6. Međunarodne konferencije o obnovljvim izvorima električne energije

GASIFICATION OF AGRICULTURAL RESIDUES AND MUNICIPAL SOLID WASTE FOR ELECTRICITY AND HEAT PRODUCTION

Aleksandar JOVOVIĆ, Marta TRNINIĆ, Dragoslava STOJILJKOVIĆ,
Miroslav STANOJEVIĆ
University of Belgrade Faculty of Mechanical Engineering

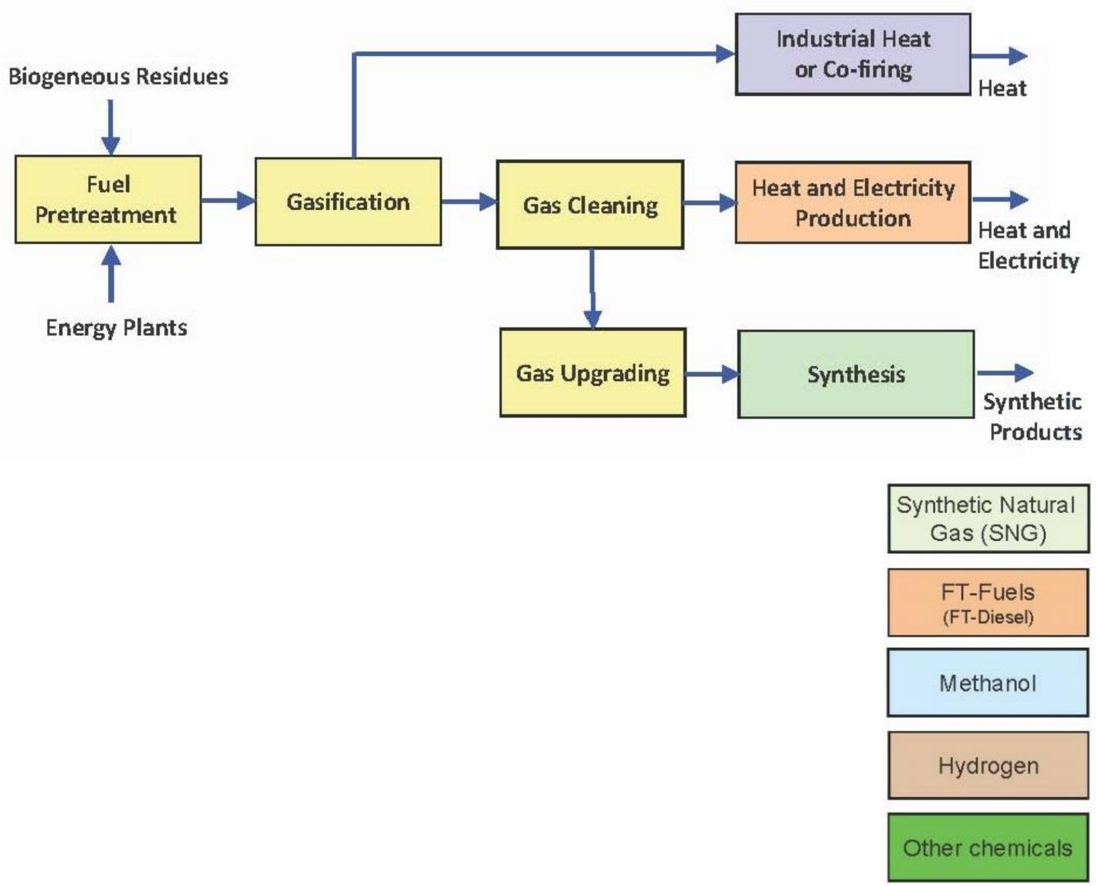
11-12 October, Belgrade, Serbia

OUTLINE

- Introduction
- Why process modelling?
- Development of a steady state model in EES that can handle different biomass feedstocks, can be sensitive enough to evaluate the influence of λ, air preheating, steam injection, oxygen enrichment and biomass moisture content on the quality and compositions of gas products
- Mathematical model development of a small-scale CHP system, based on biomass waste downdraft gasification and IC gas engine
- Powered by corn cobs (as a form of waste biomass).
- Possible to simulate how the *heat* from the producer gas and IC gas engine can be used to *increase the performance of the system* (by powering the gasification process (preheating air or generate steam) and heating water for district heating network - DHN).

MODELING GOALS

- Determining optimal operating conditions
- Studying a wider range of conditions that cannot (or easily cannot) be obtained experimentally
- Understanding experimental results and analysing improper performance of a gasifier
- Choosing an appropriate feedstock and evaluating its yield


Biogeneous Residues
Fuel Pretreatment
Energy Plants
Gasification
Industrial Heat or Co-firing
Heat
Gas Cleaning
Heat and Electricity Production
Heat and Electricity
Gas Upgrading
Synthesis
Synthetic Products
Synthetic Natural Gas (SNG)
FT-Fuels (FT-Diesel)
Methanol
Hydrogen
Other chemicals

- biomass gasification coupled with IC gas engine - to be used as preliminary tools to evaluate the characteristics of CHP biomass gasification plants.

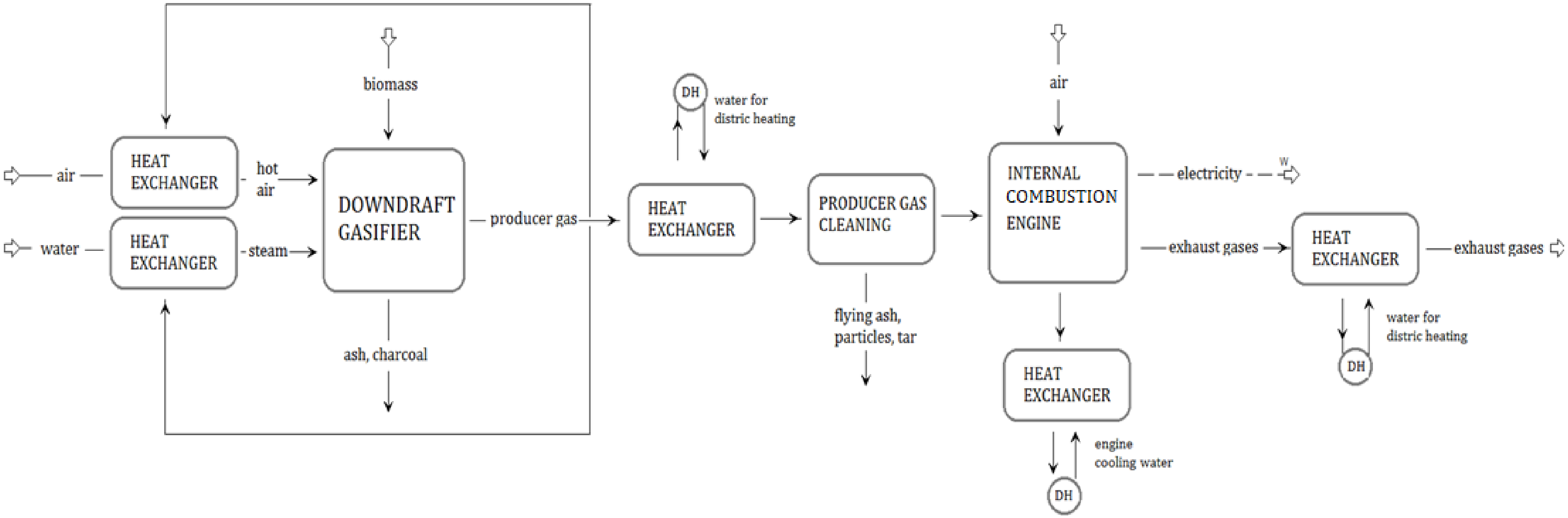
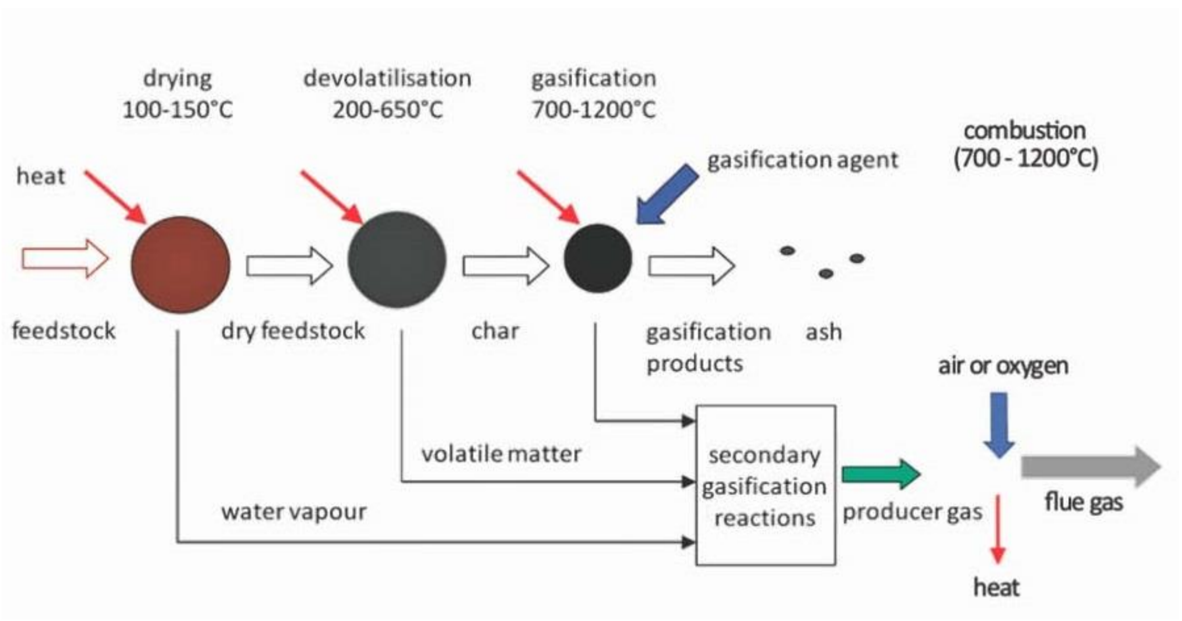
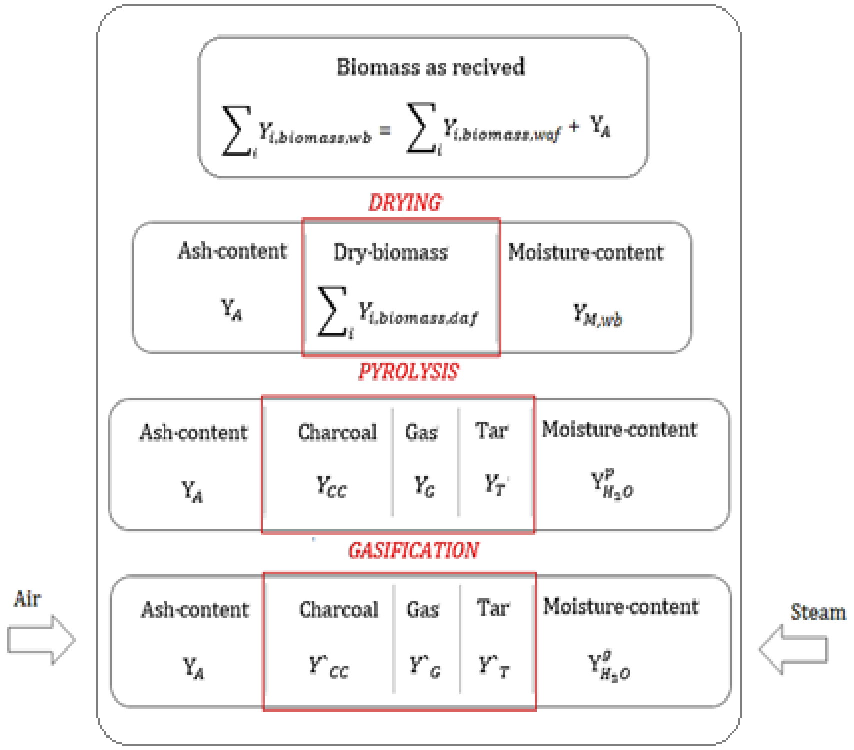


Figure 1: The block scheme of the typical components of a CHP small-scale gasification plant

- to predict the performance of the whole system under varying operating conditions: different biomass characteristics, ambient temperature, gasifying agent, etc. This model should be useful, at a design stage, to evaluate the outputs of the plant for different types of biomass and operating conditions.

DOWNDRAFT GASIFICATION MODELING APPROUCH





Gasifier model

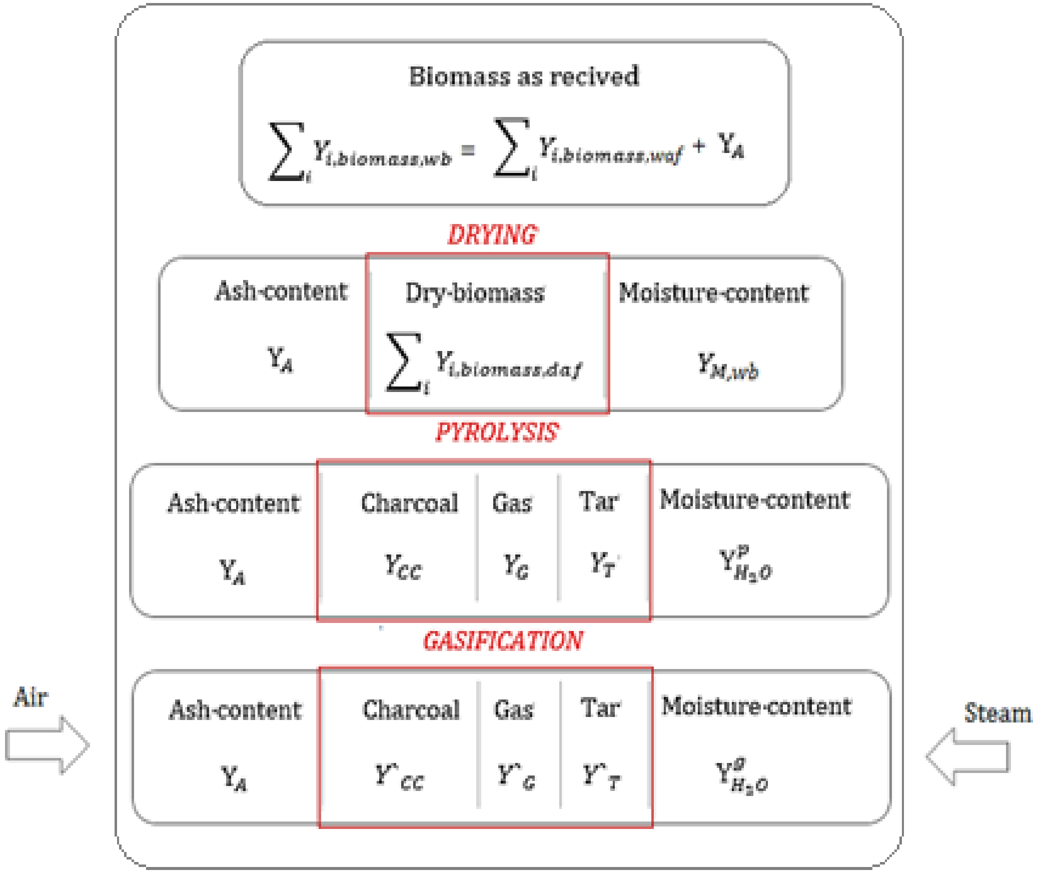


Figure 2 Overall mass balance for the biomass gasification process

the energy, mass,
molar balances for each element (C, H, O, and N)
are set and used to calculate the gasification products.

Drying:

$$\sum_i Y_{i,biomass,waf} + Y_A \xrightarrow[drying]{} \sum_i Y_{i,biomass,daf} + Y_{M,wb} + Y_A$$

Pyrolysis:

$$\sum_i Y_{i,biomass,daf} + Y_{M,wb} + Y_A \xrightarrow[pyrolysis]{} \sum_j Y^p_{j,products,daf} + Y^p_{H_2O} + Y_A$$

$$\sum_j Y^p_{Y\,j,products,daf} = Y_{CC} + Y_T + Y_G$$

$$Y_G = Y_{CO2} + Y_{CO} + Y_{CH4} + Y_{H2}$$

$$Ycc = 7.97T^2 \cdot 10^{-5} - 0.125 \cdot T + 68.8$$

$$Y_T = -1.38T^2 \cdot 10^{-4} + 0.12 \cdot T + 12.64$$

$$Y_G = 1.12T^2 \cdot 10^{-4} - 0.058 \cdot T + 30.77$$

$$Y_{CO} = -2.65T^2 \cdot 10^{-4} + 0.27 \cdot T - 32.71$$

$$Y_{CO2} = -2.85T^2 \cdot 10^{-5} - 0.029 \cdot T + 70.89$$

$$Y_{CH4} = 6.69T^2 \cdot 10^{-5} - 0.037 \cdot T + 4.28$$

$$Y_{H2} = 7T^2 \cdot 10^{-5} - 0.0371T + 5.11$$

Gasification

$$\sum_j Y^p_{j,products,daf} + Y^p_{H_2O} + Y_A + Y_{AIR} + Y_{STEAM} \xrightarrow[gasification]{} \sum_j Y^g_{j,products,daf} + Y^g_{H_2O} + Y_A$$

ASSUMPTIONS

1. Heat losses in in pyrolysis and gasification units are estimated by the user as a percentage of biomass energy input to the system
2. Corn cobs are assumed to enter the CHP plant at 25 °C and 1 atm.
3. The air for the gasification process is considered as dry, containing only: 21% O_2, 78% N_2 (volume fraction)
4. The gasification consists of a series of sub-processes:
    a. drying unit, that predicts the removal of moisture from raw biomass. The percentage of removed moisture can alternatively be set by the user.
    b. pyrolysis unit that, using empirical correlations, predicts the formation of pyrolysis products (charcoal and volatiles, including tar)
    c. gasification unit, that predicts the formation of gasification products (gas, including small amount of charcoal and tar)
    d. air preheating, and steam generation units
5. Tar and charcoal leaving the gasifier as a percentage of tar and charcoal produced in the pyrolysis unit
6. Particles leaving the gasifier are set by the user as mg/Nm^3 in the producer gas. These particles are considered to consist only of carbon
7. Gas products consists of CO_2, CO, H_2, CH_4, N_2, and H_2O

8. Setting the amount of CH_4 produced
9. The model considers that producer gas completely cleaned from particles, tar and organic and inorganic impurities (through a water scrubber cyclone, bag filter etc)
10. Modelling of the IC gas engine was carried out without consideration of the thermodynamic cycle and mechanical aspect analysis

Biomass fuel

Table 1. Proximate and elemental analysis of corn cob

Elemental analysis (wt %)^a				
C	H	N	O^b	S
47.61	6.27	0.55	43.89	0.23
Proximate analysis (wt %)^a				
Moisture content^c	VM	fix- C	ash	HHV (MJkg-1)
5.18	81.08	17.47	1.45	18.63

a Dry mass basis, b By difference and c As received.

Here, a scenario **analysis of the gasification CHP plant configuration** is presented:

1. The air is not preheated (25 ^{o}C)
2. The air is preheated up to 400 ^{o}C
3. The air and steam is preheated up to 400 ^{o}C

Internal combustion engine model

- The exhaust gas composition - calculated based on the combustion stoichiometry
- All gases are ideal gases and their enthalpies and specific heats only change with temperature.
- The electricity and heat generated by the IC gas engine are calculated based on the electrical (ηel) and thermal (ηth) efficiencies of a GE's Jenbacher JMS 208 GS-B.L gas engine ($\eta el=35.8\%$, $\eta th=41.9\%$)

Electrical and thermal efficiencies are defined as follows:

$$\eta_{el} = \frac{W}{LHV_{gas} \times V_{gas}}$$

$$\eta_{th} = \frac{Q}{LHV_{gas} \times V_{gas}}$$

The efficiency of CHP system performance

- The cold gas efficiency:

$$\eta_{cge} = \frac{Q_{pgas}}{Q_{biomass}} = \frac{V_{pgas} \times LHV_{pgas}}{m_{biomass} \times LHV_{biomass}}$$

- The electrical (ηe), thermal (ηt) and overall efficiencies (ηCHP) of a CHP plant are calculated as follows:

$$\eta_e = \frac{W_e}{Q_{biomass}}$$

$$\eta_t = \frac{Q_{DH} + Q_{steam} + Q_{AIR}}{Q_{biomass}}$$

$$\eta_{CHP} = \frac{W_e + Q_{DH} + Q_{steam} + Q_{AIR}}{Q_{biomass}}$$

RESULTS AND DISCUSSION

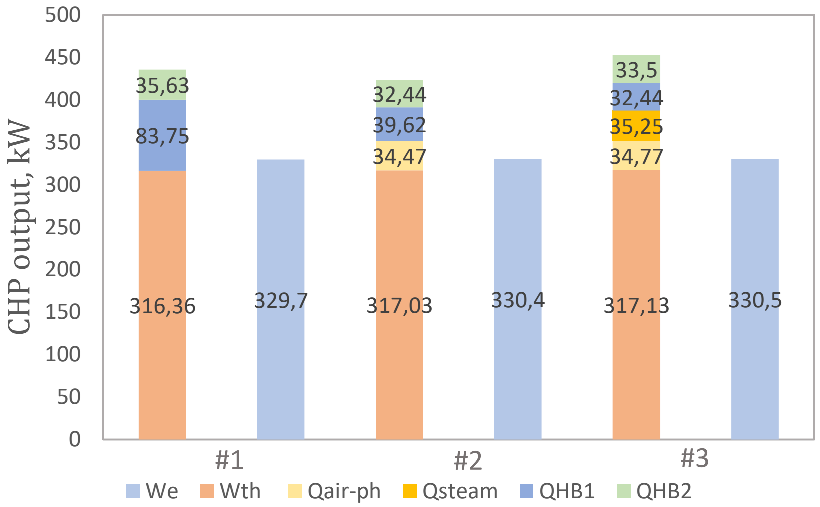
Producer Gas Characteristics

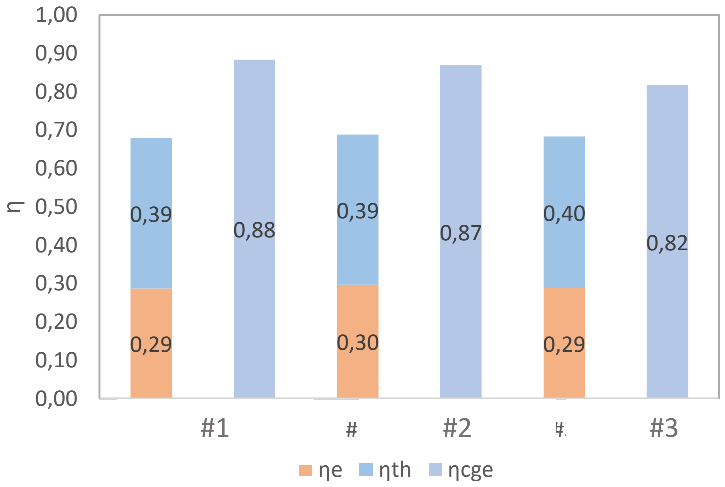
	Model **(in this study) steady state model for downdraft**		**Da Silva [63] downdraft gasification of corn cob**	**Senelwa [62] downdraft gasification of P. tomantosa with bark**
$T_{gasification}$ (^{o}C)	930 ^{o}C	955 ^{o}C	930 ^{o}C	955 ^{o}C
λ	0.25	0.19	0.25	0.19
CO	24.21	24.03	19.00	24.10
CO_2	9.68	9.51	10.30	9.50
H_2	14.84	14.47	15.90	12.90
CH_4	3.00[a]	2.50[a]	3.00	2.50
N_2	48.27	49.22	49.51	51.10
LHV of gas (MJ/Nm^3 dry)	6.22	5.52	5.66	6.11

Producer Gas Characteristics

	Configuration		
	No Air preheating (25 ^{o}C)	Air preheating	Air and steam preheating
		T_{air}=400 ^{o}C	$T_{air/steam}$=400 ^{o}C
$T_{gasification}$ (^{o}C)	955	955	955
λ	0.19	0.23	0.23
Gas composition (vol%)			
CO	24.03	26.94	25.78
CO_2	9.51	8.13	8.95
H_2	14.47	17.03	17.61
CH_4	2.50	2.5	2.5
N_2	49.22	45.41	45.17
LHV of gas (MJ/Nm^3 dry)	5.52	6.13	6.05

CPH power plant -downdraft gasification with IC gas engine specification			
Fuel Characteristics			
Fuel	Corn cob		
Size	Do=10-20 mm		
System Characteristics	#1	#2	#3
Biomass consumptions	239 kg/h	222 kg/h	229 kg/h
LHV of biomass	18.045 MJ/kg		
Pyrolysis temperature	450 °C	450 °C	450 °C
Air	293.60 Nm^3/h	240.90 Nm^3/h	249.6 Nm^3/h
Steam	-	-	10 kg/h
Air Temperature	25 °C	400 °C	400 °C
Steam Temperature	-	-	400 °C
LHV of produced gas	6.39 MJ/Nm^3	6.97 MJ/Nm^3	6.87 MJ/Nm^3
Volume of produced gas[a]	575.9 Nm^3/h	499.30 Nm^3/h	530.40 Nm^3/h
Gasification Temperature	950 °C	950 °C	950 °C
Ash	3.47 kg/h	3.22 kg/h	3.32 kg/h
Charcoal[b]	3.27 kg/h	3.04 kg/h	3.13 kg/h
Tar[c]	3.58 kg/h	3.33 kg/h	3.43 kg/h
CHP output			
Electric energy	329.70 kW	330.40 kW	330.50 kW
Heat energy	316.36 kW	317.03 kW	317.13 kW
Operating hours per year	7000 h	7000h	7000 h
Overall recoverable thermal energy	435.74 kW	389.09 kW	383.51 kW
Air preheating	-	34.47 kW	34.77 kW
Steam Generation	-	-	35.25 kW
Heat Block 1	83.75 kW	39.62 kW	32.88 kW
Heat Block 2	35.63 kW	32.44 kW	33.50 kW
Efficiency of CHP system			
η_{cge}	85.35 %	86.89 %	88.20 %
η_e	28.73 %	29.69 %	28.80 %
η_t	39.13 %	39.07 %	39.52 %
η_{CHP}	70.86 %	64.76 %	63.05 %





CONCLUSION

- Model can be used to predict the final producer gas composition and its main characteristics, for a certain biomass with a defined ultimate composition and moisture
- Model can predict influence of different gasifying agent characteristics on CHP plant performance
  - use of preheated air and air/steam mixture achieves downsizing of the plant
- Mixture of air and steam injected in biomass gasification increases slightly the H_2 content of producer gas.
- Model has proved to be effective at simulating electricity generation

  All three configurations generate the same electricity.

  The first case, with no air preheating as gasfiying agent, has the highest production of heating for the DH.

Nevertheless, all the configurations have similar values for cold gas efficiency (around 82%).

- The overall CHP efficiency is for 10% higher for cases when as a gasfiying agent is used preheated air and air/steam mixture (around 63%).