Energy Efficiency of Biorefinery Schemes Using Sugarcane Bagasse as Raw Material

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Content

Introduction

Processing of agricultural products → Non main products → Wastes → Environmental problem

Wastes → It can be used as raw material → Value-added products

Sugarcane → Sugarcane bagasse

Between 2014 and 2015, the world production of sugarcane accounted 175.1 million metric tons

From 1 ton of sugarcane processed are generated 280 kg of bagasse (Moreira, 2000)

Introduction

Sugarcane bagasse

Waste rich in polysaccharide as cellulose and hemicellulose

Sugarcane bagasse contains cellulose (38–43%), hemicelluloses (22–32%), and lignin (17–24%)

Through transformation processes can be obtained products as

Products that can be obtained by means of the use of the biorefinery concept

Ethanol, xylitol, electricity, PHB, antioxidants, syngas, nonane, octane, furfural, HMF and lactic acid, among others

Introduction

"A biorefinery is a network of facilities that integrates biomass conversion processes and equipment to produce biofuels, energy and chemicals from biomass after a proper and efficient design" (Moncada B., Aristizábal M., & Cardona A., 2016)

In any design the energy is a variable to be considered seriously

→

A tool that allows evaluating beyond the energetic changes that are made in a process is the exergy analysis

Introduction

Exergy: "***Maximum work derived from a state in concern with the environment as another heat sink or heat source***"

The consumption of exergy during a process is proportional to the entropy generated due to the irreversibilities associated with the process. The total exergy of a system consists of kinetic, potential, physical and chemical exergy

Kinetic exergy: This term is attributed to the speed of the system measured in relation to the environment

Potential Exergy: Due to the height of the system measured in relation to the environment

Physical exergy: Due to the deviation of the temperature and the pressure of the system from the environment.

Chemical exergy: Due to the deviation of the chemical composition of the system from the environment.

Methodology: Process design

Table 1. Composition of sugarcane bagasse employed in this work

Component	Moisture	Cellulose	Hemicellulose	Lignin	Protein	Ash
Percent	50.00	23.70	12.05	11.70	2.40	1.15

High content in polysaccharides

Three scenario were proposed based on the energy → Simulation process → Mass and energy balances → Exergy calculation

aspentech

Zhang, Li, Li, & Zhang, 2012

Methodology : Process design

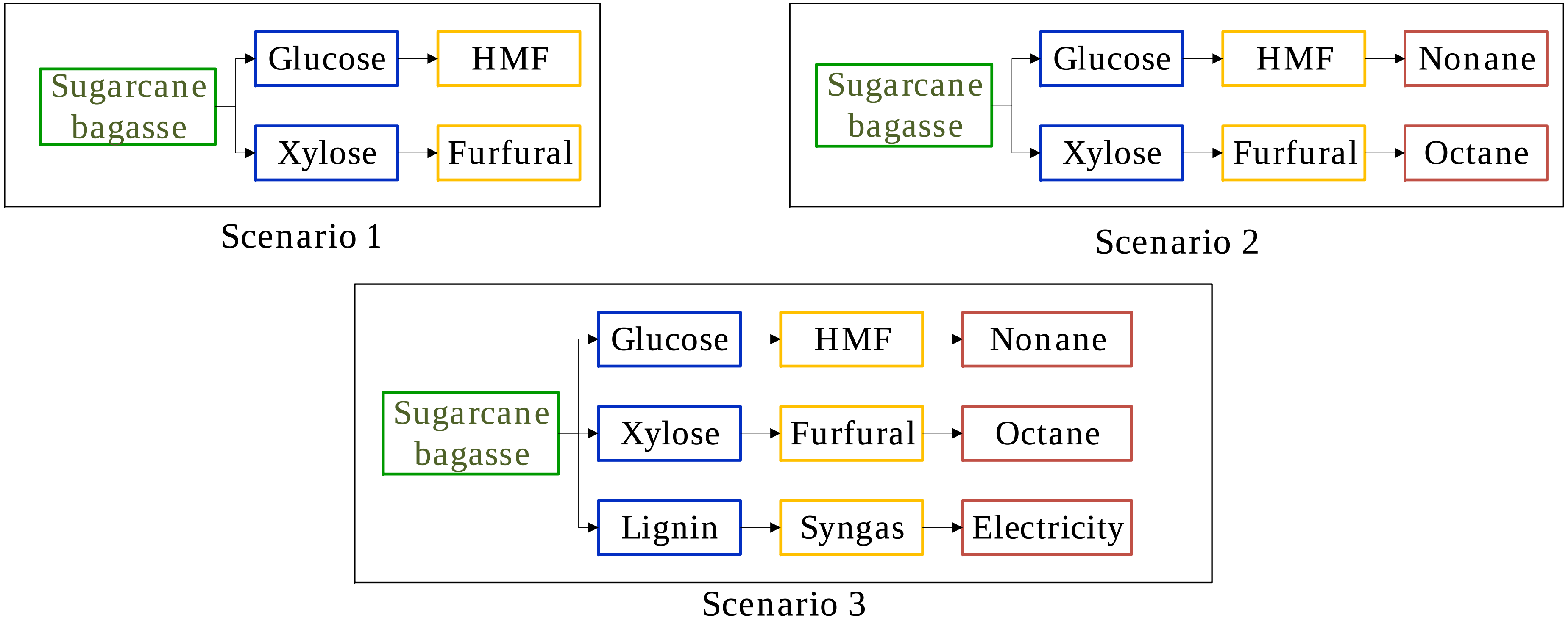

Figure 1. Scenarios to be analyzed

Methodology : Process design

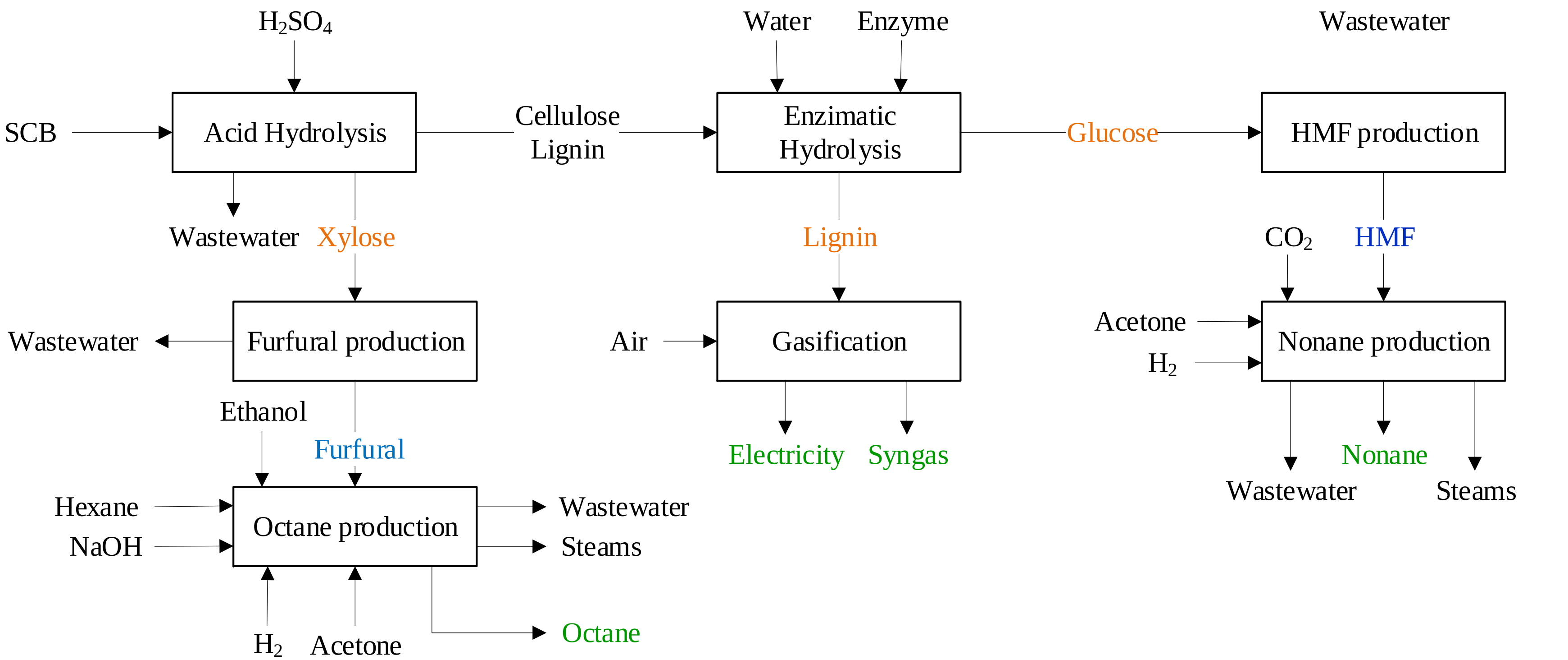

Figure 2. Flowsheet for the sugarcane processing

Methodology: Energy calculation

Energy analysis → Allow identify the energy distribution at the input (utilities and raw material) and output (products, wastes and loss)

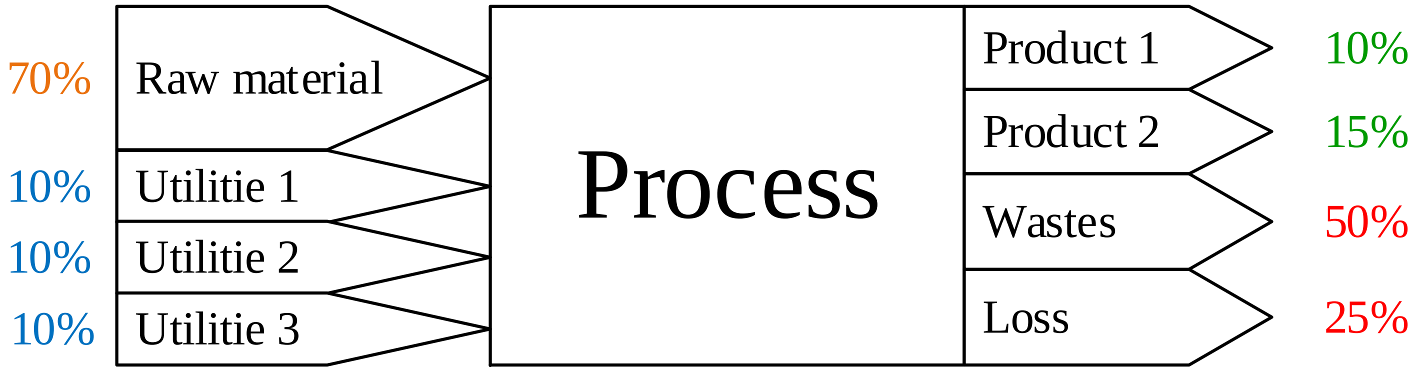

Figure 3. Main items involve in the energy distribution of the process

Methodology: Energy calculation

Heating value of the raw material/product

High Heating Value (HHV) is also known as the gross calorific value.

Low Heating Value (LHV) is defined as the net calorific value

$$HHV = 0.1739 * Cellulose + 0.2663 * Lignin + 0.3219 * Extractives \quad Eq.1$$

Experimental or theorical (HHV)

$$LHV = HHV - h_{fg}\left(\frac{F_{water}}{F_{Biomass}}\right) \quad Eq.2$$

h_{fg} = Water vaporization enthalpy

$\frac{F_{water}}{F_{Biomass}}$ = Moisture content of the material

$$E_{input/output} = \dot{m}_{input/output}\left[\frac{kg}{h}\right] * LHV_{input/output}\left[\frac{MJ}{kg}\right] \quad Eq.3$$

Energy flow for an input or output

Methodology: Exergy calculation

Exergy balance

$$Ex = Ex_1 - Ex_2 + Ex_Q - Ex_W \qquad Eq.4$$

$Ex_1 - Ex_2$	Mass flow exergy
Ex_Q	Heat exergy (energy of the process)
Ex_W	Compression and expansion exergy (work)

n_i: *Mole flow*
T_j: *Stream temperature*
Cp: *Heat specific*
P: *Operation pressure*
ex_i^{ph}: *Specific physical exergy*
ex_i^{ch}: *Specific chemical exergy*

$$Ex_i = Ex^{ph} + Ex^{ch} \qquad Eq.5$$

$$Ex^{ph} = \sum_i n_i \, ex_i^{ph} \qquad Eq.6$$

$$ex_i^{ph} = (h_j - h_o) - T_o(s_j - s_o) \qquad Eq.7$$

$$(h_j - h_o) = \int_{T_o}^{T_j} Cp \, dT \qquad Eq.8$$

$$(s_j - s_o) = \int_{T_o}^{T_j} \frac{Cp}{T} dT - RLn\left(\frac{P}{P_o}\right) \qquad Eq.9$$

Specific by each component.
Reported in literature

$$Ex^{ch} = \sum_i n_i \left(ex_i^{ch} + RT_o Ln\left(\frac{n_i}{\sum n_i}\right)\right) \qquad Eq.10$$

Methodology: Exergy calculation

- Ex_Q

$$Ex_Q = \sum_{i=1}^{n} \left[1 - \frac{T_o}{T_b}\right] \dot{Q} \qquad Eq. 11$$

- $\dot{Q}$ Heat of the equipment
- T_b Operation temperature

- Ex_W

$$Ex_W = \sum_{i=1}^{n} \left[W_{1,2} - P_o(V_2 - V_1)\right]_i \qquad Eq. 12$$

- $W_{1,2}$ Work employed in the process of volume change
- $V_2 - V_1$ Change of volume

T_o and P_o are the temperature and pressure of reference (298 K and 1 bar)

Technical Results

Table 2. Yields for each product obtained from SCB and the polysaccharide

Product	Yield (kg product per kg SCB)
Xylose	0.0813
Glucose	0.2261
Furfural	0.0464
HMF	0.1545
Octane	0.0284
Nonane	0.1078

Results. Energy assessment

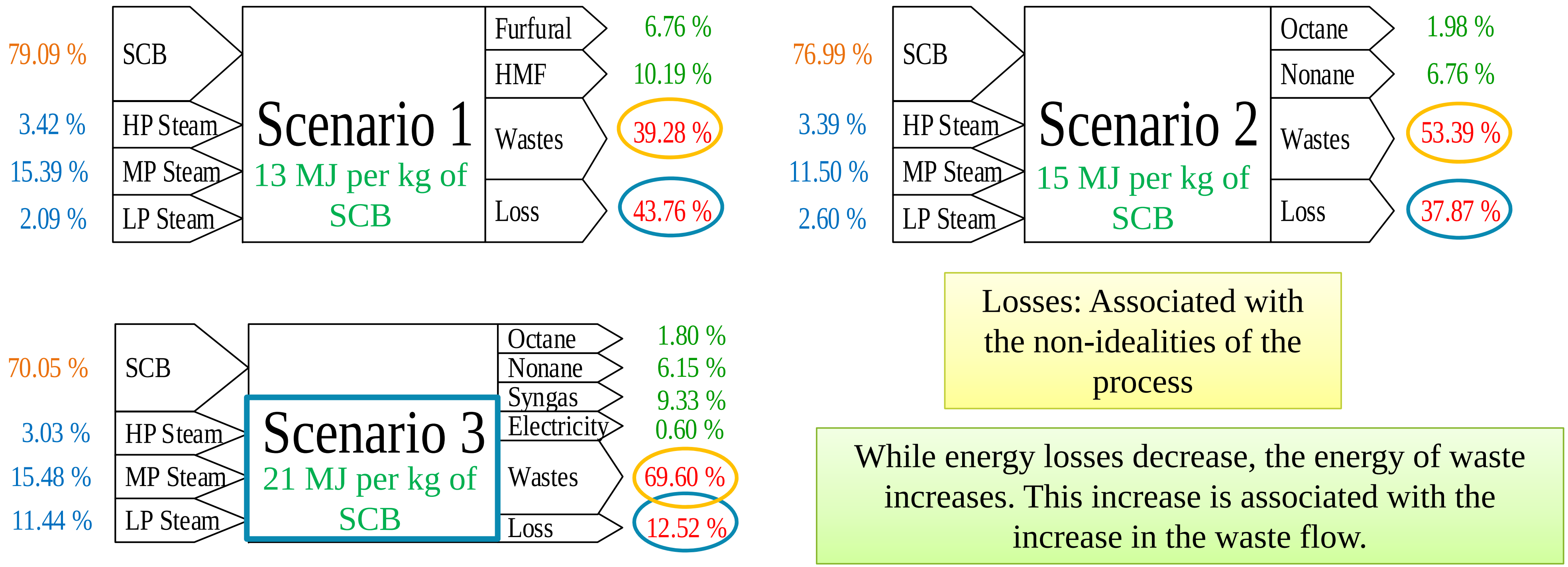

Figure 4. Sankey diagrams for the energy distribution of scenarios 1, 2 and 3

Results. Exergetic assessment

Table 3. Exergy consumption per kg of SCB

Scenario	Exergy (MJ/kg SCB)
1	0,08
2	0,09
3	0,12

Table 4. Exergy efficiency by stage in each scenario

Stage	Scenario 1	Scenario 2	Scenario 3
Acid hydrolysis	17.75	15.04	11.55
Detoxification	26.54	22.49	17.28
Enzymatic hydrolysis	20.98	17.78	13.66
Furfural	26.41	22.38	17.20
HMF	8.32	7.05	5.41
Octane	-	8.86	6.81
Nonane	-	6.40	4.92
Gasification	-	-	23.18

Results. Exergetic assessment

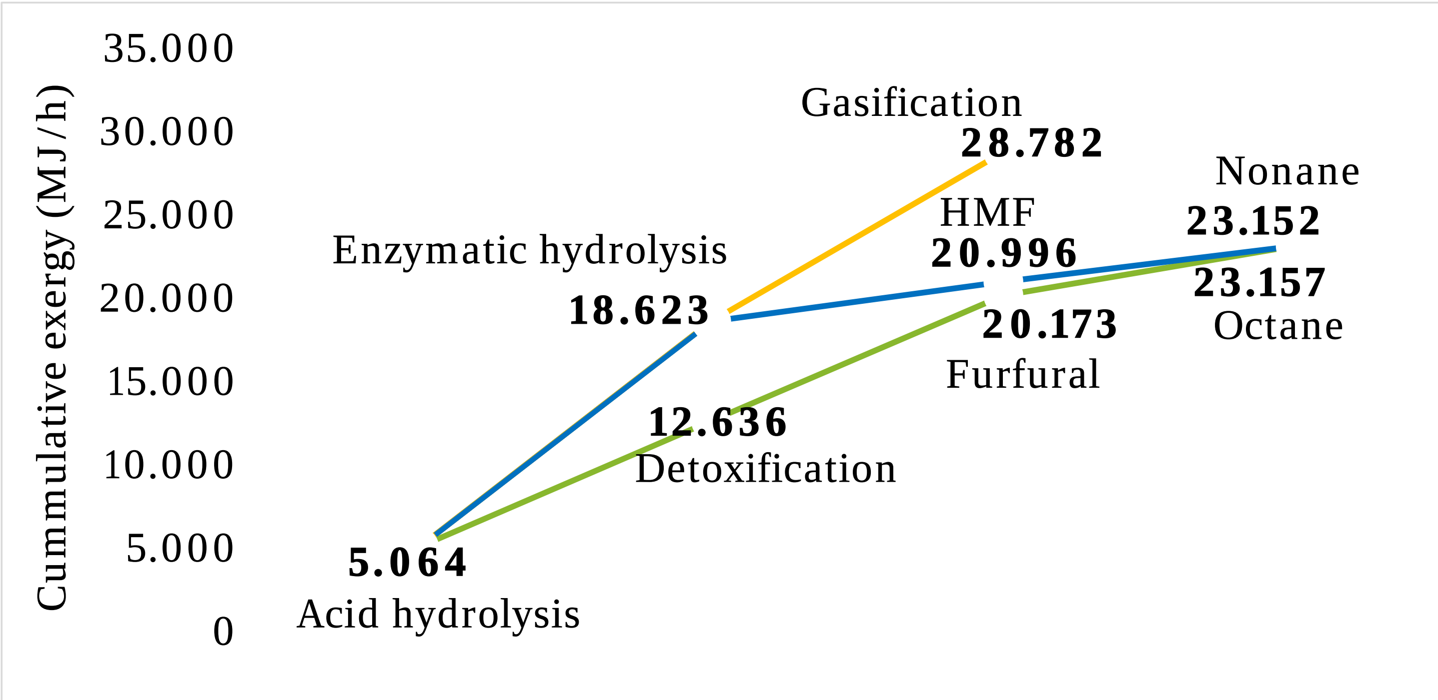

Figure 5. Cummulative exergy based on the transformation route

Results. Exergetic assessment

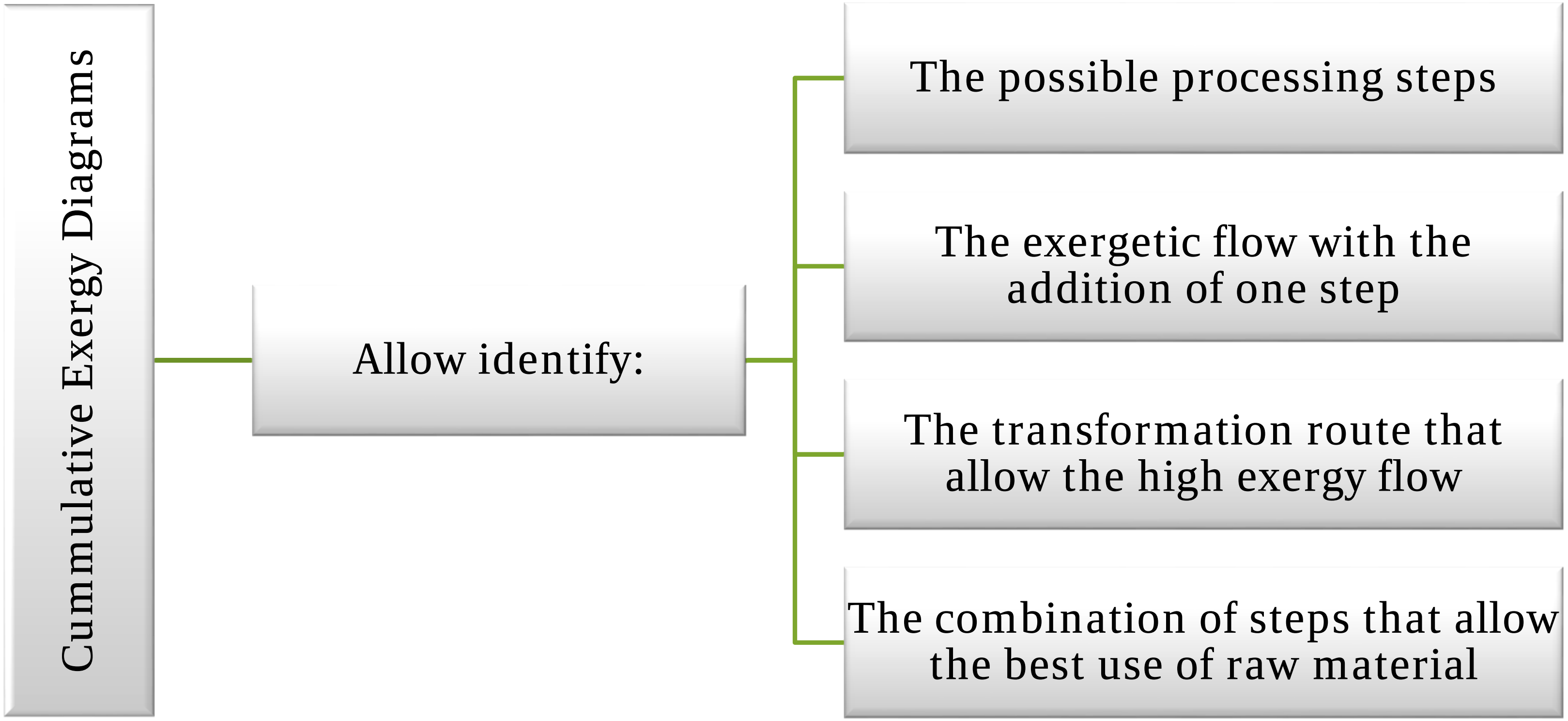

Figure 6. Benefits of cumulative exergy diagrams

Conclusions

- The addition of processing stages can lead to a reduction in the energy losses of the process. However, this causes an increase in the energy potential of the process waste by increasing the mass flow of the process waste. In order to identify the best transformation route in both technical and energy terms, it is necessary to evaluate different transformation alternatives. These would allow the identification of the best alternative for the transformation of a raw material.

- The implementation of processing stages, which allow a better use of a raw material, leads to a better use both in technical and energy terms. However, since the same raw material may have different processing routes, different alternatives must be evaluate in order to select the best possible combination.

Conclusions

- The exergy analysis allow identifying the steps of the process which have the main irreversibilities. At the same time, it demonstrates the cause of this and provide an idea of optimization. This can allow reductions in the cost of production, the environmental impact and increase on yields.

- The determination of the cumulative exergy provides information about the transformation processes involved that allow a better energy use of a raw material.

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NAXOS2018 13-16 June 2018 6th International Conference on Sustainable Solid Waste Management

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Thank you!!

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