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TECHNICAL AND ECONOMIC ANALYSIS OF THE PRODUCTION OF BIOMETHANE AND BY-PRODUCTS WITH AÇAÍ SEEDS

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ABSTRACT

Açaí seeds represent 85% of the whole açaí fruit mass, and are often wasted without adequate disposal and economic use. This work prescribes two scenarios (1 and 2) for açaí seeds conversion in heat-and-power self-sufficient industrial conversion. In Scenario (1), seeds are subjected to acid hydrolysis, followed by anaerobic digestion of the hydrolysate and biogas upgrading to biomethane via CO_2 capture with monoethanolamine, whereas (2) comprises açaí seeds combustion to generate electricity. The processes are evaluated by simulation in Aspen HYSYS with basis on literature data for biogas production. In Scenario (1), conversion of 16 t/h of açaí seeds results in 697 kg/h of biomethane, 14.11 MW of electricity to local grids, 1.7 t/h of CO_2 to storage and 19.81 t/h of concentrated digestate to fertigation. In Scenario 2, 21.17 MW of net electricity is exported to local grids. Economic analysis showed better long-term performance of biogas plant, with a net-present-value of 79.02 MM US$ and a payback of 9.75 years, against 34.65 MMUS$ and 6.52 years of the other case, due to economic leverage by extra revenues from co-products and carbon credits. Technical viability of both biomass conversion processes is demonstrated, enabling new possibilities for optimizing the açai production chain.

Keywords: Biogas. Techno-economic analysis. Açaí seeds. Anaerobic digestion. CO_2 capture

1 INTRODUCTION

About 1.9 million tons of açaí were produced in 2022 in Brazil (IBGE, 2022) and since its edible pulp corresponds to only 15% of its mass, about 1.6 million tons of seeds were generated, most of which is regarded as waste without an adequate destination. Studies have shown that açaí seeds have high concentration of polysaccharides, with mannan – a polymer of mannose – being the main carbohydrate.[1] Thus, considering that polysaccharides can be hydrolyzed and fermented, the production of biogas is an option to avail these seeds.[2] In this sense, anaerobic digestion of different substrates has been widely studied in the literature, but few works considered the use of açaí seeds. In addition, most works are essentially experimental, without looking at the industrial feasibility of producing pure biomethane. The objective of this work is to evaluate the techno-economic viability of a biomethane plant, where açaí seed hydrolysate is availed as substrate for anaerobic digestion, with captured CO_2 being compressed and dispatched for geological sequestration. The solid residue of hydrolysis is sent to a combined heat and power plant, which meets process demands. Furthermore, this work compares the production of biomethane with the direct burning of açaí seeds for electricity production. As far as we know, this is the first work that aims to evaluate these premises.

2 MATERIAL & METHODS

Two plants were simulated in steady-state conditions using the software Aspen HYSYS v8.8, with an input flow of 16 tons/h of açaí seeds: pressurized biogas[3] production at 5 bar from açaí seed hydrolysate [Scenario (1)] and açaí seed combustion to generate electricity [Scenario (2)]. The biogas plant (1) is divided into five main sections. The first section (S-100) comprises açaí seed grinding, acid hydrolysis and anaerobic digestion of the hydrolysate. CO_2 chemical absorption by monoethanolamine occurs next in another section (S-200), which is followed by downstream CO_2 compression to geological storage (S-400). Also, part of the water present in the digestate is recovered in a multistage evaporation system (S-300). Finally, the filtered solid residue of the hydrolysate is burned to co-generate electricity and low-pressure steam for heating (S-500). In contrast, Scenario (2) comprises only the S-500 section (cogeneration) for direct burning of seeds. The thermodynamic packages used in the biogas plant (1) were: NRTL - Peng Robinson (S-100, S-300, S-400 and S-500), Acid Gas (S-200) and NBS Steam for pure-H_2O streams (e.g., low-pressure steam). Direct seed burning (2) used the NRTL - Peng Robinson package. The hydrolysis step takes place in a reactor (158°C, 5 bar, 9 minutes, 0.5% H_2SO_4 in mass),[4] followed by pressurized anaerobic digestion (5 bar, 40 °C, 6 days of liquid retention). CO_2 capture using monoethanolamine aimed to achieve a CO_2 content lower than 3% (mol) in biomethane, with a heat demand lower than 4000 kJ/kg CO_2. Single-pressure Rankine cycle was used in both scenarios to generate electricity (vacuum pressure: 0.1 bar; superheated steam: 550 °C; low-pressure steam for heating: 155 °C; turbine adiabatic efficiency: 90%).[5] The economic analysis was carried out using the methods of Turton et al.[6] Table 1 describes the main assumptions used for the economic analysis of the scenarios, with the purchase prices of raw material, utilities and labor. Scenario 1 produces biomethane, carbon credits from captured biogenic CO_2, carbon credits by CO_2 emission avoidance through fossil natural gas replacement by biomethane (CBIO, credit for monetization of CO_2-equivalent avoidance by Brazilian government biofuel program *RenovaBio*), biofertilizer recovered from digestate, and electricity from Rankine cycle, where the heat source for steam generation derives from the burning of solid residue of açaí seeds hydrolysate. Scenario 2 only produces electricity through Rankine cycle, using heat from direct burning of seeds. Economic performances are evaluated assuming 3 years of construction (with investment distribution of 30%/40%/30%) and 20 years of operation.

Table 1: Assumptions for the economic analysis of simulations and scenarios 1 and 2. FCI: Fixed Capital Investment

Premise		Value	Unity
Raw Material			
	Açaí Seeds	35.00	US$/ton
Utilities			
	Process Water	0.25	US$/MWh
	Demineralized Water	0.55	US$/ton
	Sulfuric Acid	91.98	US$/ton
	Sodium Bicarbonate	394.2	US$/ton
	Cooling water	0.11	US$/MWh
	Monoethanolamine	1500	US$/ton
Labor			
	Operating labor cost by person	10	US$/h
Revenues			
	Electricity	120	US$/MWh
	Biomethane	50	US$/MMBTU
	Captured CO_2	80	US$/ton
	CO_2 avoidance (CBIO)	25	US$/ton
	Biofertilizer	7.89	US$/ton
Operating hours		8760	h/year
Income tax		34	%
Annual depreciation		10	% FCI
Annual interest rate		8	%

3 RESULTS & DISCUSSION

The results of process simulations can be seen in Figure 1.

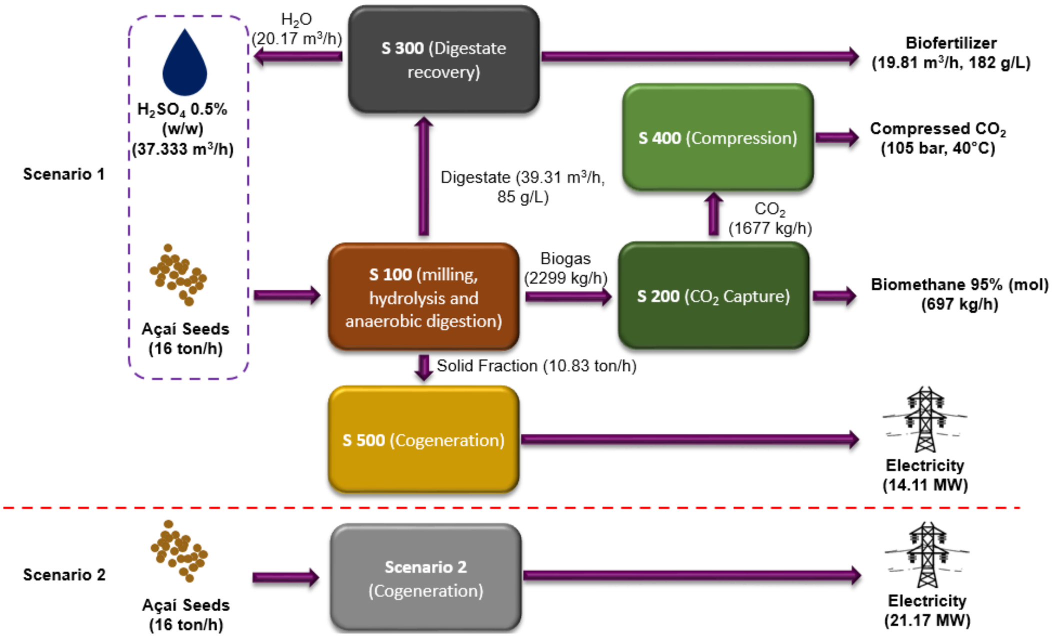

Figure 1: Description of the processes divided into blocks and results of simulations with the yield of sales products for the biomethane plant (scenario 1) and the burning of the açaí seed (scenario 2).

The conversion of 16.00 t/h of açaí seeds in scenario 1 results in 697 kg/h of pure biomethane (molar contents 95.46% CH_4, 1.60% H_2O, 2.95% CO_2) to local gas grid. The performance of chemical absorption (S-200) showed an adequate heat ratio of 3608 kJ/kg CO_2, producing 1677 kg/h of CO_2 to geological storage. In addition, 19.81 m³/h of concentrated digestate (182 g/L of carbohydrates and extractives) is exported as product for use in fertigation. Only the hydrolysate is sent as substrate to anaerobic digestion to allow relatively high conversion into biogas at lower residence times. However, the hydrolysis conditions adopted results in 28.66% of mannan hydrolysis, leaving 68% of the seed as a solid fraction that is directed for electricity generation, which explains the limited product/feed ratio of biomethane/seeds input. Electricity generation from combustion of the solid residue from seed hydrolysis (10.83 t/h) totalizes about 14.5 MW, of which 0.3 MW is consumed in the plant, with the excess being sold to the local power grid. Anaerobic digestion at 5 bar avoids two stages of downstream gas compression, saving nearly 0.13 MW. In contrast, Scenario 2 has greater net electricity output (21.17 MW) since all the feedstock feed is used in this process. In Scenario 1, the exportation of 1.7 t/h of supercritical CO_2 can be monetized by selling it as a product to another company (e.g., for enhanced oil recovery). Alternatively, since the concept prescribes the capture of biogenic CO_2, from the viewpoint of carbon lifecycle, the process can be regarded as a negative-emission technology[7] and can also be remunerated through carbon credits. This could leverage economic performance of the proposed system, together with digestate revenues. A comparison of the economic analysis of the two scenarios is shown in Table 2.

Table 2: Main variables in the economic analysis comparing biogas production (1) and burning of açaí seeds (2).

Variable	Unity	Scenario 1	Scenario 2
Fixed capital investment	MM US$	55.14	21.58
Manufacturing costs	MM US$	24.00	13.13
Revenues			
Electricity	MM US$ / year	14.83	22.25
Methane	MM US$ / year	14.22	-
Captured CO_2	MM US$ / year	1.16	-
CO_2 avoidance (CBIO)	MM US$ / year	0.15	-
Biofertilizer	MM US$ / year	1.41	-
Annual Profit	MM US$ / year	10.64	6.02
Net present value (23 years)	MM US$	79.02	34.65
Internal rate of return (IRR)	%	10%	26%
Payback	Years	9.75	6.52

Table 2 exhibits better long-term profitability of biogas production (1), despite the higher investment, as a consequence of the higher revenues generated by biomethane, electricity and other co-products, with extra contribution of carbon credits. Blocks S-100 and S-500 represented, respectively, around 47% and 29% of total fixed capital investment; while the sale of biomethane and electricity represented, respectively, 45% and 47% of total revenues. Considering the compared scenarios, burning of açaí seeds (2) led to a faster payback time and a higher internal rate of return due to lower fixed capital investment and manufacturing costs of this simpler technology when compared to biomethane production. However, the biogas plant (1) achieved a considerably higher NPV at the end of the project lifetime, which indicates being more efficient from an economic point of view in the long term. Despite the higher process complexity, scenario 1 was able to generate higher revenues and a greater variety of products, not depending exclusively on the sale of electricity. One of these products, biofertilizer, forms a cycle throughout the entire production chain, returning to the cultivation of açaí. Nevertheless, the economic performance of scenario 1 can be further improved with technological advances enabling higher yields in biomethane production. This could be achieved if the co-digestion of liquid hydrolysate with solid residue is proven efficient or a more effective hydrolysis step is adopted, using just a small fraction of the solid residue to supply heat and power process demands. Also, if a different solvent for CO_2 capture with lower regeneration heat is adopted, a positive impact on the profitability can be achieved. Thus, new experimental strategies to increase the efficiency of the hydrolysis and anaerobic digestion process should be evaluated to increase the biomethane yield and improve the whole process competitiveness.

4 CONCLUSION

Both scenarios of biomethane production by anaerobic digestion of liquid hydrolysate (1) and burning of açaí seeds (2) were technically and economically viable, achieving a payback within less than 10 years. Biogas production (1) displayed better long-term economic performance when compared to burning açaí seeds (2), having a diversified income with the generation of multiple co-products, in addition to carbon credits, which collaborate for attaining greater revenues. Even with relatively low efficiency of acid hydrolysis, such greater revenues compensate the higher fixed capital investment and manufacturing costs of scenario (1). Thus, to improve economic performance by increasing biomethane yield, further work should investigate co-digestion of liquid hydrolysate with solid residue and/or an implementation of a more effective hydrolysis step.

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