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Microalgae Biorefinery Trought Optimization of Strain Composition and Biomass Consumption

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For development of an energetic industry from biomass, at the begining is important to determine the more convenient feedstocks, also, for increasing the system sustainability was adapted the biorefinery concept for selecting economically viable products (biofuels and value-added substances)or with less detriment in profit. In previous work, an analysis of the potentially obtainable products in a biorefinery from microalgae biomass was performed, based on the metabolites composition optimization. From the previous results, is desirable perform sensitivities to evaluate points that influence the profitability of the biorefinery as the cost and consumption of raw material in order to establish a configuration of microalgae strain. Finally, based on bibliographic reviews was selected microalgae strain (Nannochloropsis sp.) for better fit the criteria and a detailed chemical composition is reported.

1. Introduction

The environmental problems caused by the use of fossil fuels and the recognition that global oil supplies are finite have led to the search for alternative renewable source of high productivity as far as possible limiting the CO_2 emission . Nonetheless, several factors must be considered for biofuels sustainable production. For example there are critical needs for optimizing: feedstock selection, preprocessing stages, processing technologies and manufactured products; in this paper the aim is define economic criteria for select the feedstock from the products taking into account the biorefinery concept (Figure 1). This methodology is adjusted to select a strain of microalgae that are increasingly seen as an alternative to the traditional biofuels feedstocks such as edible vegetable oils (Mata, et al., 2010a), animal fats and other residual products like spent coffee grounds (Caetano and Silva, 2012). Furthermore, they can produce substances at commercial scale such as nutritional supplements for humans or animals like lipids with more than 20 carbons and several unsaturations called PolyUnsaturated Fatty Acids PUFAs, in the cosmetics industry is useful as extracts of valuable pigments like chlorophylls, phycobilins and carotenoids. However, with the current level of development of the technologies, the production of biofuels from microalgae doesn't compete favorably front to fossil fuels, there arises a need to include the whole use of biomass, it means, defining several routes for obtaining both of biofuels as high added value products (González-Delgado and Kafarov, 2012). In this work the strain which could combine the criteria set forth below was selected and the minimum volume of production was determined from which positive returns was generated in a microalgae biorefinery for valuable substances and energy.

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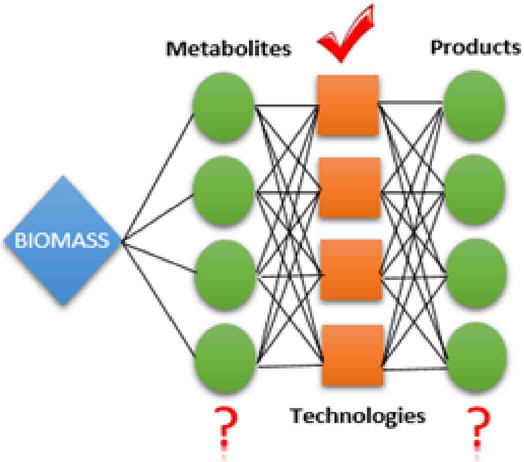

Figure 1: General configuration of a biorefinery with feedstock and products unknown.

2. Methodology

The methodology (Figure 2) was based on a previously published model, which determined the Minimum Profitable Composition of each Metabolite in the Microalgae MPCMM (Pinzón Frias et al., 2014). At the beginning of methodology were defined the following inputs: plant data, such as raw material consumption (t/y) and its cost ($/t); data on the technologies discussed as efficiency, Annual Fixed Capital AFC and Annual Operating Cost AOC of the production; moreover, must be known the product data, as the selling price in the market and its theoretical chemical yield when it comes to a previous reaction for obtain them. Finally to obtain a product involves both investment and operational costs, that can be calculated by specific factors to each cost and represented by particular indicators (α for investment costs indicator and β for operational costs indicator) for each technology route. Assuming that all production is sold, the selection criterion to determine the profitability of each product was the highest revenue evaluated by the analysis called "break even point".

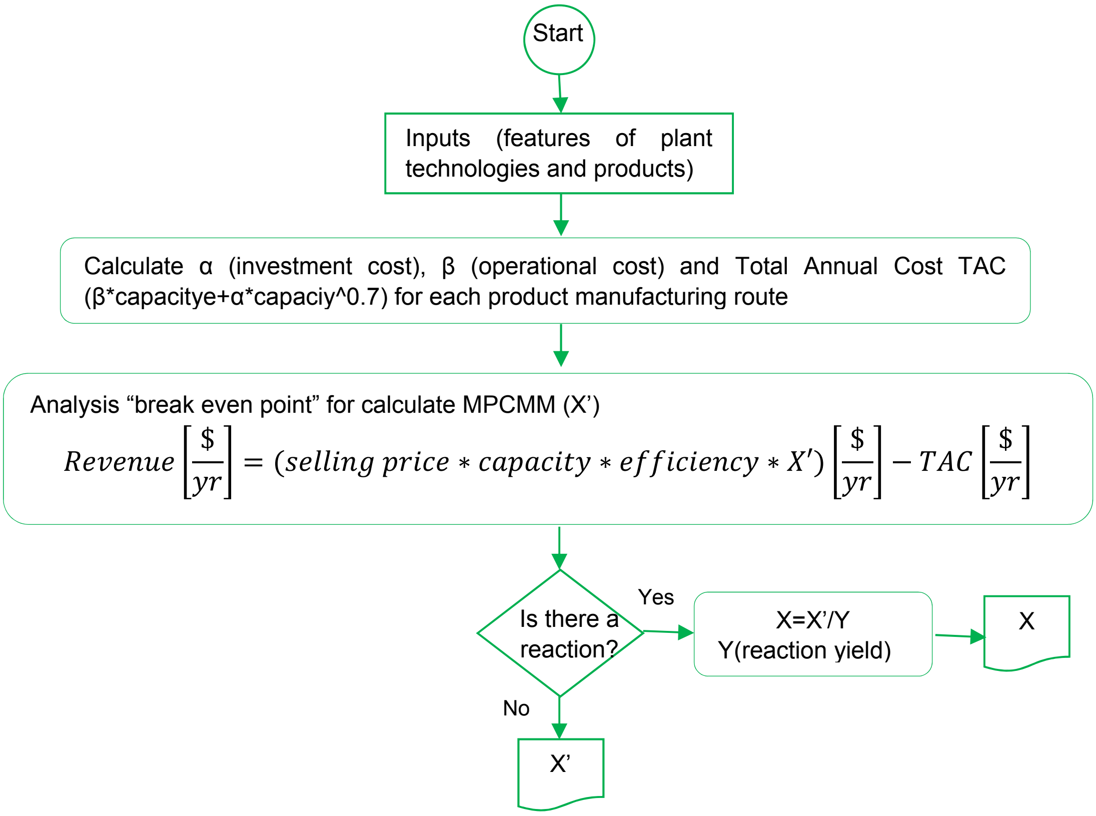

Figure 2: Procedure flowchart for determine the minimum profitable composition of each metabolite.

2.1 Sensibility analysis of MPCMM for production capacity and feedstock cost

The most relevant variables that were set in the past studio (Pinzón Frias et al., 2014) requires a sensitivity analysis to select the best scenario for energy production from microalgae. The outstanding values are from biodiesel's MPCMM variation, criterion for production capacity was the curve slope and for feedstock cost was the equilibrium point where biodiesel MPCMM reaches its real maximum possible (100 %).

2.2 Biorefineries, possible configurations and profitable composition of the microalgae strain

Given that the strain composition is based on the metabolities combination, would be appropriate to define an ideal configuration where revenues from valuable substances is simultaneous to large amounts of energy production. Accordingly,in this biorefinery were selected as main products biofuels; compositions of extracted metabolites , as fine chemicals, were limited to maximum 5% of pigments and 10% of PUFAs (not Diesel-like lipids); and the other metabolites were limited by the composition ranges reported in the literature. The ranges for each metabolite varies but generally found high concentrations of lipids 2% - 90% (Becker, 1994) (Chisti, 2007), must take into account that high percentages are under specific nutrient limitation condition that causes a decrease in the biomass growth; carbohydrates in microalgae in form of starch, glucose, other sugars and polysaccharides are present in concentrations from 5% to 50 % (Spolaore et al., 2006); finally, the proteins compose 10% -50% of microalgae (Becker, 1994) (Spolaore et al., 2006).

3. Results

More detailed information on the model and the results can be found in the previous publication (Pinzón Frias, et al., 2014), the Figure 3 represents the valorization of microalgal metbolities as function of general potential products, regardless special substances of each strain. Given that, the aim would be develop an economically viable biorefinery of energy production, assuming that the negative profits of biofuels can be counteracted with revenues due to the marketing of fine chemicals.

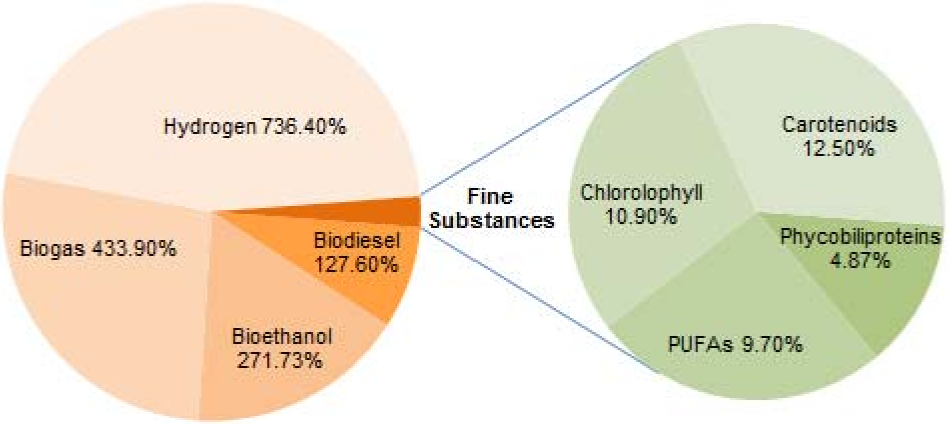

Figure 3: Minimum profitable composition of metabolites for microalgae products

3.1 Sensibility analysis

Figures 4 and 5 show the MPCMM variation with respect to plant capacity, in terms of raw material, and the cost of feedstock. The outstanding value for microalgal biomass consumption on dry basis is 220,000 t/y, which corresponds to curve slope of biodiesel variation, biofuel with lower MPCMM registered, from this point begins the curve to balance out; this behavior is evident from the valuable products curves (PUFAs and pigments). The outstanding value of feedstock cost is $ 196.8/t, balance point where biodiesel MPCMM reaches its maximum possible real composition of lipids in the microalgae (100 %).

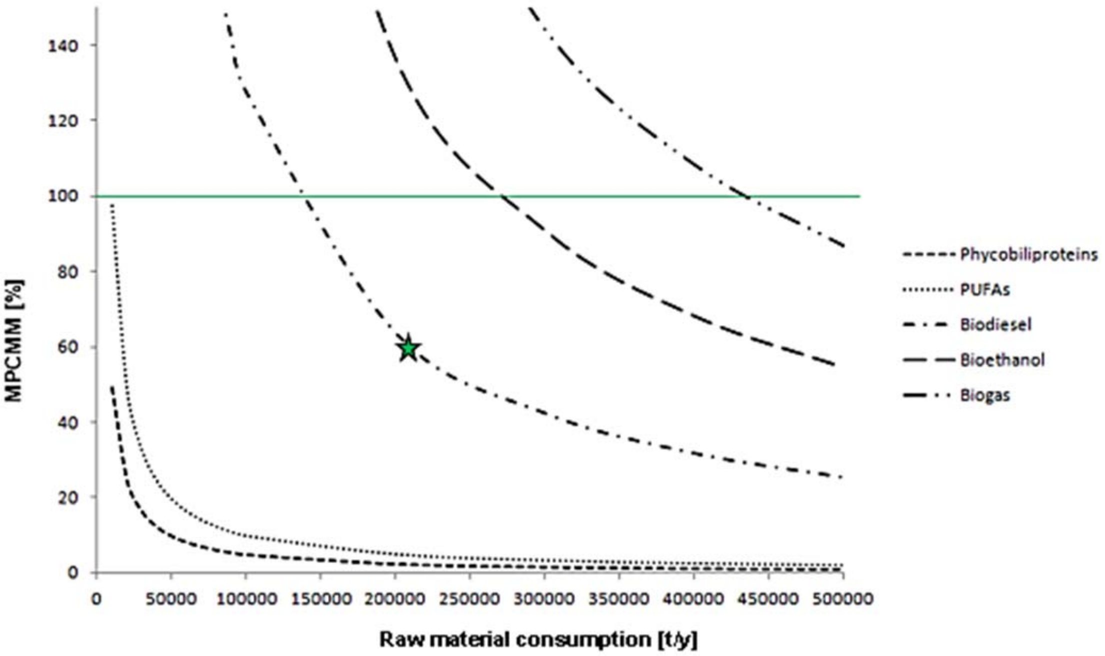

Figure 4: Sensibility analysis of MCPCMM for different raw material consumption

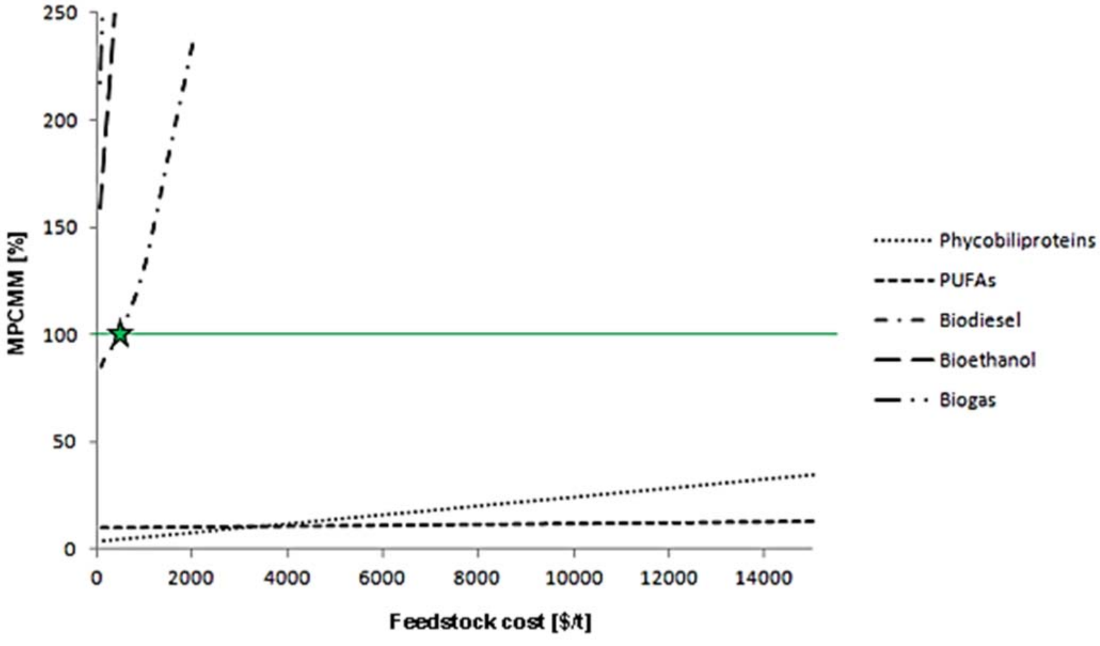

Figure 5: Sensibility analysis of MPCMM for different feedstock cost

3.2 Biorefinery capacity and profitability strain composition of microalgae

The profitability strain composition is: 58.3 % Disel-like lipids, 10 % PUFAs, 8.3 % carbohydrates, 28.3 % proteins and 5 % pigments; these conditions were assumed for develop the break even point analysis showed in Figure 6. The balance between plant capacity, in terms of raw material, and null annual income, represents the start point, 100493.2 t/y, where microalgae biorefinery for obtaining valuable products and energy can be converted in profitable industry.

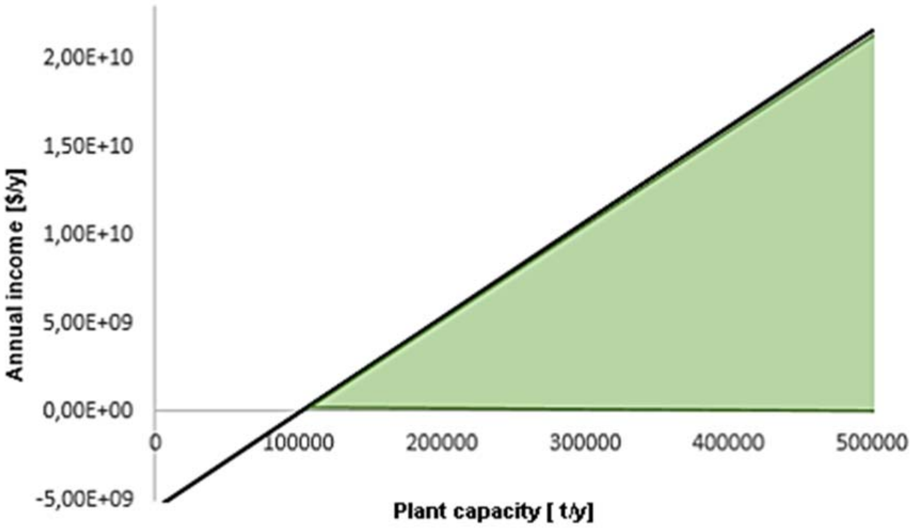

Figure 6: Break even point for annual incomes of a microalgae biorefinery

3.3 Selected microalgae strain

From a literature review of different strains compositions, two possible microalgae could be adjusted to previously criteria established: Nannochloropsis sp and Neochloris Oleabundans. The decision factor between both strains was valuable substances content; in this case, Nannochloropsis sp was selected for its high PUFAs content. Table 1 collects the detailed chemical composition of selected strain from data reported in the literature, it should be noted that the bulk composition of metabolites may vary with respect to the environmental conditions in their culture.

Table 1: Chemical composition of Nannochloropsis sp.

Fatty acids (Brown, et al., 2012)	%		%		%
14:0	5.31	17:0	0.33	20:3	0.16
14:1	0.92	17:1	0.45	20:4	5.12
15:0	0.31	18:0	0.42	20:5	29.9
15:1	0.26	18:1	3.37	22:0	0.49
16:0	19.75	18:2	2.1	22:1	0.27
16:1	29.52	19:0	0.42	22:2	0.12
Aminoacids (Yin, et al., 2013)					
aspartic acid	9.4	Alanine	8.4	tyrosine	3.9
Threorine	5.0	Valine	6.5	phenylalanine	5.4
Serine	4.4	Methionine	1.6	histidine	2.0
glutamic acid	13.7	Isoleucine	5.0	lysine	6.9
Glycine	6.4	Leucine	9.8	arginine	6.3
Proline	5.3				
Carbohydrates (Xiao, et al., 2013)		***Pigments*** (Nobre, et al., 2013)			
Trehalose	0.3	violaxanthin/neoxanthin	13.7	canthaxanthin	4.9
Manitol	98.3	Astaxanthin	14.2	chlorophyll a	3.5
Glucose	1.1	Vaucheriaxanthin	35.5	beta-carotene	5.2
Galactose	0.2	lutein/zeaxanthin	23.1		

4. Conclusion

Through previous results and its sensibility analysis of raw material consumption and cost with respect to the Minimum Profitable Composition of Metabolites in Microalgae (MPCMM) to obtain valuable substances and energy from microalgae, an ideal strain composition was established like promising for a microalgae biorefinery (48.3 % Diesel-like lipids, 10 % not Diesel-like lipids, 8.3 % carbohydrates, 28.3 % proteins and 5 % pigments); this configuration is economically feasible from a production volume of 100,493.2 t/y. From the literature review, a strain that can be adjusted to these requirements was Nannocloropsis sp. especially for its high content of PUFAs.

References

Becker E. W., 1994, Microalgae: Biotechnology and Microbiology (Vol. 10). Cambridge: Cambridge University Press, New York, USA

Brown T. M., Duan P., Savage P. E., 2012, Hydrothermal Liquefaction and Gasification of Nannochloropsis sp. Energy & Fuels, 24, 3639-3646.

Caetano N., Silva V., 2012, Valorization of coffee grounds for biodiesel production. Chemical Engineering Transactions, 26, 267-272, DOI: 10.3303/CET1226045.

Chisti Y., 2007, Biodiesel from microalgae. Biotechnology Advances, 25(3), 294-306.

González-Delgado Á.D., Kafarov V., 2012, Microalgae Based Biorefinery: Evaluation of Several Routes for Joint Production of Biodiesel, Chlorophylls, Phycobiliproteins, Crude Oil and Reducing Sugars. Chemical Eengineering Transactions, 29, 697-612, DOI:10.3303/CET1229102.

Mata T., Cardoso N., Omelas M., Neves S., 2010ª, Sustainable production of biodiesel from tallow, lard and poultry fat and its quality evaluation. Chemical Engineering Transactions, 19, 13-18.

Nobre B., Villalobos F., Barragán B., Oliveira A., Batista A., Marques P., et al., 2013, A biorefinery from Nannochloropsis sp. microalga – Extraction of oils and pigments. Production of biohydrogen from the leftover biomass. Bioresource Technology, 135, 128-136.

Pinzón Frias A., González-Delgado Á., Kafarov V, 2014, Optimization of Microalgae Composition for Development of a Topology of Biorefinery based on Profitability Analysis. CET Chemical Engineering Transactions, 37, 457-462. DOI: 10.3303/CET1437077.

Spolaore P., Joannis-Cassan C., Duran E., Isambert A., 2006, Commercial applications of microalgae. Journal of Bioscience and Bioengineering, 101(2), 87-96.

Xiao Y., Zhang J., Cui J., Feng Y., Cui Q., 2013, Metabolic profiles of Nannochloropsis oceanica IMET1 under nitrogen-deficiency stress. Bioresource Technology, 130, 731-738.

Yin X. W., Min W. W., Lin H. J., Chen W., 2013, Population dynamics, protein content, and lipid composition of Brachionus plicatilis fed artificial macroalgal detritus and Nannochloropsis sp. diets. Aquaculture, 380-383, 62-69.