MODELLING OF A DOWNDRAFT GASIFIER FED BY AGRICULTURAL RESIDUES

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Introduction

- Gasification is a thermo-chemical process next to combustion and pyrolysis, in order to produce energy.
- Numerous systematic overviews of implemented and tested gasification technologies have been developed providing the categorization which is illustrated in the following table.

Reactor type	**Fixed bed**	**Moving bed**	**Entrained bed**
	1. Updraft 2. Downdraft	3. Crossdraft	
Fuels	Biomass/coal	biomass	Coal
		Capacity* (* = output is referred to thermal power)	
Downdraft	**Updraft**	**Entrained flow**	**Fluidized bed**
10kW-1MW	1MW-10MW	>50MW	1MW-100MW

Gasification stages

- The *pyrolysis* process occurs when the carbonaceous matters heat up. When the temperature raises, volatiles are released and char is produced.
- The volatile products and some of the char from the pyrolysis process react with oxygen to primarily form carbon dioxide and small amounts of carbon monoxide. These reactions provide enough heat for the reactions for the gasification process.
- During the gasification process, the char reacts with carbon dioxide and the gasification agent (air/steam/oxygen), in order to produce carbon monoxide and hydrogen.

$$CO_2 + C \rightarrow 2CO \quad \text{(R1)} \quad (\Delta H = -172.6\ \text{KJ/mol})$$

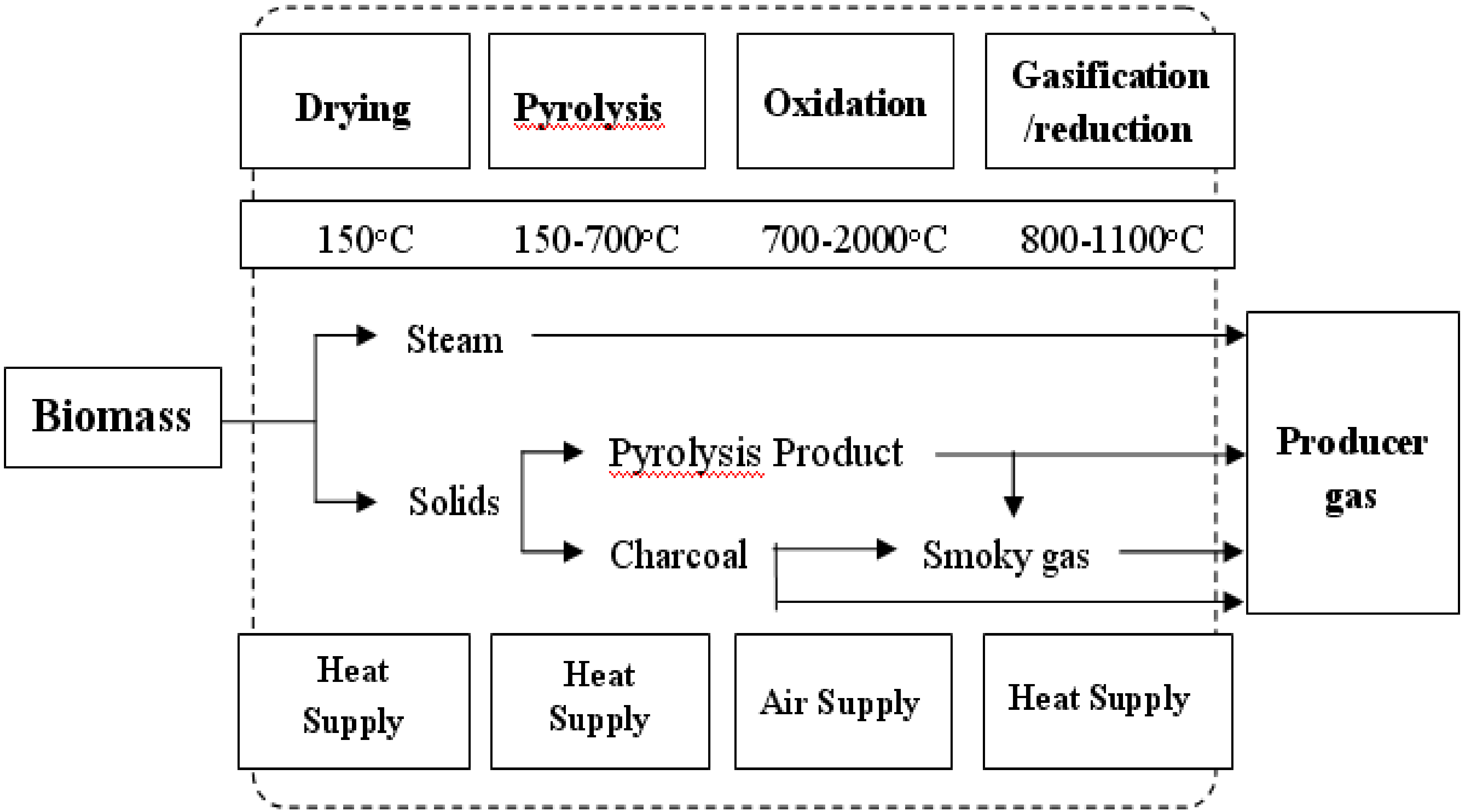
$$C + H_2O \rightarrow H_2 + CO \quad \text{(R2)} \quad (\Delta H = -131.4\ \text{KJ/mol})$$

$$C + 2H_2 \rightarrow CH_4 \quad \text{(R3)} \quad (\Delta H = +75\ \text{KJ/mol})$$

$$CO + H_2O \rightarrow CO_2 + H_2 \quad \text{(R4)} \quad (\Delta H = 41.2\ \text{KJ/mol})$$

Gasification process

- Temperature ranges of each stage



Model developed

- A thermodynamic model of a downdraft fixed-bed gasifier fed by three different kind of biomass was developed.
- The thermodynamic equilibrium calculations are suitable for studying the influence of fuel and process parameters.
- The proposed methodology predicts the potential syngas yield and its composition.
- Applying the thermodynamic equilibrium approach a chemical equilibrium should be established in order to predict the amount and the composition of the syngas.
- The chemical equilibrium methodology of the non-stoichiometric equilibrium model is developed through two different approaches (i) stoichiometric model and (ii) minimization of the Gibbs free energy.

$$G_{total} = \sum_{i=1}^{N} n_i \Delta G^0_{f,i} + \sum_{i=1}^{N} n_i RT \ln\left(\frac{n_i}{\sum n_i}\right)$$

Inserted feedstock

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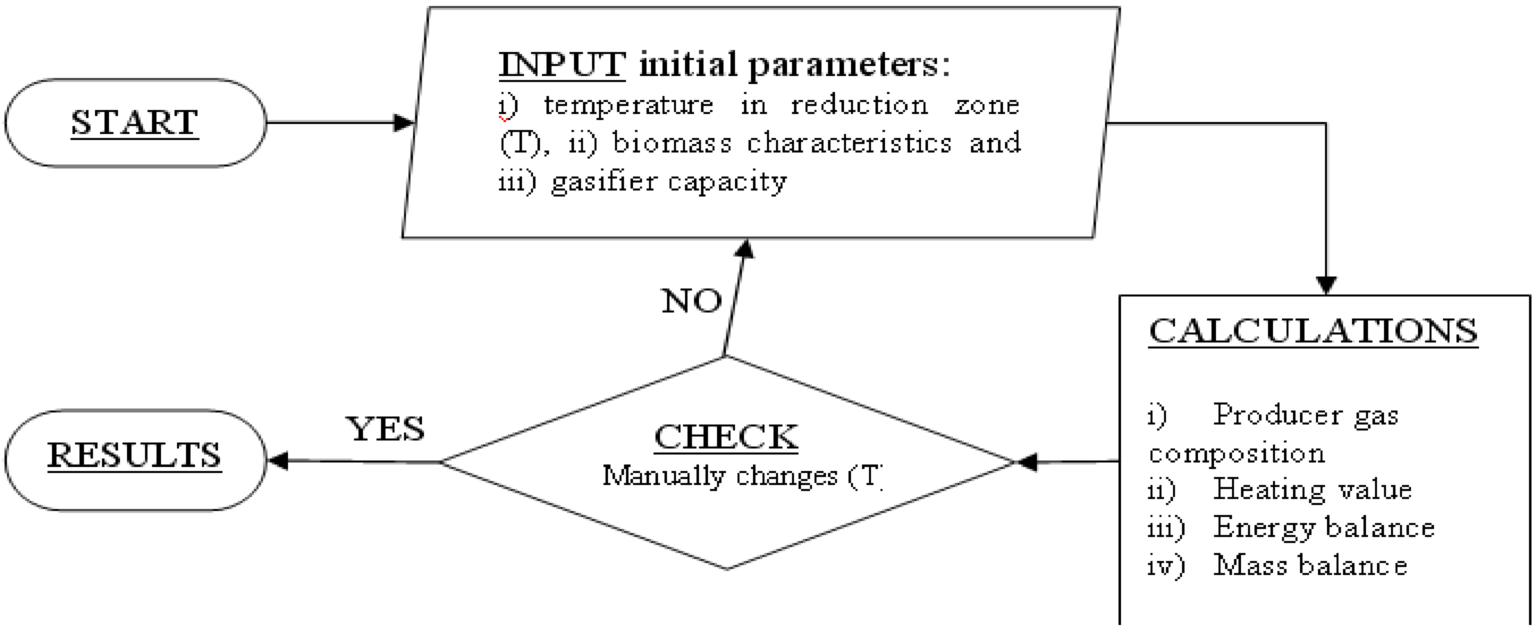
- Proximate and ultimate analysis for the three feedstocks is presented in the following table.
- Miscanthus, olive wood and cardoon were selected as inserted feedstocks in the model.
- Physicochemical characteristics are illustrated.

Proximate analysis (%)				
Inserted fuel (%)	**Volatile matter**	**Fixed Carbon**	**Moisture**	**Ash**
Miscanthus	71.9	14	11.4	2.7
Olive wood	74.3	16.1	6.6	3
Cardoon	73	13.1	10	3.9
Ultimate analysis (%)					
	C	**H**	**S**	**N**	**O**
Miscanthus	49.2	6	0.15	0.4	44.2
Olive wood	49	5.4	0.03	0.7	44.9
Cardoon	39	6.6	0.2	1.5	52.7

Model's structure

- The proposed gasification model is a tool for predicting the produced gas' composition and it's heating value.
- In order to investigate the impact of the gasification temperature (i.e. the temperature of the reduction zone) in the produced gas' composition and its heating value, the developed model was applied parameterically in a manual fashion.



Design parameters

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- The main parameters for estimating the mass balance of a gasifier are the produced gas flow, its lower heating value (LHV) and the fuel feed rate.

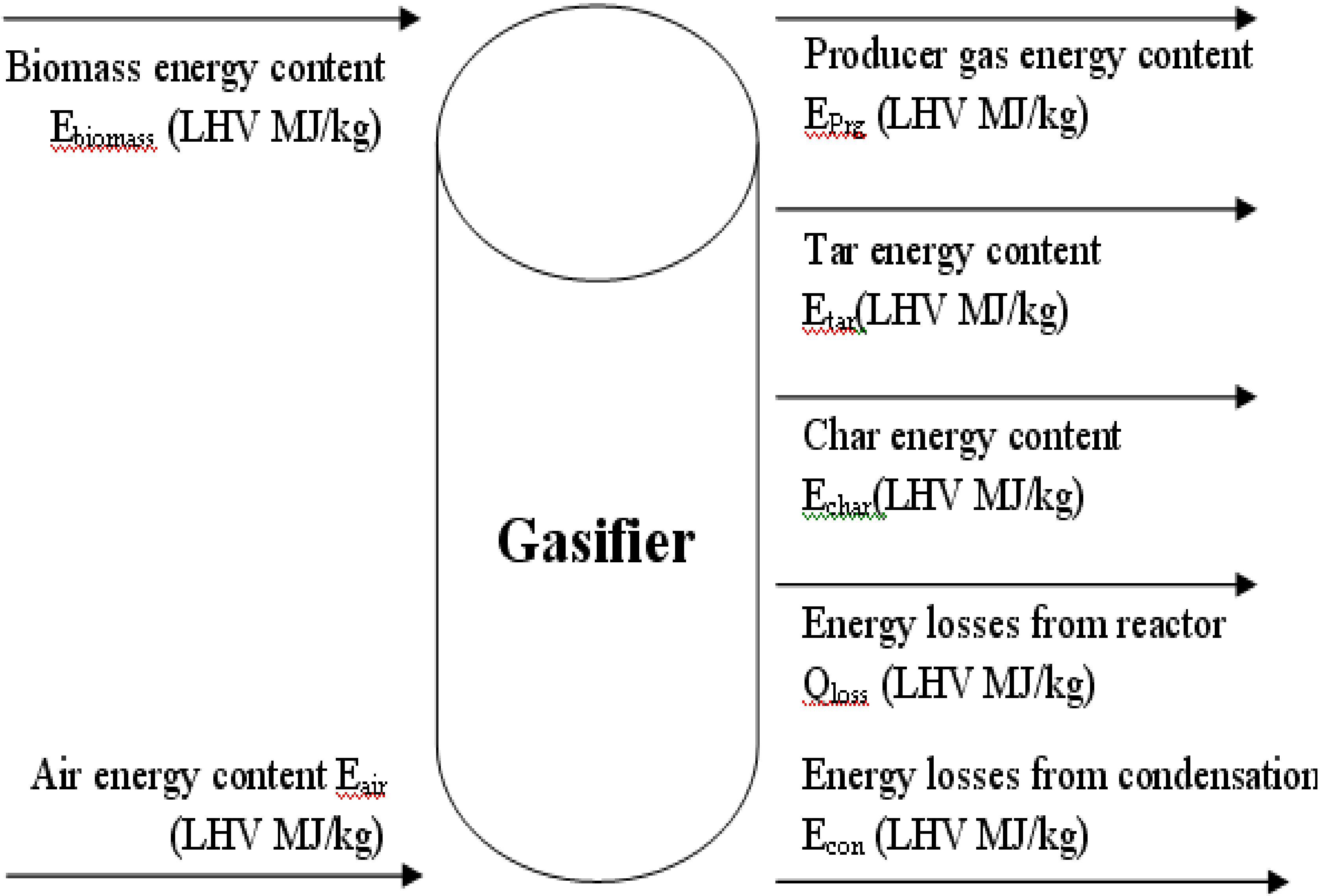
$$\lambda(<1)_g = \frac{Actualair}{Stoichiometricair}$$

$$V_g = \frac{Q}{LHV_g} Nm^3/s \qquad M_g = \frac{Q}{LHV_{fuel} n_{gef}}$$

- Energy balance: The standard Gibbs free energy of each chemical species is calculated by subtracting the standard enthalpy from the standard entropy at a specific temperature T

$$Q_{loss} + \sum_{r=react} n_r \overline{H}_r^o(T_r) = \sum_{p=prod} n_p \overline{H}_p^o(T_p) + \Delta H$$

Energy balance



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Energy balance - parameters

Symbol	Energy content	Description
	Energy input	
$E_{biomass}$	Biomass energy content	$= LHV_{biomass} * M_f$
E_{air}	Air energy content	$= LHV_{air} * m_{air}$
	Energy output	
E_{Prg}	Producer gas content	$= LHV_{pg} * V_{pg}$ V_{pg} is the producer gas flow
E_{tar}	Tar energy content	$= (LHV_{tar} * M_{tar} + M_{tar} * cp_{tar} * \Delta T)/1000$ In downdraft gasifiers tar content is about 0.1% of the inserted wood material, so the tar amount is almost negligible
E_{char}	Char energy content	$= (LHV_{char} * M_{char} + M_{char} * cp_{char} * \Delta T)/1000$ In this model char reacts with carbon dioxide and steam to produce carbon monoxide and hydrogen
Q_{loss}	Heat losses	$Q_{loss} = (Q_{convection\text{-}top} + Q_{convection\text{-}bottom}) + (Q_{radiation\text{-}top} + Q_{radiation\text{-}bottom})$ Q_{losses} are appeared in the top and the bottom part of the gasifier as free convection and radiation
E_{con}	Energy from condensation	$= M_y * (h_{Treduction} - h_{Tambient})/1000 + (M_{wv} * cp_{wv} * \Delta T)/1000$ E_{con} is the energy produced from the water condensation and the sensible heat of generated steam. It is assumed that the generated steam is fully condensated.
ΔH	Energy from reactions	Controls the temperature in reduction zone ($\Delta H < 0$ => manually reduction of temperature in reduction zone, $\Delta H > 0$ => manually increase of temperature in reduction zone)

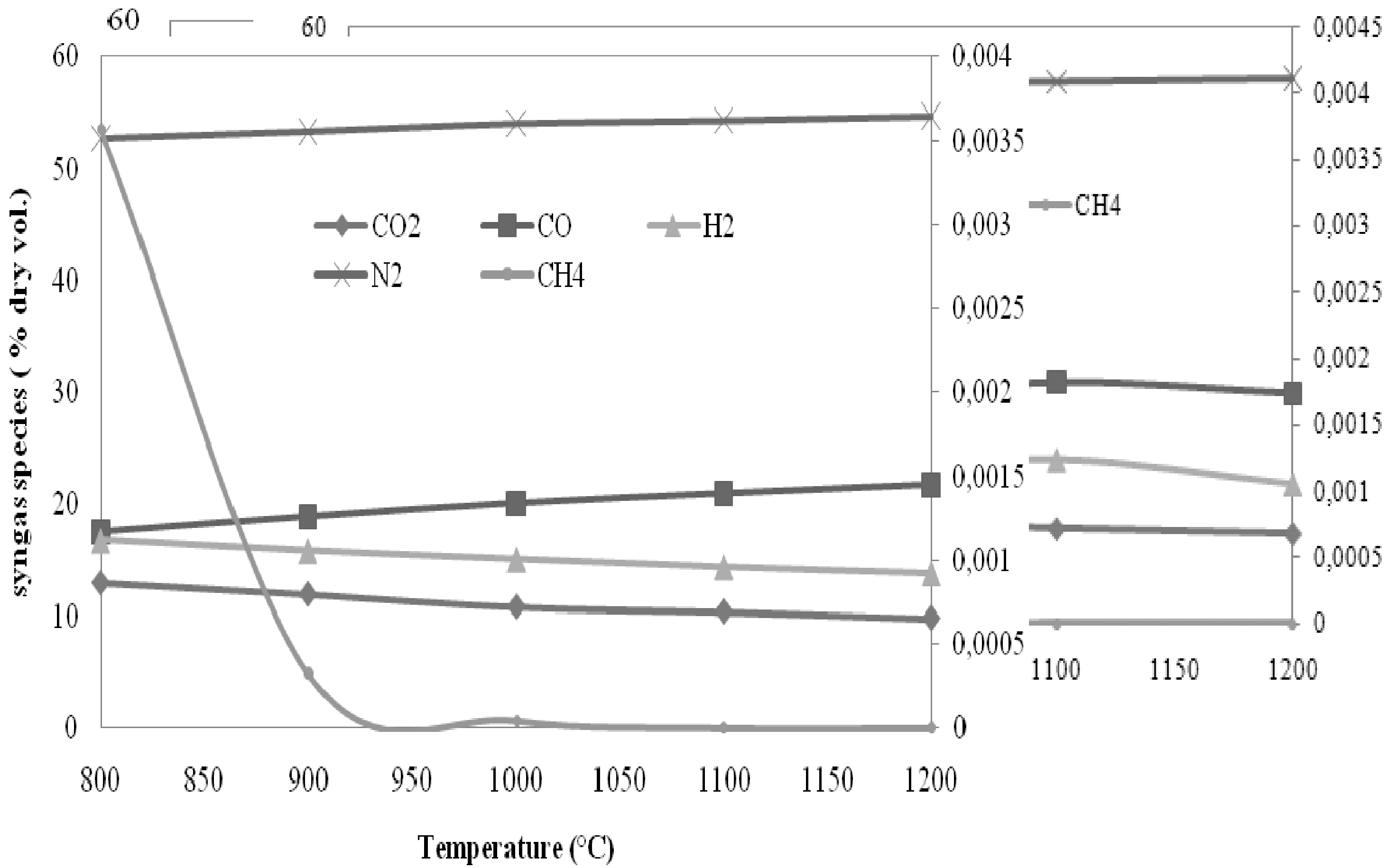
Model's parameters-assumptions

1. The feeding material of this model is biomass, which produces low tar (~3% of the inserted feedstock material). For that reason, the tar was estimated to be constant in relation to the inserted fuel.
2. All carbon of the inserted fuel is converted into gas.
3. No pressure drop occurs in the reactor.
4. The produced gases behave like ideal gases.
5. The produced gas includes only methane as far as hydrocarbons are concerned.
6. The concentrations of NOx, OH, C(g) and O2 are negligible in the producer gas.

Model was structured in the EES® software.

Thermal capacity: 0.5 MWth, biomass feeding rate: 556 kg/hr

- **Effect of temperature on syngas species concentration:** (a) miscanthus, (b) cardoon and (c) olive wood



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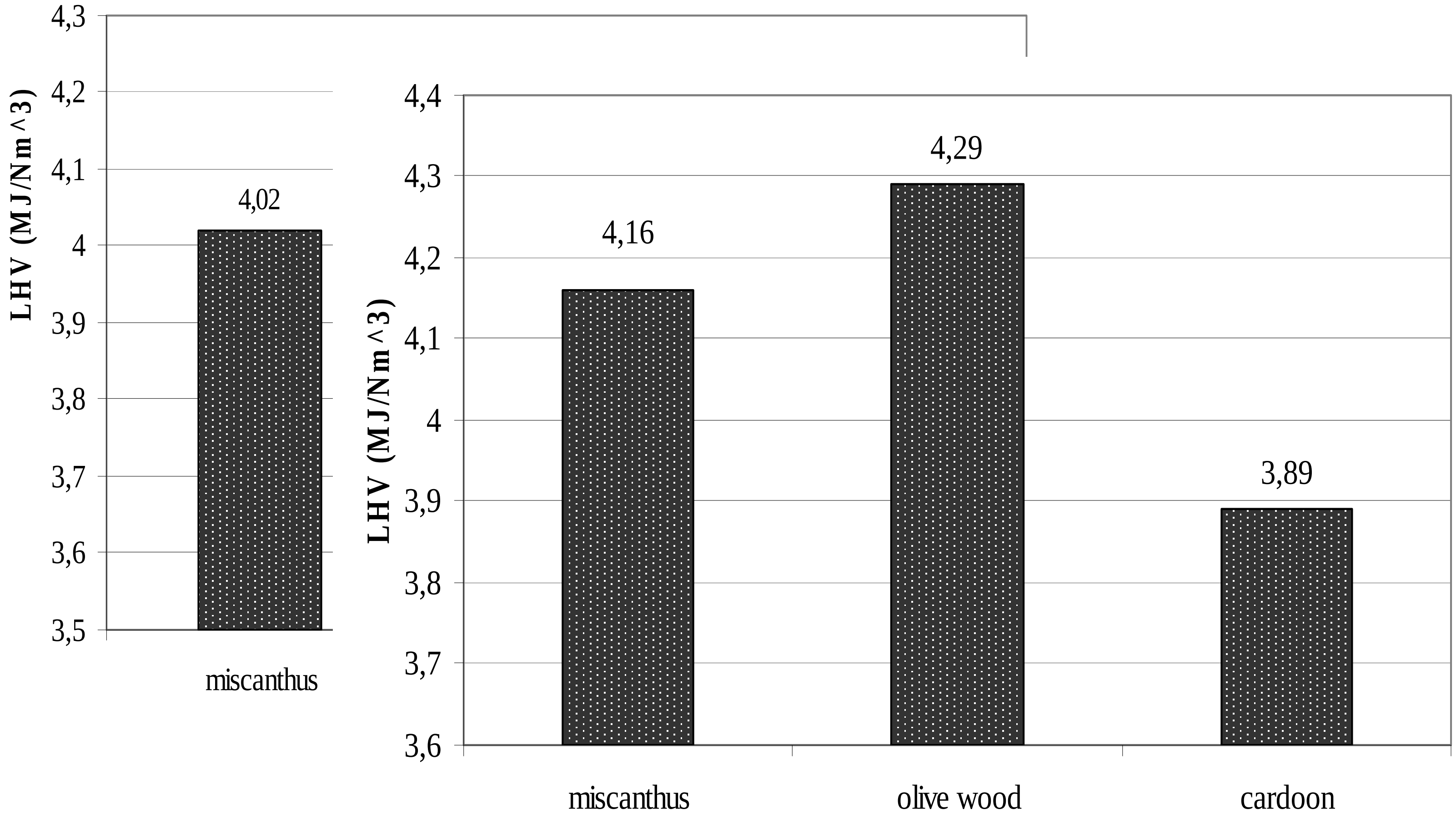
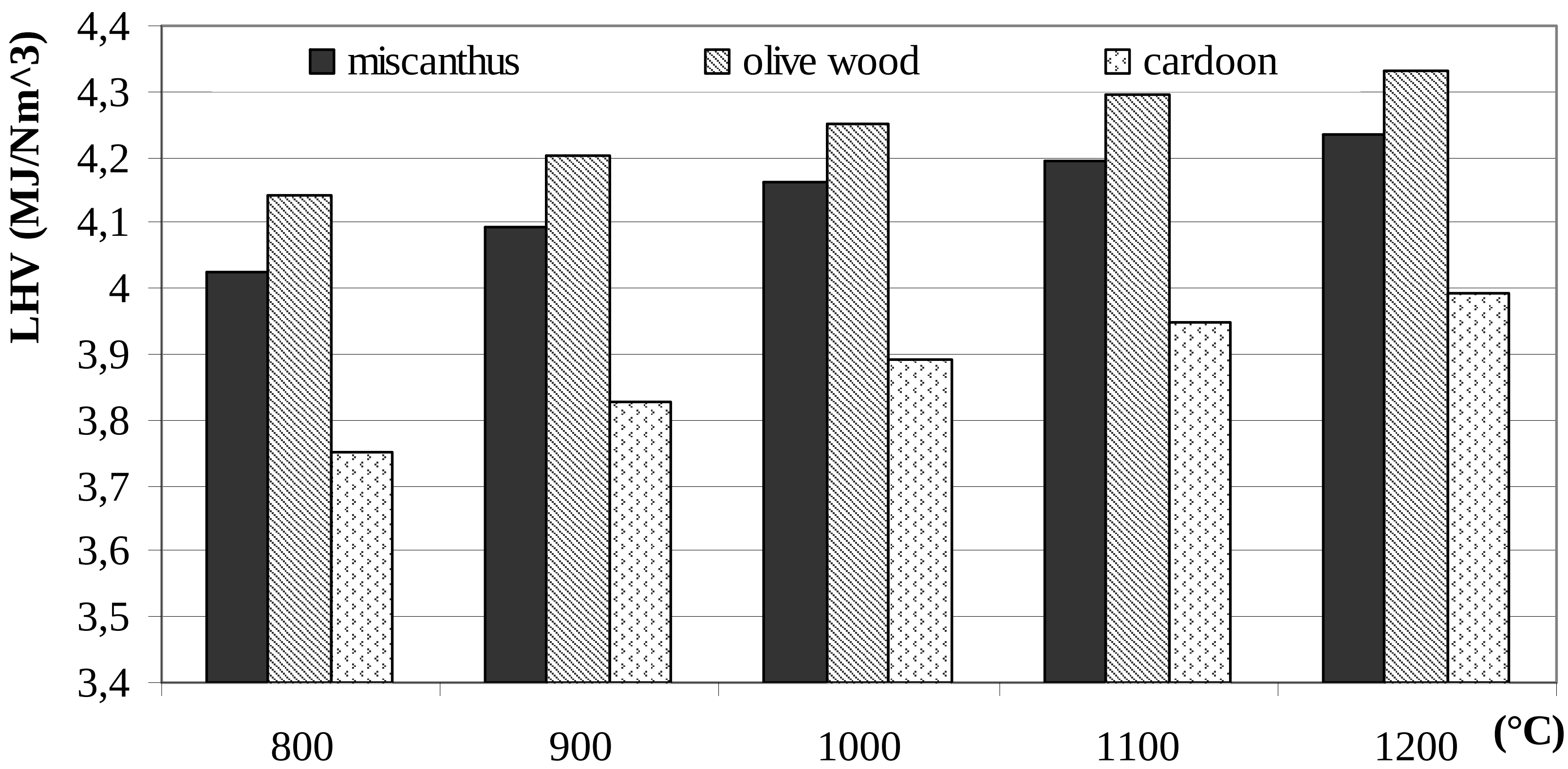
- **Effect of temperature on the LHV of syngas**: (a) 800°C and (b) 1000°C



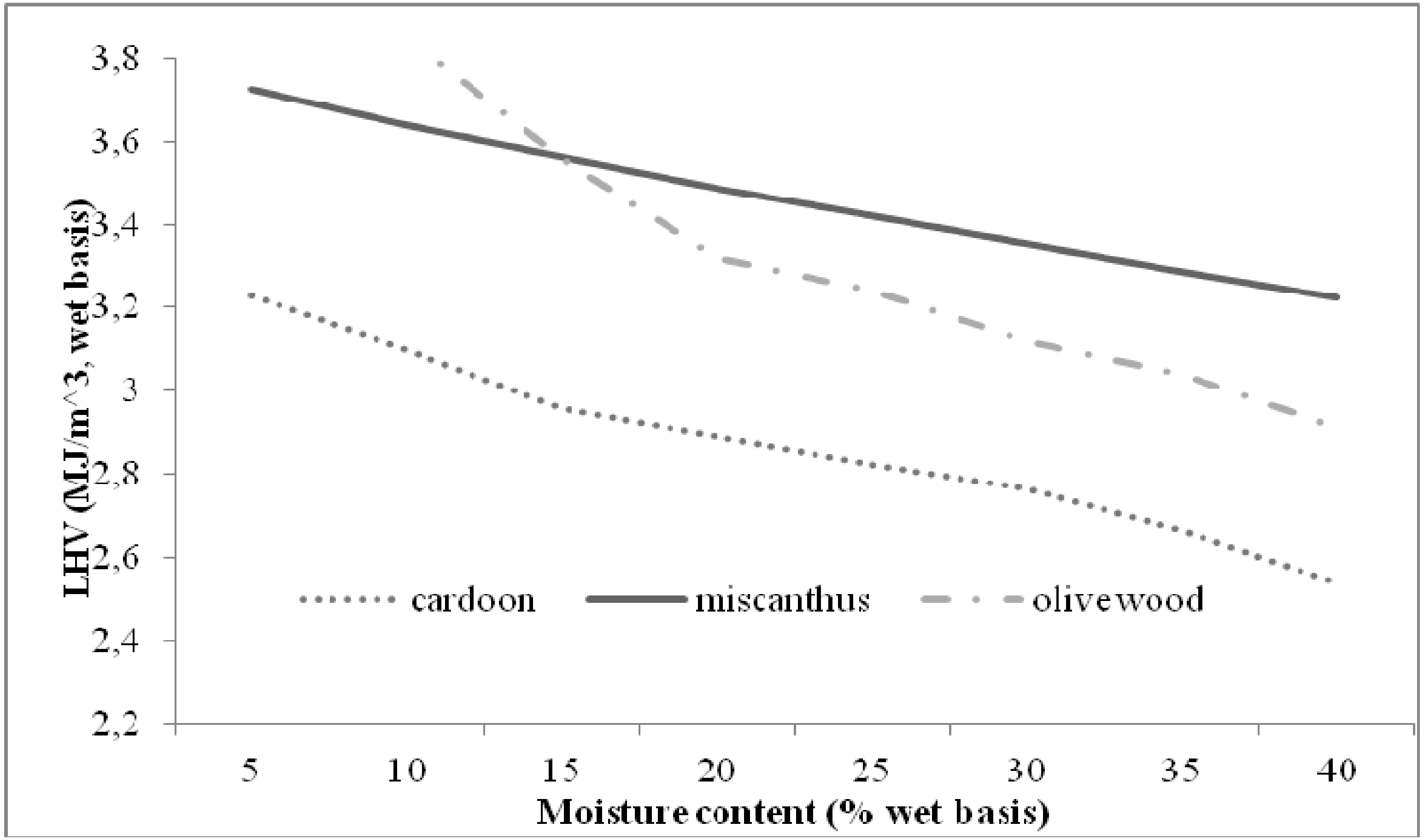
Results

- Produced gas' LHV for three biomass fuels at selected gasification-zone temperatures (between 800-1200°C)



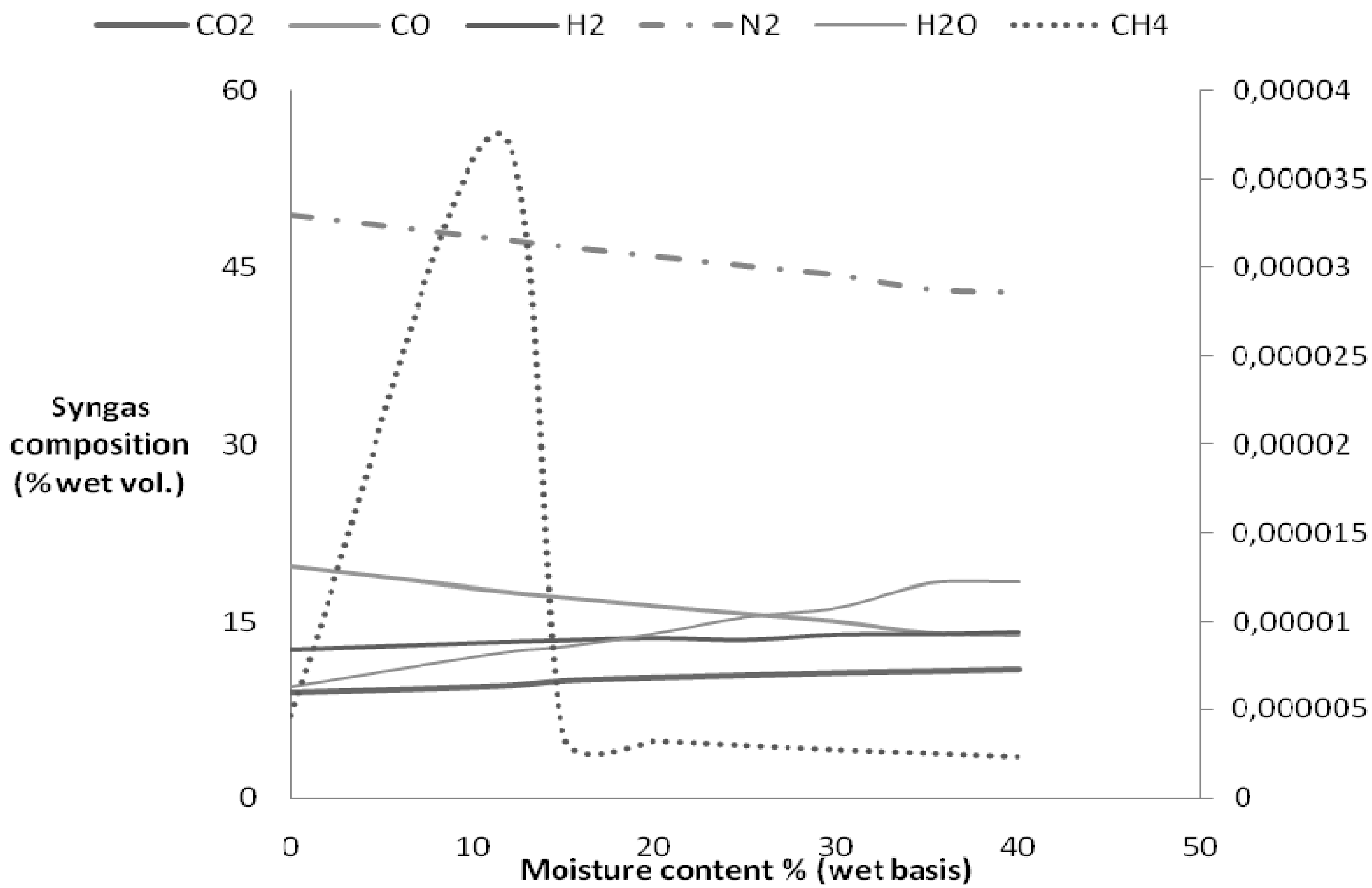
Results

- Effect of moisture content on syngas' LHV (olive wood, miscanthus, cardoon; wet basis)



Results

- Effect of moisture content on syngas' composition (miscanthus).



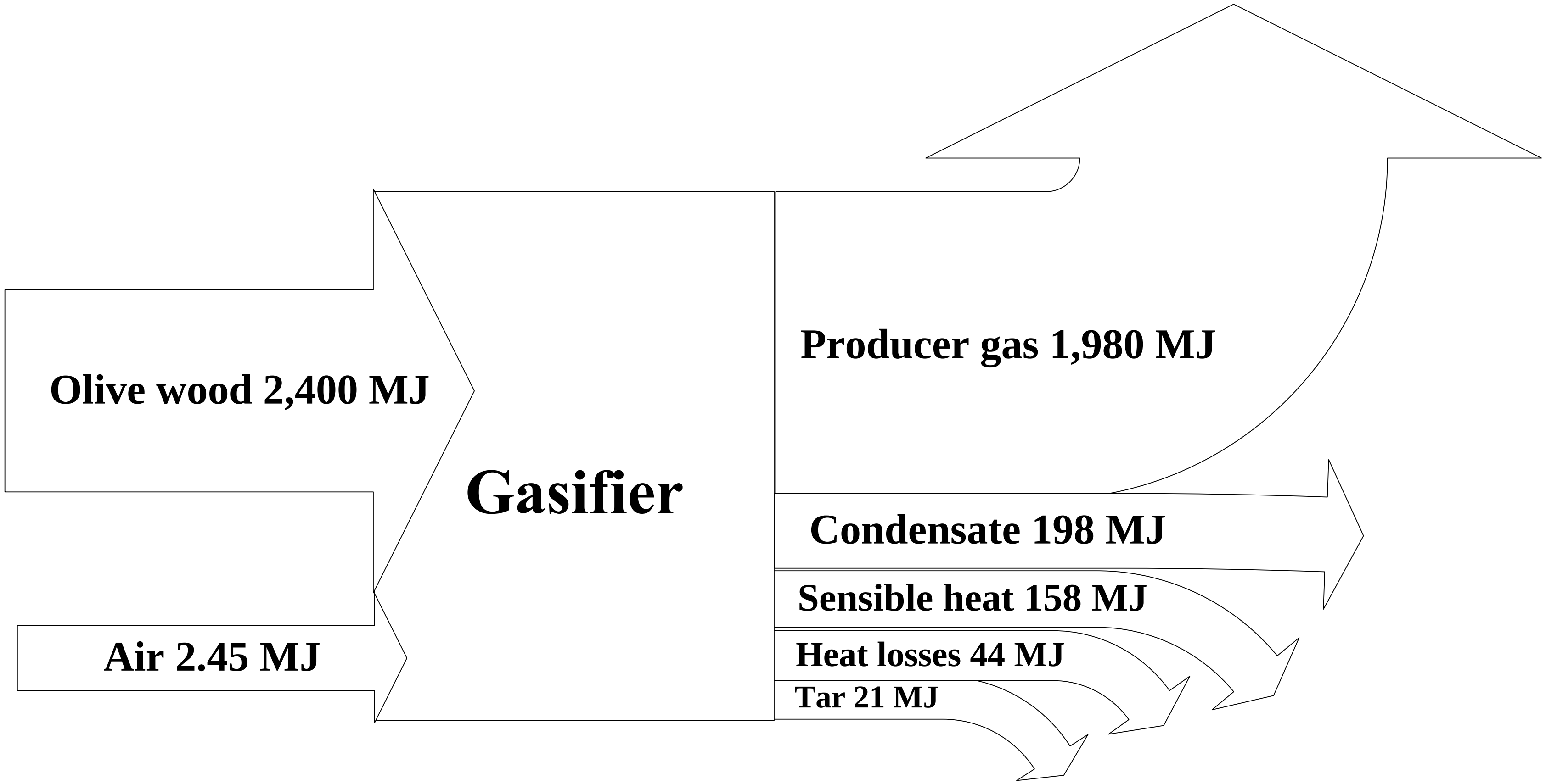
Results

- Model's results inserted feedstock: olive wood; thermal capacity: 0.5 MWth, feeding rate: 557.64 kg/hour, temperature in reduction zone: 1000 C

Software	Parameters	Olive wood
Input data in software	Feed size	20-25 mm width, 60-75mm length
	Feed rate	557.64 kg/h
	LHV fuel	4304 KJ/kg
	Gasification temperature	1,000°C
	Gasification pressure	1 bar
	Thermal capacity	0.5 MW_{th}
Assumption	Gasifier efficiency	75%
Output data format	Tar	0.56 kg/h
	Air flow rate	1,400 kg/h
	Hot gas efficiency	81.73%
	Product gas flow rate	465.84 m^3/h
	LHV producer gas (dry basis)	4.252 MJ/Nm^3
	Electrical energy output	209 kW_e

Results

- Energy performance of the modeled gasifier; Sankey chart



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Conclusions - Recommendations

- The linear equations derived to predict syngas composition based on knowledge of ultimate analysis and moisture content of biomass is a significant achievement that can be applied to the gasification process to find the upper limit of syngas production from an existing plant.
- The effect of moisture content and temperature is also studied through the equilibrium model, which serves as an improvement tool also in the field of gasifier design.
- The presented procedure gives the opportunity to optimize the entire gasification process. Several parameters of the entire process could be investigated in order to define their impact on the produced gas' composition. Main target of the optimization process is the maximization of the heating value of the produced gas (syngas).
- If the produced gas will be used in an internal combustion engine connected to a generator set, the hydrogen composition has to be maximized.

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Conclusions - Recommendations

- Six major components were found in the produced gas composition, while its heating value was about 4-6 MJ/m3 for each supplied feedstock.
- LHV of produced gas is reduced around 23-40%, when the feedstock's moisture is increased.
- The moisture content reduces CO fraction in syngas significantly, thus also reducing the HHV of the gas.
- The olive wood had the best performance in the present model.
- The model was based on the method of minimization of Gibbs free energy and was structured in such a way, in order to investigate the best temperature range in the reduction zone (which has a strong impact on its heating value).
- Heating value is a crucial parameter affecting the gasifier's efficiency, as it directly determines the generated energy.

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Concluding remarks

- Gasification: A strongly emerging technology for biomass and wastes.
- Still sensitive on the homogeneity of the feedstock (‘waste’ cases: RDF, SRF).
- Appropriate for small-to-medium scale applications.
- Particularly suitable when ICE already available from former applications.
- Thermodynamic models can help the proper design of gasifiers.

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Thank you for listening!

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