

Bioenergy production and net-zero carbon dioxide emissions investigation for a small scale biorefinery unit

1. INTRODUCTION

For the production of solid biofuels and advanced liquid biofuels it is required to examine the associated carbon dioxide emissions in the chain of production. The objectives were to:

- Overview woody biomass feedstocks for large scale use in biorefineries.
- Develop a methodology for the estimation of energy input and bioenergy production output, and for the evaluation of the chain of emitted carbon dioxide (CO2).
- Investigate a small rural biorefinery unit, using real data.



Figure. Woody biomass collection at site.

The unit receives wood chips, pruning and other biowaste from gardens, forest industry etc. The final products include briquettes (Φ=70mm) and pellets (d=7, 10mm), produced by a stamping machine.



Figure. Woody biomass at the biorefinery unit collection area.



Figure. Wood pellets final product at the biorefinery unit storage area.

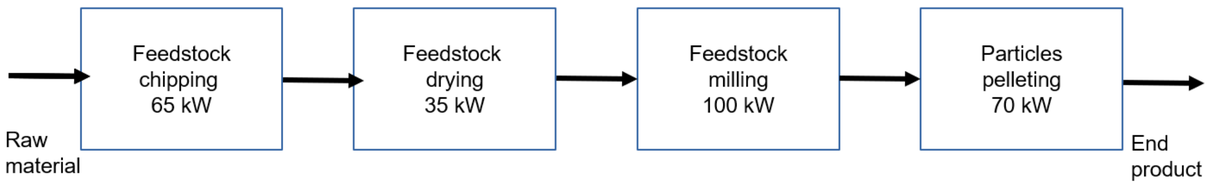


Figura. Flowchart of production processes and installed power at the biorefinery unit.

2. METHODOLOGY

The energy input per mass of feedstock pretreated is given by Eq. (1),

$$E_{pr,unit} = \frac{P_{inst}\, n_{h,day}}{m_{feed,day}} \quad (1)$$

The energy input in kWh for the production of 1 kg of woody pellets is estimated by Eq. (2),

$$E_{pr,pellet} = \frac{m_{feed}}{y_{pellet}}\, E_{pr,unit} \quad (2)$$

The fuel energy in a power plant for providing electricity for the operation of biorefinery unit is estimated by Eq.(3),

$$E_{plant} = \frac{E_{pr,pellet}}{n_{th}} \quad (3)$$

The mass of fossil fuel per 1 kg of pellets that is produced at the biorefinery unit in kg fuel/kg pellet is given by Eq.(4)

$$m_{fuel} = \frac{E_{plant}}{LHV} \quad (4)$$

For 1 kg of pellets the energy saving in kJ is given by Equation (5),

$$E_{pellet,saving} = y_{pellet}\, m_{feed}\, LHV_{pellet}\, n_{comb} \quad (5)$$

From the energy saving the amount of mass of fossil fuel saving is estimated in kg fuel/kg pellet by Eq. (6),

$$m_{fuel,saving} = \frac{E_{pellet,saving}}{LHV} \quad (6)$$

The net mass of fossil fuel consumed corresponding to the operation of the biorefinery unit from Eq. (7),

$$m_{fuel,net} = m_{fuel} - m_{fuel,saving} \quad (7)$$

The stoichiometric combustion equation Eq. (8) for a typical hydrocarbon fuel burnt with air,

$$C_aH_b + \left(a + \frac{b}{4}\right)(O_2 + 3.773\, N_2) \rightarrow aCO_2 + \frac{b}{2}H_2O + 3.773\,(a + \frac{b}{4})N_2 \quad (8)$$

The amount of CO2 mass that is produced by stoichiometric combustion by applying mass balance,

$$m_{CO_2} = \frac{N_C\, MW_{CO_2}}{MW_{fuel}}\, m_{fuel} \quad (9)$$

where N_C= 14 is the number of carbon atoms in the chemical compound of the fossil fuel, MW_{CO2}= 44 kg/kmol is the molecular weight of CO2 and MW_{fuel}= 200 kg/kmol is the molecular weight of the fuel.

3. RESULTS

Input data	Value	Units
P_{inst}	270	kW
$n_{h,day}$	8	h
$m_{feed,day}$	4000	kg
y_{pellet}	75	%
n_{th}	35	%
LHV	42500	kJ/kg
LHV_{pellet}	16000	kJ/kg
n_{comb}	90	%

Table. Mass and energy calculations input data.

- Energy input required to produce one kg of pellets is 0.96 kWh/kg, which corresponds to 0.232 kg of fossil fuel burnt at the power plant.
- The use of pellets in furnaces replaces 0.254 kg of fossil fuel resulting in negative net mass -0.022 kg fossil fuel.
- The operation of the power plant results in 0.716 kg CO2/kg pellet, while the reduction of CO2 emissions replacing fossil fuel is -0.783 kg CO2/kg pellet, reaching a negative CO2 emissions of -0.067 kg CO2/kg pellet.

4. CONCLUSIONS

Woody biomass and waste utilization is a promising solution for sustainable bioenergy production, resulting in negative CO2 emissions. The methodology developed can be further used for future large-scale biorefinery technology selection and evaluation, for reaching net-zero CO2 emissions. For woody biomass utilization, the production of syngas and advanced biofuels should be examined, using partial oxidation, pyrolysis and gasification thermochemical pathways, for upgrading and optimizing existing biorefinery units.

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