

Q. Wang et al., Energy and fuels, 2019, 33, 6226-6233

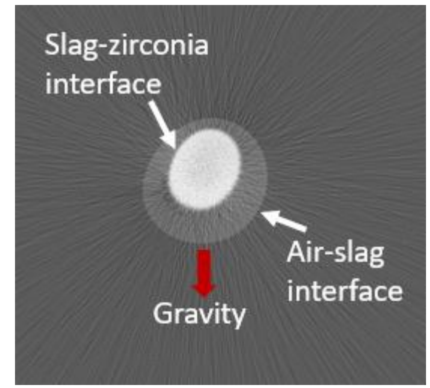
SLAG-REFRACTORY REACTIVITY

1400 °C, 2 h, synthetic ash melting





X-ray CT slice near the neck structure



Brightness ∝ mass density

Chemical Composition (wt%)				
SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO
60.39	24.67	8.14	3.78	3.02

+ The competition between gravity (density) and surface tension will determine the slag ring shape.

+ We will test the effectiveness of slag ring morphology approach in determining mixed feedstock slag density and surface tension.

Objective 4

- This study will inform researchers about the <u>capital and operating costs</u> 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 <u>**expected outcome**</u> of this study is that we will able to understand the cost of producing hydrogen and required process units.

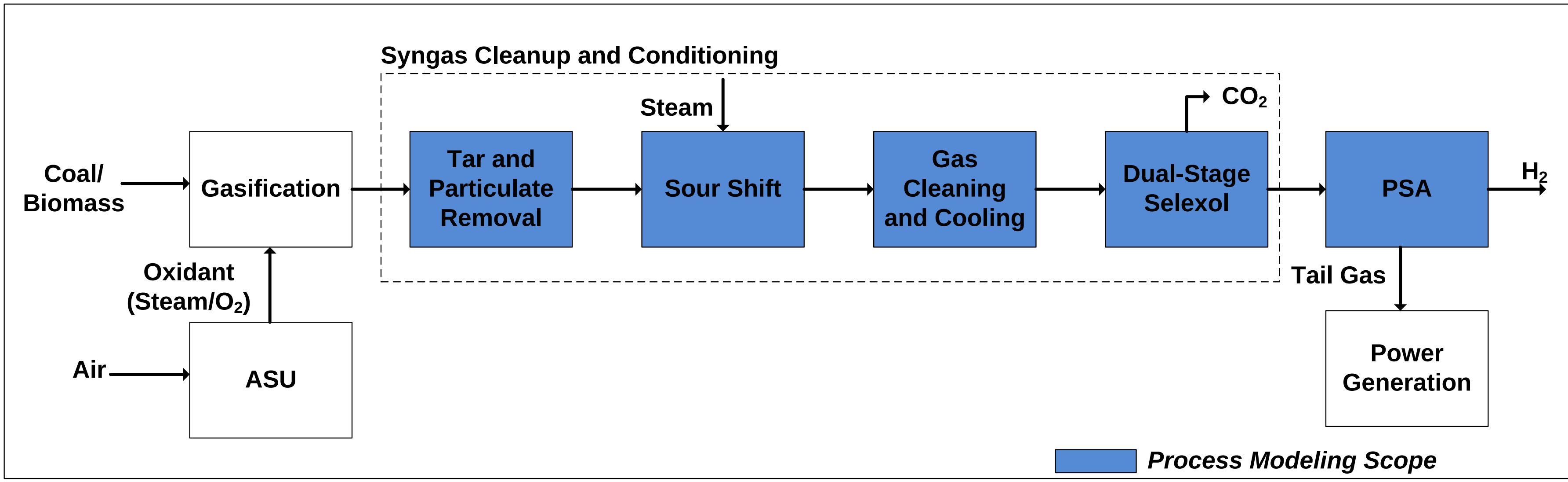
PROCESS MODELING- GOALS, OBJECTIVES & APPROACH

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

- Process modeling will achieve-
  - Process design for hydrogen production from coal, biomass and waste plastics gasification
  - Comparison of emerging advanced technologies with conventional state-of-the-art technologies for syngas cleanup and conditioning
  - Estimation of capital and operating costs for hydrogen production from selected wastes

- 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 will be developed using RTI's emerging advanced syngas cleanup and conditioning technologies that provide process and economic benefits over conventional technologies

BASE CASE PLANT USING CONVENTIONAL TECHNOLOGIES (2000 TPD)

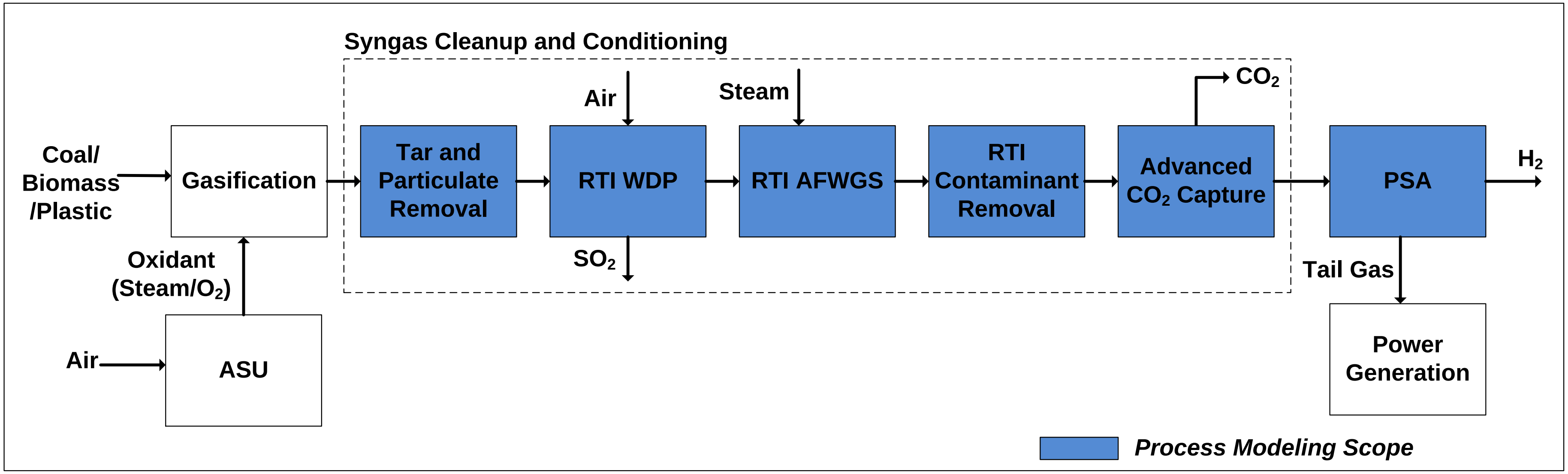


Selected Conventional Syngas Cleanup and Conditioning Technologies -

- Sour WGS process adjusts syngas composition and performs COS hydrolysis in the presence of H_2S
- 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
- PSA can achieve >99.99 vol% hydrogen purity

Process Simulations will be used to estimate Capital and Operating Costs for Hydrogen Production

Advanced Case Plant using Emerging Technologies



Selected RTI's Emerging Syngas Cleanup and Conditioning Technologies:

- 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 or RTI-NAS (Non-Aqueous Solvent) will be evaluated

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

THANK YOU!