

## Co-gasification of Waste Biomass and Plastic for Syngas Production with CO<sub>2</sub> Capture and Utilization: Thermodynamic Investigation

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### ABSTRACT

This work presents an integrated plant-wide process for co-gasification of waste biomass and plastics using steam and CO<sub>2</sub> to produce an industrially important feed stock *i.e.*, syngas with molar ratio of H<sub>2</sub>/CO<sub>2</sub>. The proposed plant wide process is designed with key feature of Carbon Capture and Utilization (CCU) and made self-sustainable by utilizing a fraction of syngas for meeting the heat, steam and CO<sub>2</sub> demands with additional heat recovery and steam generation and power generation sections. Further, steady state plant wide models are developed using ASPEN Plus, and simulations are performed for the co-gasification of High-Density Polyethylene (HDPE) and Rice Husk (RH) at varying feed compositions (0%-100% HDPE). Further, rigorous sequential parametric sensitivity analysis is performed to determine the optimal process parameters and investigate the impact of feed composition on the product yield. Results revealed that Steam to Carbon ratio (S/C) should be maintained above 1.2 to attain complete carbon conversion within the gasifier which tends to enhance the overall performance of the integrated scheme. The comparative investigation on co-gasification of HDPE and RH revealed that an increase in weight percentage of HDPE in the feed mixture resulted in increased syngas production and plant efficiency due to the high carbon and low ash content of HDPE. Gasification of pure HDPE waste resulted in the maximum output of 2.2 kg of syngas/kg of feed with a net plant efficiency of 68%, while in the case of pure RH the syngas production and efficiency dropped to 0.60 kg/kg of feed and 35%, respectively.

**Keywords:** Biofuel; Waste plastic; Rice husk; Co-gasification; Syngas

### Highlights

- Thermodynamic modelling for co-gasification of Rice Husk (RH) and polyethylene.
- CO<sub>2</sub> and steam used as gasifying agent for syngas production with H<sub>2</sub>/CO ratio of 2.
- Process steam and CO<sub>2</sub> demand decreases with increase in RH wt.% in feed mixture.
- Syngas production and efficiency decreases with increase in RH wt.% in feed mixture.

### INTRODUCTION

Plastic waste is one of the major causes of environmental pollution, as it is not biodegradable and it can end up in landfills, oceans, and other natural environments, causing harm to wildlife and ecosystems. Moreover, plastic waste breaks down into micro plastics, it can enter the air, water and food chain leading to severe health hazards to humans and animals. Globally, more than 400 Million Tons per Annum (MTA) of plastic waste is generated and India ranks as the second-highest annual producer of plastic waste (27 MTA), behind the United States (34 MTA) [1]. Among the generated waste globally, only

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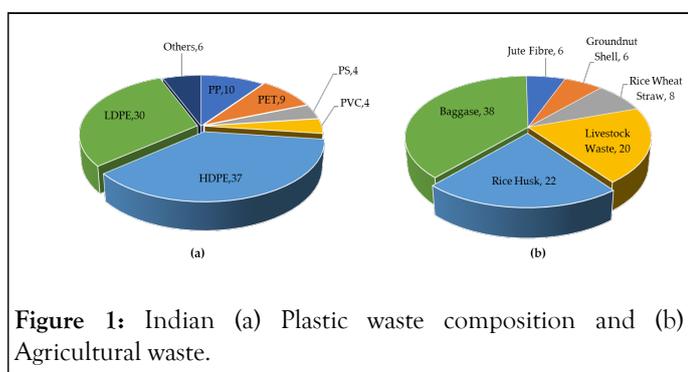
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9% is recycled, 12% is incinerated, and the remaining 79% ends up in landfills and dumps which becomes a major threat to the environment [2]. High Density Polyethylene (HDPE) accounts for most of the plastic waste generated globally, weighing in at ~40%, compared to India, where it makes up 35%-38%, as shown in Figure 1A. Another important class of waste generated in large quantities is agricultural waste such as rice husks, wheat straw, and corn stover which is estimated to be around 1400 MTA globally [3]. Among the various agricultural waste, rice husk is the most prevalent type as shown in Figure 1B. India and China together generates ~72 MTA i.e., almost 50% of the world's rice husk [4]. According to statistics, ~0.30-0.70 kg of fuel (equivalent to petroleum) can be produced from 1 kg of biomass waste [5,6]. Since these abundant agricultural wastes are carbonaceous, they can be used as a replacement for fossil fuels and as a large-scale source of clean energy production, reducing the nation's reliance on imported gasoline and diesel (Figure 1).



However, most of these biomass/plastic wastes are either burned openly or disposed in landfills, resulting in release of greenhouse gases (CO<sub>2</sub> and CH<sub>4</sub>) along with other hazardous gases (SO<sub>x</sub> and NO<sub>x</sub>) and particulate matters [7]. Utilization and conversion of waste to useful products are essential for addressing environmental, social, and economic challenges associated with plastic waste. As a result, over the past decade the attention has shifted to thermochemical conversion of plastic and biomass *via* pyrolysis, gasification, or combustion because of their potential to generate heat and power. Among those methods gasification has drawn the greatest interest because of its wide adaptability towards various feed and capability to produce different products depending upon the type and amount of the gasifying agents i.e., air, O<sub>2</sub>, steam or CO<sub>2</sub> used. Lately, co-gasification of biomass and plastic waste has emerged as one of the most effective way to manage waste while also producing value added syngas [8]. It is also useful for waste reduction, makes energy recovery easier, helps to mitigate

climate change, promotes resource conservation, and has several economic benefits by generating new jobs in waste management and energy production and lowering the cost of waste disposal and energy production. Through literature review on co-gasification of biomass and plastic waste, through Web of Science with keywords “Co-gasification”, “plastic” and “biomass” in all fields yielded 133 results of which just 14 articles have performed thermodynamic modelling using ASPEN plus. Table 1 provides a detailed literature review on ASPEN plus modelling studies for co-gasification of different biomass and plastic waste. Various biomass such as Rice Husk (RH), sawdust, wood chips, wheat straw, olive pomace, hazelnut shells, Barley and vine pruning's have been reported to be co-gasified with different waste plastics such as Polyethylene (PE), High Density Polyethylene (HDPE), Polypropylene (PP), Polyethylene Terephthalate (PET), Polystyrene (PS), Plastic Solid Waste (PSW), and Sachet Water Plastic Waste (SWPW). Except for one study that utilized CO<sub>2</sub> and steam as gasifying agents, most of the reported thermodynamic studies have used air, O<sub>2</sub> or steam both to produce syngas with varying H<sub>2</sub>/CO ratios. The major driving force of our study is to examine the thermodynamic viability and potential benefits of integrating “co-gasification of waste biomass and plastic” with “Carbon Capture and Utilization (CCU)” in terms of syngas generation, H<sub>2</sub>/CO ratio, CO<sub>2</sub> utilization, and net plant efficiency. Co-gasification coupled with CCU process are still not developed sufficiently for commercialization, necessitating additional research to make ground-breaking discoveries. The current work is primarily focused on thermodynamic investigation of an integrated process for co-gasification of Rice Husk (RH) and High-Density Polyethylene (HDPE) for syngas production with CCU. Steady state plant wide models are developed using ASPEN Plus, for the co-gasification of RH and HDPE (at varying composition ranging from 0-100% RH) with CCU for syngas production with H<sub>2</sub>/CO of 2. The integrated scheme is made self-sustainable by burning a fraction of syngas produced to meet the process heat and steam demand along with the incorporation of Heat Recovery and Steam Generation (HRSG) and power generation sections. Further, sequential parametric sensitivity analysis is performed to determine the optimal process parameters and investigate the impact of feed composition (i.e., wt.% of plastic in total feed), steam to carbon ratio, and CO<sub>2</sub> to carbon ratio on the overall performance of the integrated scheme (Table 1).

**Table 1:** Modelling studies on plastic waste and biomass conversion.

Process type	Feed		T (°C)	Gasifying agents	Product	References
	Biomass	Plastic				
Co-gasification	Rice husk	PE	850	Air, steam	Syngas	Tian, et al.
Co-gasification	Sawdust	HDPE	700	Steam, CO <sub>2</sub>	Syngas	Chai, et al.
Co-gasification	Sawdust	PE, PP	750	Steam	Syngas	Singh, et al.

Co-gasification	Algae	PE	800	O <sub>2</sub>	H <sub>2</sub>	Rosha, et al.
Co-Pyrolysis	Fiberglass, olive pomace	PP	500	-	Syngas	Ouazzani, et al.
Pyrolysis	Wood chips	PS	500	-	Power	Gunukula and Tran
Co-gasification	Barley and wheat straw	PE, PP	850	Air	Bio-jet fuel	López-Fernández, et al.
Co-gasification	Vine prunings	PET	800	Air, steam	Syngas	Tavares, et al.
Co-gasification	Vine prunings	PET	600	O <sub>2</sub>	Syngas	Ramos, et al.
Co-gasification	Rice husk	SWPW	850	Steam	Power	Salisu, et al.
Co-gasification	Hazelnut shells	Sewage sludges	850	Air	Syngas	Barontini, et al.
Plasma gasification	MSW	PSW	850	O <sub>2</sub> , steam	Syngas, H <sub>2</sub>	Mazzoni and Janajreh

## MATERIALS AND METHODS

### Process description

Figure 1 provides the plant-wide schematic for the conversion of waste plastic to syngas. In this work, a feed mixture consisting of RH and HDPE is investigated at mass ratios ranging from 0 to 100% of RH in the feed mixture. The proximate and ultimate analysis of RH and HDPE is provided in Table 2. Initially, the waste plastics are cleansed to remove the dirt and sand with an equal mass ratio of water, then crushed to 1-3 mm particle size. Plastic waste is then completely dried to remove all the moisture content, at 140°C. Similarly, RH was crushed to 1-3 mm size without washing. The crushed waste materials were then co-fed to the gasifier, where they were initially paralyzed at 500°C into their volatile constituents and char. The char obtained is then completely gasified at 850°C using steam to produce syngas. The lower hydrocarbons/volatile matters obtained during gasification and pyrolysis are then reformed using CO<sub>2</sub> and steam at 850°C to obtain syngas with H<sub>2</sub>/CO molar ratio of 2. The outlet gas (or reformer gas) from the gasifier is then cooled to 150°C in Heat Recovery and Steam Generation (HRSG) section to produce High Pressure (HP) steam at 80 atm, which is expanded in a Steam Turbine (ST) to generate power. The exhaust from ST at 1 atm is sent to the gasification and reforming sections to meet the process steam demand. The reformer gas at 150°C from the HRSG section is then used for drying/preheating the feed mixture to 140°C. The reformer gas then enters the gas cleanup section where it undergoes cleaning in three stages for the removal of moisture in condenser, sulfur impurities *via* Selexol process and finally CO<sub>2</sub> capture. The energy required during the Selexol process and CO<sub>2</sub> capture

unit were reported to be 5000 kJ/kg of SO<sub>x</sub> and 3950 kJ/kg of CO<sub>2</sub>, respectively. A fraction of the CO<sub>2</sub> captured was utilized during the gasification/reforming. The clean syngas obtained with H<sub>2</sub>/CO of 2 was then compressed to 5 atm and stored. A fraction of the compressed syngas was burnt in the combustor using compressed air at 5 atm. The products of combustion were then expanded in the gas turbine to generate power. The hot exhaust from the gas turbine was further used to jacket the gasifier to supply the required heat to the process (Figure 2 and Table 2).

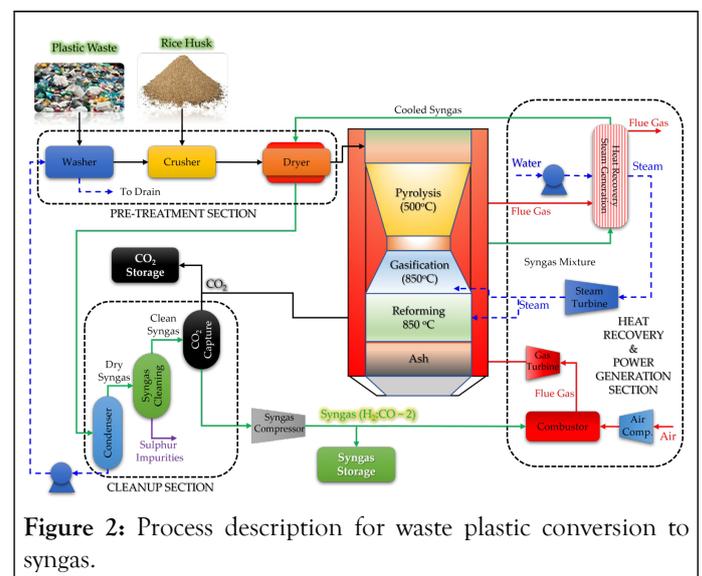


Figure 2: Process description for waste plastic conversion to syngas.

Table 2: Proximate and ultimate analysis of different waste plastics.

### Proximate analysis

Components	Rice husk	HDPE
Moisture	9.88	0
VM	66.12	99.9
FC	14.18	0
Ash	19.7	0.1
<b>Ultimate analysis (dry basis)</b>		
C	37.55	83.3
H <sub>2</sub>	4.61	13.9
N <sub>2</sub>	0.46	0.13
S	0.01	0.07
O <sub>2</sub>	37.67	2.5
Ash	19.7	0.1

### Process modelling and simulation

Self-sustained steady state plant-wide ASPEN Plus models were developed for co-gasification of RH with HDPE to produce syngas coupled with CCU. The models were developed and optimized individually for 11 different compositions of RH and HDPE feed mixture ranging from 0-100% RH. The ASPEN Plus model flow sheet for the integrated process is shown in Figure 2. A stream class called MCINCPD is defined before the simulation begins, as the overall process contains RH and HDPE, which are categorized as non-conventional streams with particle size distribution, while H<sub>2</sub>, CO, CH<sub>4</sub>, CO<sub>2</sub>, NO<sub>2</sub>, NO, O<sub>2</sub>, H<sub>2</sub>O, S, SO<sub>2</sub>, and SO<sub>3</sub> are regarded as conventional streams, and C is a pure solid representing char. The enthalpy and density of the feed mixture in this case were evaluated using the HCOALGEN and DCOALIGT methods. The Peng Robinson-Boston Mathias (PR-BM) method was used to simulate the properties of all components. No tar formation is considered during thermochemical conversion due to high gasification temperature and use of oxidizing agents (steam and CO<sub>2</sub>) in excess [9,10]. 100 kg/h of feed mixture was taken as the basis for the comparison of the 11 different cases of feed composition. The crushed feed of RH and HDPE were initially pyrolyzed using separate RYield reactors (B5 and B7) to break them down into its constituent elements based on their respective ultimate analysis as reported in Table 2. The constituent's elements of RH and HDPE obtained from the RYield reactors are mixed and co-fed to the RGibbs reactor (B9) which acts as a gasifier. The char is gasified using steam and products are obtained from the RGibbs reactor based on the minimization of Gibbs free energy. Further the product gas from B9 unit enters another RGibbs reactor which acts as the reformer where the unconverted hydrocarbons/volatile matters such as CH<sub>4</sub> is converted using CO<sub>2</sub> and steam to syngas with H<sub>2</sub>/CO ratio of 2. The syngas obtained is cooled in HeatX (B9)

unit while simultaneously producing HP steam. The partially cooled syngas is further used as jacket (B13) for pre-heating/drying the plastic waste. The cooled syngas is then purified by moisture removal in Flash (B14), sulfur removal in Separator (B15), CO<sub>2</sub> removal in Separator (B16) units. The energy required for sulfur and CO<sub>2</sub> separation were assumed to be 5000 kJ/kg of SO<sub>x</sub> and 3950 kJ/kg of CO<sub>2</sub>, respectively. The cleaned syngas was then compressed and a fraction of it was burnt to meet the process energy needs [11,12]. Table 3 gives detailed specifications of the ASPEN Plus modules that were used during the modelling. Multiple design specs and calculator blocks are used as feed backward and feed forward controllers to manage the process parameters heat, steam, CO<sub>2</sub> and temperature demands. The details of the design specs and calculator blocks used is provided in Tables 4 and 5, respectively (Figure 3 and Tables 3-5).

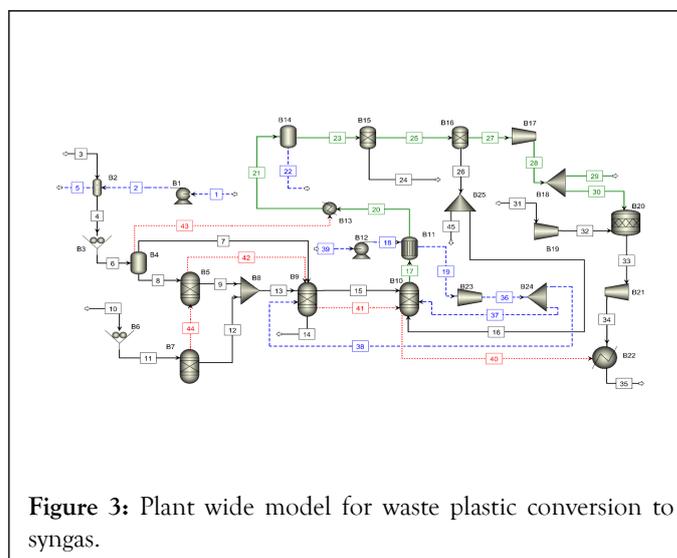


Figure 3: Plant wide model for waste plastic conversion to syngas.

**Table 3:** Details of ASPEN Plus modules used.

Unit	Module	Description	Operating conditions
B1	Pump	Water pumping for washing	Discharge Pressure (DP): 1.1 atm
B2	Sep	Washing plastic waste	Water in WP=5 wt. %
B3	Crusher	Reducing particle size to <3 mm	PSD: 1 mm-3 mm
B4	Flash2	Dryer: Removing all moisture	T:140°C, P:1 atm
B5	RYield	Pyrolyzer: Decomposing plastic waste to its elemental composition	T:500°C, P:1 atm
B6	Crusher	Reducing particle size to <3 mm	PSD: 1 mm-3 mm
B7	RYield	Pyrolyzer: Decomposing Rice Husk its elemental composition	T:500°C, P:1 atm
B8	Mixer	To mix both streams coming from pyrolyzer 1 and 2	
B9	RGibbs	Gasifier: Convert fixed carbon and other volatile matter using steam	T:850°C, P:1 atm
B10	RGibbs	Reformer: To obtain H <sub>2</sub> /CO molar ratio of 2 using CO <sub>2</sub> and steam	T:850°C, P:1 atm
B11	HeatX	HP steam generator and cools RG	Hot stream outlet T: 150°C
B12	Pump	Pumping water for HP steam	P: 80 atm
B13	Heater	Jacketing dryer using RG	P: 1 atm
B14	Flash2	Removing moisture from SG	T:25°C, P:1 atm
B15	Sep	Removing sulphur impurities	S, SO <sub>2</sub> , SO <sub>3</sub> in stream 19 is 0
B16	Sep	CO <sub>2</sub> separation	CO <sub>2</sub> in stream 21 is 0
B17	Compr	SG compressor	DP: 5 atm, Isentropic Efficiency: 0.9
B18	Splitter	Splits SG for burning and storing	Split fraction controlled by Design Spec
B19	Compr	Air compressor	DP: 5 atm, Isentropic Efficiency: 0.9
B20	RStoic	SG combustion	Q: 0 kW, P: 5 atm
B21	Compr	Gas turbine	DP: 1 atm, Isentropic Efficiency: 0.9
B22	Heater	Jackets the waste plastic conversion process <i>i.e.</i> , reactors B5, B7, B9 and B10	P: 1 atm
B23	Compr	Steam turbine	DP: 1 atm, Isentropic Efficiency: 0.9

B24	Splitter	Splits hot steam to the gasification and reforming units	Split fraction controlled by design spec
B25	Splitter	Splits captured CO <sub>2</sub>	Split fraction controlled by design spec

**Table 4:** Design Specifications (DS) considered in the proposed schemes model development.

S. no.	Design specifications	Target variable	Manipulated variable
DS1	To obtain syngas with desired H <sub>2</sub> /CO ratio of 2 by varying the mass flowrate of captured CO <sub>2</sub> entering the reformer	H <sub>2</sub> /CO in steam 17: 2	Mass flowrate of stream 16
DS2	To allow HDPE to retain only 5% of moisture content during washing	Mass fraction of H <sub>2</sub> O in stream 4: 0.05	Mass flowrate of stream 5
DS3	To avoid violation of 2 <sup>nd</sup> law of thermodynamics by keeping the temperature of the exhaust gas (from gas turbine) after supplying heat to the gasifier, 10°C above the dried HDPE feed temperature (140°C) by burning the required amount of syngas in the combustor	Temperature of stream 35: 150°C	Mass flowrate of stream 30
DS4	Minimum amount of steam required to be sent to the gasifier to completely convert all the char obtained during pyrolysis of RH and HDPE to syngas	Mass flowrate of stream 38: (1.46* mass flow rate of C in stream 13) mass flowrate of stream 7	Split fraction of B24

**Table 5:** Calculator Blocks (CB) considered in the proposed schemes model development.

S. no.	Description	Manipulated variable
CB1	Excess air required to maintain the combustor temperature of 1300°C, which in turn avoids the temperature of the exhaust gas to not fall below 150°C, after supplying the process heat	Molar flowrate of stream 31: 2.65* stoichiometric air required to burn H <sub>2</sub> , CO and CH <sub>4</sub> in stream 30
CB2	Amount of HP-steam to be generated should be 20% in excess to the steam demand of the gasifier	Mass flowrate of stream 39: 1.2* Mass flowrate of stream 38
CB3	Amount of water required for washing HDPE should be equal to the mass flowrate of HDPE	Mass flowrate of stream 1: Mass flowrate of stream 3

CB1	Excess air required to maintain the combustor temperature of 1300°C, which in turn avoids the temperature of the exhaust gas to not fall below 150°C, after supplying the process heat	Molar flowrate of stream 31: 2.65* stoichiometric air required to burn H <sub>2</sub> , CO and CH <sub>4</sub> in stream 30
CB2	Amount of HP-steam to be generated should be 20% in excess to the steam demand of the gasifier	Mass flowrate of stream 39: 1.2* Mass flowrate of stream 38
CB3	Amount of water required for washing HDPE should be equal to the mass flowrate of HDPE	Mass flowrate of stream 1: Mass flowrate of stream 3

## RESULTS AND DISCUSSION

Sequential parametric sensitivity analysis is used to analyze and obtain the optimal process parameters for each of the 11 cases of different feed mixture ranging from 0 to 100% HDPE. Figure 4 shows the effect of varying the Steam to Carbon (S/C) ratio from 0.8 to 2, on carbon conversion within the gasifier for the case of 50% of RH and 50% of HDPE at 850°C. It was found that as the S/C ratio rises, the amount of unconverted carbon in the gasifier reduces which becomes zero at a S/C ratio of 1.2 [13-15].

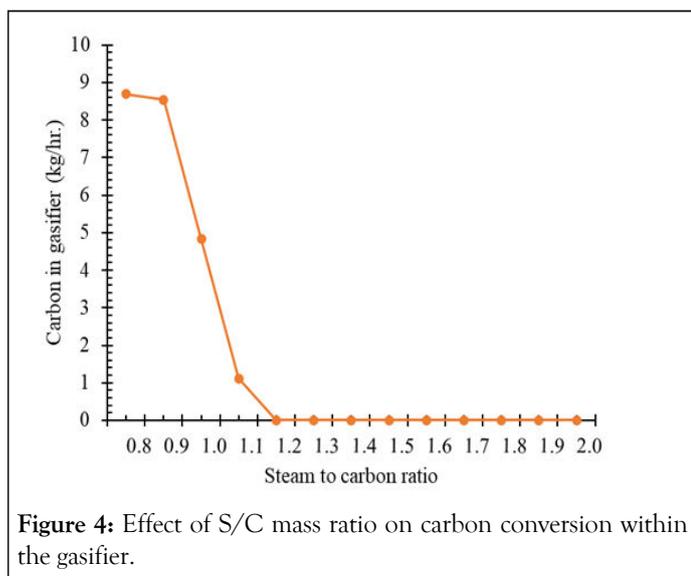


Figure 5 shows the effect of S/C ratio on the overall syngas production, net amount of syngas consumed to meet the process heat demand and net plant efficiency. It was observed that as the S/C ratio increased from 0.8 to 1.4 the net plant efficiency increased from 50.57% to a maximum of 61.08%. Further increase in S/C ratio from 1.4 to 2 tends to gradually decrease the net plant efficiency from 61.08% to 52.07% due to the increase in consumption/burning of produced syngas from 50.76% to 56.87%, respectively. Therefore, S/C of 1.4 within the gasifier is chosen as the optimal ratio for all the cases [16].

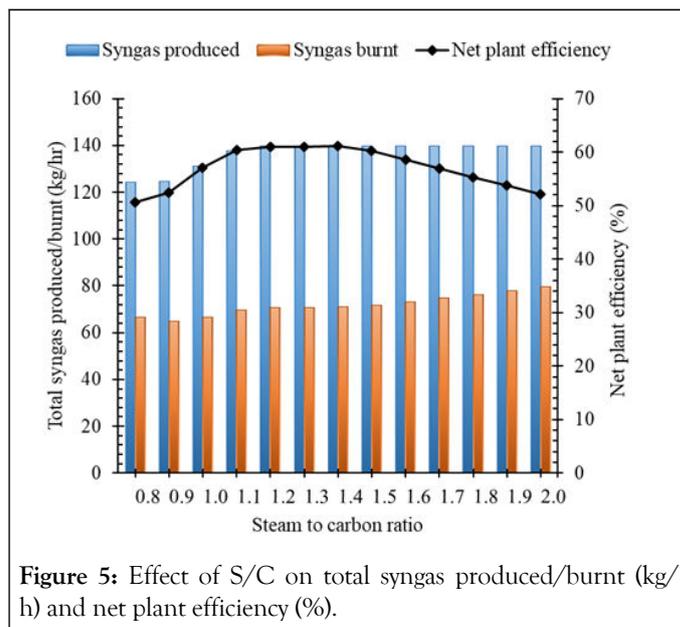


Table 6 compares the optimal results from the 11 different cases with various feed ratios. The comparison was based on the co-gasification of 100 kg/h of feed mixture to produce syngas with H<sub>2</sub>/CO ratio of 2 while supplying process heat by burning a portion of the produced syngas [17].

Table 6 shows that when RH concentration rises, less steam and CO<sub>2</sub> are needed for gasification and reforming since there is less carbon in the feed mixture. Further, the concentration of O<sub>2</sub> in the feed mixture also increases as a result of the increase in RH weight percent, which tends to partially oxidize and reform the hydrocarbons and char, thereby reducing the demand for steam and CO<sub>2</sub> as oxidizing agents. Further it can also be observed from the Table 6 and Figure 6 that with the increase in HDPE weight% in the feed mixture (or decrease in weight% of RH) the amount of syngas produced is increased due to the higher carbon content in feed which is in agreement with the results reported by Chai, et al. [3,18]. Air compression requires the majority of the process power, followed by syngas compression and CO<sub>2</sub> separation. Results also show that the power needed for CO<sub>2</sub> compression rises with an increase in RH weight percent because more CO<sub>2</sub> is produced during the gasification stage due to an increase in intrinsic O<sub>2</sub> content in the feed. Almost the same amount of power was required for crushing RH and HDPE in each case. The amount of water pumped for washing HDPE and HP steam generation was found to be

decreasing with an increase in RH weight percent. The energy required for sulphur removal was also found to be decreasing with the increase in RH weight percent due to the lower sulphur content of RH compared to HDPE [11]. Further, it was observed that increase in the weight% of RH in the feed mixture resulted in decrease in the amount of syngas production and amount of syngas burnt to meet the process heat demand. However, it was also observed that a rise in RH weight percent in feed was inversely proportional to the fraction produced syngas that was burnt. Approximately 50% of the produced syngas was burnt in case of pure HDPE, compared to 60% in case of pure RH [12]. Table 6 also shows that more than 90% of the captured CO<sub>2</sub>

was recycled back for co-gasification, demonstrating the efficacy of the proposed process to utilize CO<sub>2</sub>. However, as the HDPE content in the feed mixture drops, the CO<sub>2</sub> utilization is found to decline, and it falls to just 11% in the case of pure RH. Finally, the net power generation and net plant efficiency tend to decrease with the increase in RH content in the feed mixture. The overall plant efficiency was found to be highest at 68% in case of pure HDPE which decreased to almost half *i.e.*, 35% in case of pure RH, due to the high ash content of the RH in comparison to no ash content in case of HDPE [19,20].

**Table 6:** Performance comparison for syngas production.

Parameters	Units	Composition of rice husk with HDPE										
		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11
RH flowrate	kg/h	0	10	20	30	40	50	60	70	80	90	100
HDPE flowrate		100	90	80	70	60	50	40	30	20	10	0
Steam to gasifier		121.3	109.7	98.1	86.8	79.6	73.7	67.9	62	56.2	50.3	50
Steam to reformer		27.3	30.4	33.5	36.3	35	32.4	29.7	27.1	24.4	21.8	13.6
CO <sub>2</sub> to reformer		31.6	29	26.4	23.8	21.1	18.5	15.9	13.2	10.6	8	5.3
<b>Reformer gas mass flow</b>												
C	kg/h	0	0	0	0	0	0	0	0	0	0	0
CH <sub>4</sub>		0.6	0.5	0.4	0.3	0.2	0.2	0.1	0.1	0.1	0	0
H <sub>2</sub>		27.5	25.5	23.5	21.6	19.6	17.6	15.6	13.6	11.6	9.6	7.6
CO		191.1	177.4	163.6	149.8	136	122.1	108.3	94.4	80.5	66.5	52.6
CO <sub>2</sub>		35	36.3	37.5	38.8	40.1	41.4	42.7	44	45.3	46.6	48
H <sub>2</sub> O		31	32.1	33.2	34.3	35.5	36.6	37.8	38.9	40.1	41.2	42.4
O <sub>2</sub>		0	0	0	0	0	0	0	0	0	0	0
N <sub>2</sub>		0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4
NO <sub>2</sub>		0	0	0	0	0	0	0	0	0	0	0
NO		0	0	0	0	0	0	0	0	0	0	0
S		0	0	0	0	0	0	0	0	0	0	0

SO <sub>2</sub>		0.12	0.12	0.11	0.1	0.09	0.08	0.07	0.05	0.04	0.03	0.02
SO <sub>3</sub>		0	0	0	0	0	0	0	0	0	0	0
<b>Power/energy requirement</b>												
Crushing	kW	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pumping water		0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.2	0.2
SG compressor		32.1	29.8	27.5	25.1	22.8	20.5	18.2	15.8	13.5	11.2	8.8
Air compressor		100.7	94	87.3	80.6	73.9	67.1	60.4	53.7	46.9	40.2	33.4
SG cleaning		0.18	0.17	0.15	0.14	0.12	0.11	0.09	0.08	0.06	0.04	0.03
CO <sub>2</sub> separation from SG		37.9	39.3	40.6	42	43.4	44.8	46.2	47.6	49.1	50.5	51.9
<b>Power generated</b>												
Gas turbine	kW	307.2	286.8	266.4	246	225.5	205	184.5	163.9	143.4	122.8	102.2
Steam turbine		36.7	34.7	32.6	30.6	28.5	26.4	24.4	22.3	20.3	18.2	16.1
<b>SG details</b>												
Total SG produced	kg/h	219.2	203.4	187.5	171.7	155.8	139.9	124	108	92.1	76.1	60.2
SG burnt		108.6	101.5	94.3	87.1	79.8	72.6	65.4	58.1	50.8	43.5	36.2
Fraction of SG burnt	%	49.6	49.9	50.3	50.7	51.3	51.9	52.7	53.8	55.2	57.2	60.2
SG stored	kg/h	110.6	101.9	93.3	84.6	75.9	67.3	58.6	49.9	41.3	32.6	23.9
CO <sub>2</sub> utilization	%	90.4	80	70.3	61.2	52.7	44.7	37.2	30.1	23.4	17.1	11.1
H <sub>2</sub> /CO		2	2	2	2	2	2	2	2	2	2	2

LHV of SG stored	kW	733	675.9	618.7	561.4	504.1	446.7	389.3	331.7	274.2	216.6	159
Total amount of power/energy required		171.4	163.7	156	148.4	140.7	133	125.3	117.6	109.9	102.2	94.6
Total power generated		343.9	321.5	299	276.5	254	231.4	208.8	186.2	163.6	141	118.3
Net power generated		172.5	157.7	143	128.2	113.3	98.4	83.5	68.6	53.7	38.7	23.8
Net plant efficiency	%	68.4	67.1	65.6	63.9	61.8	59.4	56.5	53	48.6	43	35.7

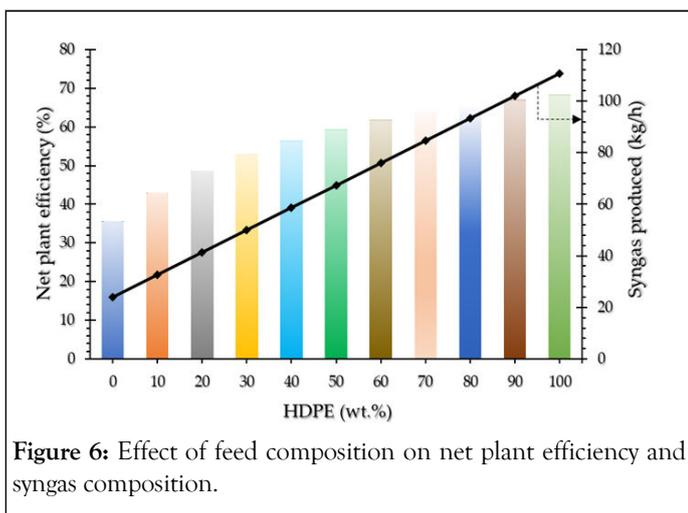


Figure 6: Effect of feed composition on net plant efficiency and syngas composition.

## CONCLUSION

Thermodynamic models for the co-gasification of Rice Husk (RH) and High-Density Polyethylene (HDPE) with a Carbon Capture and Utilization (CCU) system was developed using ASPEN Plus for the generation of syngas with H<sub>2</sub>/CO ratio of 2. The integrated system was made self-sustainable by adding heat recovery and steam generation and power generation section to meet the process steam and power requirements. The heat demand of the gasifier and reformer is met by burning a fraction of the produced syngas. Sequential parametric sensitivity analysis performed for the case of 50% RH and HDPE showed that complete carbon conversion to syngas within the gasifier can be attained at Steam to Carbon (S/C) ratio of 1.2. However, the net plant efficiency was found to be maximizing at S/C ratio of 1.4. Further the comparative analysis of the 11 different co-gasification cases revealed that the increase in weight percent of RH in feed mixture, resulted in lower carbon content, but higher O<sub>2</sub> and ash content during gasification which resulted in

- Decrease in process steam and CO<sub>2</sub> demand.
- Decrease in amount of syngas produced.
- Increase in fraction of produced syngas that was burnt to meet process heat demand.
- Decrease in utilization of the captured CO<sub>2</sub>.
- Decrease in net power generation and net plant efficiency.

Due to the high ash concentration of the RH in comparison to the absence of ash content in the case of HDPE, the total plant efficiency was found to be at its best in the case of pure HDPE at 68% and decreased to practically half (35%), in the case of pure RH.

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