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Article

Study of the economic feasibility of thermal catalytic process of Açaí seeds (*Euterpe Oleracea*) and Scum from grease traps

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Abstract: This work aims to investigate systematically the tecno-economic feasibility of thermos-catalytic cracking process for two solid waste materials, a lipid-base material (residual fat/scum from retention box of the University Restaurant of UFPA) and a lignin-cellulosic material Açaí seed (*Euterpe oleracea.* Mart*)*. The thermo-catalytic processes were carried out in pilot scale (THERMTEK/LEQ/UFPA/IME/RJ), and their economic feasibility analyzed. The yields of biofuels produced by fractional distillation were also studied. The physicochemical characteristics of the raw materials, the organic liquid product (bio-oil) and the chemical composition of kerosene, light-diesel and heavy-diesel from the lipid-base material, as well as those of kerosene and light-diesel from the Açaí seed were also determined. The economic indicators for the evaluation of the most viable cracking (pyrolysis) and distillation process of bio-oils were: a) the simple payback criterion, b) discounted payback, c) net present value (NPV), d) internal rate of return (IRR), and e) index of profitability (IP). The analysis of the indicators showed the economic viability of crude palm oil (*Elaeis guineensis*, Jacq) and *unfeasibility* for the palm oil neutralization. The minimum fuel selling price (MFSP) obtained is this work for the biofuels was of 1.34 US$/L) and the breakeven point obtained was of 1.28 US$/L. *The sensibility analysis demonstrated that the pyrolysis and distillation yields are the most important variables to affect the minimum fuel selling price (MFSP).*

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Keywords: Scum from fat box; Açaí seeds, Thermal processing; Biofuels, Economic analysis; Technical feasibility.

1. Introduction

In view of global climate changes and the depletion of non-renewable energy sources, there is a dependence on fossil fuels, in particular petroleum-based fuels, such as gasoline, diesel, liquefied petroleum gas and natural gas. Criticism associated with its polluting nature has intensified the search for new, cleaner and more sustainable energy sources. Climate change, a result of global warming caused by greenhouse gases GHGs, mainly carbon dioxide (CO_2), the product of burning fossil fuels, is causing significant changes in ecosystems (CASTRO, 2019).

It is estimated as a direct consequence of approximately 150.000 additional deaths per year (TESKE and SCHAFER, 2014), an increasing risk of hunger for millions of people, floods and water shortages, in addition to the increased occurrence of diseases such as malaria (ALMEIDA, 2015).

Energy efficiency and diversification of the energy matrix are the keys to balancing energy demand and supply, as well as minimizing environmental problems. In this context, other forms of energy, mainly renewable, must be studied and developed in order to reduce or even eliminate the environmental impacts caused during the stages of energy production, from the raw material to the final consumer (CASTRO, 2019). The use of a renewable energy source contributes to reducing the emission of greenhouse gases, such as carbon dioxide (CO_2). These gases are essential for maintaining the stability of the climate and terrestrial ecosystems, being responsible for having the capacity to retain heat in the atmosphere. In this way, the use of biofuels allows the short carbon cycle to be complete, in which carbon dioxide (CO_2) is absorbed in the plant growth process and released in the combustion of the biofuel in the engine (CASTRO, 2019).

Biofuel is a renewable source of energy produced from natural raw materials (DERMIBAS, 2011). These biofuels have been compared to fossil fuels and the results show partial agreement with fossil fuel specifications. Technologies for energy production from biomass are those that best fit the concept of sustainable development, since the carbon dioxide (CO_2) production process is neutral, and therefore environmentally correct (KATIKANENI *et al.*, 1998). In this scenario, biofuels have been proposed as sustainable technological alternatives to replace fossil fuels (FENGWEN *et al.*, 2013). Thus, fuels derived from renewable sources, such as biomass, including vegetable oils, as palm oil, soybean oil, sunflower oil, cottonseed oil, in addition to residues from frying oils, and even lipid material from fat boxes have been intensively studied in recent years (BISWAS and SHARMA, 2013; CORRÊA, 2014).

Biofuels, including bioethanol, charcoal, biodiesel, bio-oil bio-gasoline, biogas, bio-kerosene, are defined as solid, liquid or gaseous fuels, produced from renewable biomass, in partial replacement or total to fossil fuels (SANTOS *et al.*, 2010; TAMUNAIDU, 2007), being used mainly in internal combustion engines in motor vehicles, as well as in electric power motor generators (ONG and BHATIA, 2009). The pyrolysis or cracking of triacyl-glycerides (TAG) consists of the thermal decomposition of triacyl-glycerides in the absence of oxygen or any other oxygenated compounds (SANTOS *et al.*, 2010) as well as on the presence or absence of catalysts, resulting in a mixture of hydrocarbons, consisting mainly of molecules of linear chains, rich in fractions similar to gasoline, kerosene and diesel of fossil origin (TAMUNAIDU and BHATIA, 2007; ONG and BHATIA, 2009).

The cracking process of vegetable oils or animal fats takes place in two successive and distinct phases. The first stage is characterized by the formation of fatty acids in high concentrations, due to thermochemical decomposition of triacyl-glyceride molecules. The second stage is characterized by the degradation of fatty acids produced in the first stage, forming hydrocarbons with properties similar to those of petroleum products (ONG and BHATIA, 2009). Among the various advantages of biofuels, sustainability, reduction of greenhouse gas emissions, among others (FRÉTY, 2011; MOTA, 2013).

The oils and fats used in the food frying process generate a considerable amount of waste (BARROS *et al.*, 2008). It is known that a liter of frying oil released into the sewer system, or released into a "body of water", has the property of contaminating an inconvenience to its treatment, as due to increase population in urban areas, it is necessary to increase the demand for drinking water, this being a product considered of high need for human beings (SILVA FILHO, 2012). In commercial establishments (restaurants, cafeterias, etc.), as well as in homes, the residual oils and fats from frying are collected in Grease Bins, being generally disposed of in sanitary landfills, generating significant volumes of residues. In this sense, the use of these wastes, rich in lipid material and of low cost, has been investigated as a raw material for the production of biofuels (RATTON, 2012), enabling the obtainment of biofuels from lipid residues from fat boxes, as well as the reduction of the quantity and volume of waste deposited in sanitary landfills (MARCHETTI, 2005).

In this context, the present work investigated the feasibility of producing fractions of biofuels similar to green kerosene, light diesel and heavy diesel via catalytic thermal cracking of the residual fat (lipid material) from the fat retention boxes of the University Restaurant of UFPA, using sodium carbonate (Na_2CO_3) in the proportion of 15% (wt.) as catalysts, followed by distillation of organic liquid product (OLP) using a pilot distillation unit.

In Pará state (Brazil), the açai fruit is one of the most consumed products in the northern region of the county, whose residue is the seed, which is an environmental liability, mainly in the city of Belém. The state of Pará is the largest national producer of Açai with 1.072.740 tons/year, still without adequate economic destination being discarded without any treatment in rivers and dumps (SEDEME, 2017). With this, the vast amount of solid waste generated in Belém, makes the study of the production of biofuels from Açai seeds a promising alternative, considering the amount of raw material available, enabling the reuse of these residues for the generation of renewable energy (CASTRO, 2019).

In this context, this work proposes to investigate the process of biofuel production, via pyrolysis of açai seed chemically impregnated with sodium hydroxide (NaOH) in pilot scale, evaluating the quality and the yield of reaction products obtained at 450 °C, followed by fractional distillation of organic liquid products to produce bio-kerosene and light-diesel, using a pilot unit. The chemical composition of these products and yields are also presented (CASTRO, 2019).

Among the alternative renewable energy sources that are mature enough to be used commercially, only biomass has been identified with high technological efficiency (CORTEZ *et al.*, 2011). Biomass has the flexibility to generate both electric energy and transportation fuels (CORTEZ *et al.*, 2011).

WRIGHT *et al.*, (2010) presented a techno-economic study which examined fast pyrolysis of corn stover to bio-oil with subsequent upgrading of the bio-oil to naphtha and diesel range fuels. In this study, 2000 (two thousand) tons/day of dry feed material was the scenario analyzed for the development of on-site fuel upgrading, while the second scenario relies on production of hydrogen. Fuel product value estimates are US$3.09 and US$2.11/gallon of gasoline equivalent (US$0.82 and US$0.56/L).

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According BROWN *et al.*, (2013) a previous Iowa State University (ISU) analysis published in 2010 investigated the technical and economic feasibility of the fast pyrolysis and hydro-processing of biomass, and concluded that the pathway could produce cellulosic biofuels for a minimum fuel selling price (MFSP) of US$2.11/gallon (0.56 US$/L). In 2013 a new study was presented, the MFSP for a 2000 MTPD facility employing fast pyrolysis and hydro-processing to convert corn stover into gasoline and diesel fuels was calculated to quantify the economic feasibility of the pathway. The present analysis determines the MFSP of bio-gasoline and bio-diesel fuel produced by fast pyrolysis and hydro-processing to be US$2.57/gallon (0.68 US$/L).

ZHANG *et al.*, (2013) presented the economic feasibility of a facility producing monosaccharides, hydrogen and transportation fuels (gasoline and diesel) via fast pyrolysis and upgrading pathway was evaluated by modeling a 2000 dry metric ton biomass/day facility using Aspen Plus. A facility internal rate of return (IRR) of 11.4% based on market prices of US$3.33/kg-hydrogen, US$2.92/gallon (US$0.77/L) gasoline and $0.64/L diesel was calculated.

Several studies have reported yields of 50-75% bio-oil (although yields above or below this range are not uncommon, depending on the kind of feedstock, reactor and operational conditions employed (BROWN *et al.*, 2013)), 15-25% char (wt.), and 10-20% (wt.) gas (GREGOIRE and BAIN, 1994; MULLANEY and FARAG, 2002).

MOTA (2013) studied the production of biofuels by catalytic cracking of palm oil at different scales of production. Part of the product obtained was distilled using a laboratory Vigreux column and a Raschig-rings packed pilot scale column. MOTA (2013) investigated the thermal cracking and thermal-catalytic cracking of palm oil, as well as the effect of different types of catalyst and the content of catalyst on the yield of liquid products. It was obtained results for the yields of bio-oil, coke, and gas of 63.6% (wt.), 8% (wt.) and 28.4% (wt.).

According to THILAKARATNE *et al.*, (2014) a techno-economic analysis of mild catalytic pyrolysis (CP) of woody biomass followed by upgrading of the partially deoxygenated pyrolysis liquid was performed to assess this pathway's economic feasibility for the production of hydrocarbon-based biofuels. A minimum fuel selling price (MFSP) of $3.69/gallon (0.98 US$/L) was estimated assuming 10% internal rate of return. The process gives a product fuel yield of 58.6/gallon per MT of biomass which is equivalent to a mass conversion rate of 17.7% (wt.).

With growing concerns about our use of fossil-based fuels and associated greenhouse gas emissions, utilization of biomass for alternative fuel sources is on the rise. Biomass is defined as organic matter that is renewable and bio-degradable (BADGER *et al.*, 2011). Biomass can be converted to the either ethanol or bio-oil. Pyrolysis is the chemical composition organic materials by heat (around 500 ºC) in the absence of oxygen (BRIDWATER *et al.*, 1999). After cooling and condensation, a dark brown liquid (bio-oil) is formed. The pyrolysis process produces three main products: a liquid organic (bio-oil), coke, and gases (MOTA, 2013; SANTOS, 2015; CASTRO, 2019). Bio-oil from fast pyrolysis of biomass has great potential to be one of the main renewable energy sources (JAROENKHSEMMESUK and TIPPA VAWONG, 2015).

For nearly a decade techno-economic analysis have been performed for pyrolysis oil production (GREGOIRE and BAIN, 1994; MULLANEY and FARAG, 2002; RINGER *et al.*, 2006). Large-scale plant systems tend to generate lower production costs (BADGER *et al.*, 2011). This study focuses on the economic evaluation of the production of catalytic pyrolysis bio-oil, coke and methane gas from processing biomass on bath reactor. The incentives for producing with thermal-catalytic pyrolysis technology are (LAPPAS, 2022; LAPPAS, 2012). (1) better oil quality with a high energy content (28-30 MJ/kg) compared with 16-18 MJ/kg for bio-oil from thermal pyrolysis (BRIDGWATER *et al.*, 1999; RINGER *et al.*, 2006), (2) higher stability in storage and transportation, and (3) lower acidity and as a result less corrosive. For these reasons, it is important to estimate the cost of producing bio-oil and, therefore, be in a better position to consider its further use in commercial applications for either transportation fuels or chemicals. The economic analysis is accomplished based on pilot plant data with commercially available catalyst (Na_2CO_3) in all experiments evaluate in this work.

Energy from biomass is produced by thermal-catalytic cracking (pyrolysis) and distillation process (MOTA, 2013). Pyrolysis of biomass, such as palm oil (*Elaeis guineensis*, Jacq), can produce biofuels. After distillation, these organic liquid products (biofuels) are similar to gasoline, kerosene, and diesel of fossil origin (ONG and BHATIA, 2009).

Economic feasibility of two raw materials, lipid material and açaí seed, has been studied to evaluate the best investment alternative. The economic feasibility analysis of these raw materials was based on the following economic indicators: simple payback criterion, discounted payback, net present value (NPV), internal rate of return (IRR), and index of profitability (IP). In order to evaluate the various influence over the minimum fuel sale price (MFSP) an analysis of sensibility was accomplished. Besides, it is presented the breakeven point of the viable project.

Figure 1 presents the scheme used in the process by ALMEIDA (2015) to convert the lipid material (residual fat/scum from fat retention box of University Restaurant of UFPA) into organic liquid product (bio-oil), coke and methane gas by pyrolysis process using 10% (wt.) sodium carbonate as a catalyst at 440 °C, followed by distillation to obtain biofuels (green kerosene, light-diesel and heavy-diesel).

Figure 2 illustrates the scheme used in the process by CASTRO (2019) to convert the Açai seeds (*Euterpe Oleracea)* into organic liquid product (bio-oil), coke and methane gas though pyrolysis process at 450 °C, followed distillation to obtain biofuels (biokerosene and light green diesel).

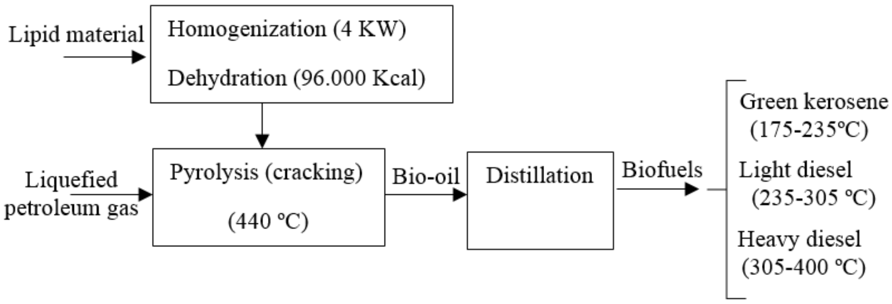

Figure 1: Scheme of conversion of lipid-base material in biofuels.

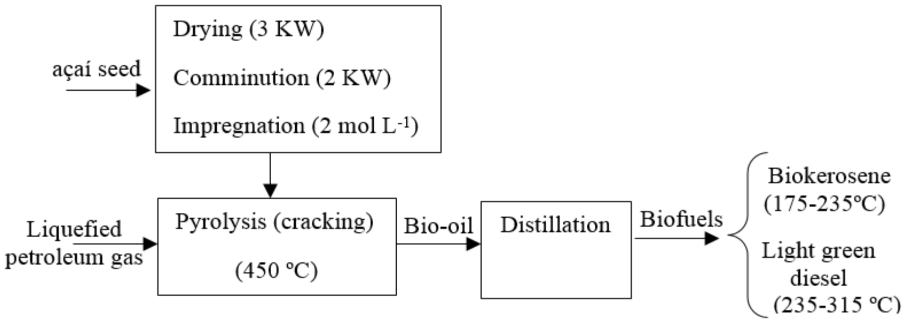

Figure 2: Scheme of conversion of açaí seed (*Euterpe oleracea)* in biofuels.

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2. Materials and Methods

1.1. Materials

2.1.1 Lipid-base materials

The residual fat/scum from retention box of the University Restaurant of UFPA was obtained and pre-processed as described in the literature (ALMEIDA, 2015).

2.1.2 Açai Seeds (Euterpe Oleracea, Mart.)

The seeds of Açaí in nature were collected and pre-processed as described in details in the literature (CASTRO, 2019).

2.2 Thermal-cracking, thermal-catalytic cracking and distillation process

The pyrolysis, thermal-catalytic cracking and distillation processes of Açaí seed (*Euterpe Oleracea, Mart.)* and lipid-base material from fat retaining box of the University restaurant of UFPA, were described in details by ALMEIDA (2015) and CASTRO (2019), respectively.

2.3 Project evaluation criteria

2.3.1 Simple Payback

Simple payback is the time required for the investment made in the project to be fully recovered. The investor establishes the maximum term as a criterion to consider the feasibility of the project. Simple payback has the following characteristics [35]:

- *It does not consider the value of money over time, which is contrary to the basic principle that a currency unit today is worth more than the same currency unit tomorrow.*
- *The project's cash flow, the amounts recorded, are considered historical (fixed).*
- *All amounts indicated in the cash flow that are positioned after the simple payback are not considered in the judgment analysis (comparison between the time defined by the investor for the return on investment and the return time obtained in the payback study).*

2.3.2 Discount Payback

The discounted payback method is similar to the simple payback, except that it considers the attractiveness or discount rate. It considers the value of money over time by adding the company's cost of capital to the simple payback. All cash flow elements are discounted at the defined rate, which is usually the current value on the zero date (RÊGO *et al.*, 2010). The discounted payback period is the investment recovery time at a chosen interest rate. This method is close to the criterion of Net Present Value (NPV).

Simple payback and discounted payback can be used to break similar NPV situations where faster cash recovery becomes relevant. They can also be used as a secondary analysis filter as a measure of liquidity risk or they can be generalized as a degree of project risk. Over time, the uncertainties associated with the project, such as revenue forecasts and corresponding costs, tend to increase, and with them, the associated risk. Finally, they assist in the analysis of projects without major financial significance for investors.

2.3.3 Net Present Value (NPV)

This criterion considers the value of money over time. It consists of two basic principles:

1. *A currency unit today is worth more than a currency unit tomorrow,*
2. *A secure currency is better than an uncertain currency.*

NPV is a criterion that works with the entire cash flow over a period of time. The values pertaining to cash flow are: 1. fixed investment; 2. investment in working capital; 3. gross operating revenue; 4. total operating cost; 5. project lifetime.

Together they are referred to as endogenous values. The equations below are used to prepare cash flow using the NPV criterion:

Total Revenue = Sales Price x Quantity (1)

Total Cost = Total Unit Cost x Quantity (2)

Total Unit Cost = Unit Fixed Cost + Unit Variable Cost (3)

A variable effective interest rate is used in the NPV as an exogenous measure because it is a variable obtained from the financial market. Its value includes the premium for the decision to implement a project in the chemical industry that comes with risk.

By definition, NPV is the difference between the present value of cash flow ($PV_{C.F}$) and the value of investment (INV) made in the project, according to equation (4):

$$NPV = INV + PV_{C.F} \tag{4}$$

The present value of the cash flow ($PV_{C.F}$) is the result of moving all the values recorded in each period, at a certain minimum attractiveness rate [10].

NPV criteria decision rules

The project is considered viable if the NPV is greater than zero, because this guarantees that the present value of the cash flow ($PV_{C.F}$) is greater than the value of the investment; therefore, it can be defined as follows:

a) recovers the full value of the investment;

b) a value is added to the company's equity, equivalent to the result obtained from the NPV.

If the NPV is equal to zero, then the company is in an uncertain situation and may or may not invest in the project. The final decision depends on other considerations.

If the NPV is negative, then the investment should not be made because the investment value will be higher than the present value of the cash flow ($PV_{C.F}$). In such situations the investment is not entirely recoverable.

The NPV criterion works with discounted cash flow, which means that future cash flow values when transported to point to suffer a loss in value due to the application of the interest rate.

2.3.4 Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) criterion represents the value of a rate that belongs to the project itself. This means that the criterion is an endogenous measure because there is no need, as is the case with the NPV criterion, to use an attractive rate to move future values to the zero point.

This criterion is widely used because its result, which is given in the form of quantified percentage values, is easy to understand and interpret. This criterion works with the entire cash flow and considers the value of money over time. The IRR is specific to each project and its definition is as follows: "It is a rate that makes the NPV equal to zero". The point at which the NPV becomes zero corresponds to the IRR (RÊGO *et al.*, 2010).

IRR decision-making criteria

The IRR decision-making process can then be summarized as follows:

a) cost of capital < IRR, project must be accepted (NPV > 0);

b) cost of capital = IRR it can be accepted or not (NPV = 0).

c) cost of capital > IRR, project must be rejected (NPV < 0).

2.3.5 Index of Profitability (IP)

This criterion involves characteristics similar to the previous criteria, as it also considers the value of money over time and uses all cash flow. This criterion is close to the NPV criterion, as it is defined as follows:

The index of profitability is the ratio of the NPV plus the investment divided by the entire investment (INV), according to equation (5), as follows:

$$IP = \frac{NPV + INV}{INV} \tag{5}$$

Index of Profitability (IP)

The index of profitability is the ratio of the NPV plus the investment divided by the entire investment (INV), according to equation (5), as follows:

Index of Profitability (IP) decision criteria

A project will be viable if the value of IP is greater than one, which means that the INV has been recovered and something has been added to the company's equity.

If the IP is equal to one, the decision will depend on other aspects, because in such a case, only the recovery of the investment is guaranteed.

For results in which the IP is less than 1, the project is not viable, because the investment is not fully recoverable.

2.4 Calculation Methodology

The calculations, from item 2.3.1 up to item 2.3.16, are applied to Table 5.9 (Revenues and expenses using lipid-base material as feed) and the Tables 5.20 (Revenues and expenses using Açai seeds *(Euterpe Oleracea, Mart.)* as raw material). Table 1 shows the parameters used in the equations below.

Table 1: Process parameters used in the equations.

Process parameters	Value	Unit
M is the mass of lipid material	145	Kg
M is the mass of açai seed	150	Kg
N_{sh} is the number of shifts per day	3	-
N_{bat} is the number of batchs per shift using lipid material considering the feed rate	5	-
N_{bat} is the number of batchs per shift using açaí seed considering the feed rate	3	-
d is the density of the lipid material	$0.98 \,.\, 10^{-3}$	kg/L
d is the density of the açai seed	$1.49 \,.\, 10^{-3}$	kg/L
Y_{oil} is the pyrolysis process yield of the bio-oil from the lipid material	68.73	%
Y_{oil} is the pyrolysis process yield of the bio-oil from the açaí seed	11.03	%
Y_{coke} is the pyrolysis process yield of coke from the lipid material or açaí seed	5.03	%
Y_{coke} is the pyrolysis process yield of coke from the açaí seed	39.84	%
P_{coke} is the price of coke	0.30	US$/kg
d_{coke} is the coke density	1.10^{-3}	kg/L
Y_{gas} is the pyrolysis process yield of methane gas from the lipid material	26.24	%
Y_{gas} is the pyrolysis process yield of methane gas from the açaí seed	31.62	%
P_{LPG} is the price of liquefied petroleum gas	0,503	US$/L
d_{gas} is the methane gas density	$0.72 \,.\, 10^{-3}$	kg/L
Y_{bio} is the distillated process yield of lipid material	15.07	%
Y_{bio} is the distillated process yield of açai seed	90	%
P_{RM} is the price of raw material of lipid material (it was considered 10% of the soy oil price)	1.295	US$/kg
P_{RM} is the price of raw material of the açaí seed	0.027	US$/kg
P_{cat} is the price of catalyst	0.52	US$/kg
C_m is the cost of manpower in thirty days	1562.5	US$/month
N_{bat} is the number of batchs per day to lipid material considering the distillation	16	-
N_{bat} is the number of batchs per day to açaí seed considering the distillation	3	-
P_{KW} is the power of the distillation colum	5	KW
t is the distillation operation time during one day	24	h
P_{KWh} is the price of the KWh	0.2186	KWh
SP_{bio} is the sale price to the biofuels produced with lipid material and açaí seed	1.34	US$/L
N_{bat} is the number of batchs per day to the lipid material considering the homogenization	15	-

P_{KW} is the power of the homogenization system	4	KW
t is the homogenization operation time per batch	0.33	h
P_{deh} is the power of the boiler	$96.\,10^{6}$	cal
f_{KWh} is the factor of conversion from calories (cal) to KWh	$11.62\;.\;10^{7}$	KWh/cal
t_{deh} is the time of dehydration per batch	2	h
N_{deh} is the number of dehydration batch per day	3	-
P_{dry} is the power of the equipment of drying	3	KW
t_{dry} is the time of Drying per day;	24	h
N_{dry} is the number of drying batches per day	12	-
P_{com} is the power of the equipment of comminution	3	KW
t_{com} is the time of comminution per batch	1	h
N_{com} is the number of comminution batch per day	24	-
P_{NaOH} is the price of sodium hydroxide	3.67	US$/L
N_{mol} is the number of moles	2	moles/L
M_{mol} is the molecular mass of sodium hydroxide is 40	40	kg/Kgmol
V_{sol} is the sodium hydroxide solution volume it was	1	L

2.4.1 Feed rate

$$Q = \frac{M\,.\,N_{sh}\,.\,N_{bat}}{d} \qquad (6)$$

Where Q is the volumetric flow rate of lipid material or açaí seed [L/day], M the mass of lipid material or açai seed *(Euterpe Oleracea)* in [kg] per shift;

N_{sh} = number of shifts per day [-]; N_{bat} = number of batchs per shift using lipid material or açaí seed [-]; d = density of the lipid material or açaí seed in [kg/L].

2.4.2 Flow of Organic liquid product (OLP)

$$Q_{bio} = (\,Y_{oil}\;.\;Q\,)/100 \qquad (7)$$

Q_{bio}= flow of liquid product organic (bio-oil) [L/day]; Y_{oil} = pyrolysis process yield of the bio-oil from the lipid material or açaí seed in [%]; Q = flow of lipid material or açai seed [L/day].

2.4.3 Flow of Solid product (coke)

$$m_{coke} = \frac{(Y_{coke}\;.\;Q\;.\;P_{coke})}{100\,.\;d_{coke}} \qquad (8)$$

m_{coke} = flow of coke [US$/day]; Y_{coke} = pyrolysis process yield of coke from the lipid material or açaí seed in [%]; Q = flow of lipid material or açaí seed in [L/day]; P_{coke} = price of coke [US$/kg]; d_{coke} = coke density [kg/L].

2.4.4 Flow of Gaseous product (Biogas)

$$m_{gas} = \frac{(Y_{gas}\;.\;Q\,.\;f2\;.\;P_{LPG}\;.\;f1)}{100\,.\;d_{gas}} \qquad (9)$$

m_{gas} = flow of methane gas [R$/day]; Y_{gas} = pyrolysis process yield of methane gas from the lipid material or açaí seed in [%]; Q = flow of lipid material or açai seed in [L/day]; P_{LPG} = price of liquefied petroleum gas [US$/L]; $f1$ = it was considered that the methane gas flow it is 10% of the Y_{gas} pyrolysis process yield of methane gas; $f2$ = it was considered that the price of the methane gas is 50% of the liquefied petroleum gas (L.P.G) [-]; d_{gas} = methane gas density [kg/L].

2.4.5 Flow of Distilled biofuel

$$D_{bio} = (Y_{bio} . Q_{bio}) / 100 \tag{10}$$

D_{bio} = distillated biofuel [L/day]; Y_{bio} = distillated process yield of lipid material or açai seed in [%]; Q_{bio} = flow of organic liquid product (bio-oil) [L/day].

2.4.6 Cost of Raw Material

$$C_{RM} = \frac{P_{RM} \ . \ Q}{d_{RM} \ . \ (D_{bio} + m_{coke} + m_{gas})} \tag{11}$$

C_{RM} = cost of raw material of lipid material or açai seed [R$/L]; P_{RM} = price of raw material of lipid material (it was considered 10% of the soy oil price) or açaí seed in [US$/kg]; Q = flow of vegetable lipid material or açaí seed in [L/day]; d_{RM} = density of the lipid material or açaí seed in [kg/L].

2.4.7 Cost of Catalyst

$$C_{cat} = \frac{Q \ . \ d \ . P_{cat} \ . m_{cat}}{100 \ . \ (D_{bio} + m_{coke} + m_{gas})} \tag{12}$$

C_{cat} = cost of catalyst Na_2CO_3 in [R$/L]; P_{cat} = price of catalyst (0,52) [US$ / Kg]; m_{cat} = percent of catalyst in relation the feed rate (10% to lipid material and 15% to açai seed) in [%].

2.4.8 Cost of Liquefied petroleum gas (LPG)

$$C_{LPG} = \frac{Q \ . \ P_{LPG} . m_{LPG}}{(D_{bio} + m_{coke} + m_{gas})} \tag{13}$$

C_{LPG} = cost of liquefied petroleum gas in [US$/L]; P_{LPG} = price of liquefied petroleum gas (0,503) [US$/L]; m_{LPG} = percent of liquefied petroleum gas in relation the feed rate (10) for all raw materials [%].

2.4.9 Cost of Manpower

$$C_{MP} = \frac{C_m}{30 \ . \ (D_{bio} + m_{coke} + m_{gas})} \tag{14}$$

C_{MP} = cost of manpower [US$/L]; C_m = cost of manpower in thirty days [US$/month].

2.4.10 Cost of Distillation (Heating)

The number of distillation columns depending the bio-oil produced in each pyrolysis process. It was considered 120 Kg per unit of distillation to the lipid material and 50 Kg per unit to the açaí seed use (once the flow yield of the process using açaí seed is only 11.03%, which means low amount of bio-oil to be distillated).

$$D_c = \frac{N_{bat} \ . \ P_{KW} \ . \ t \ . \ P_{KWh}}{(D_{bio} + m_{coke} + m_{gas})} \tag{15}$$

D_c = distillation cost in [US$/L]; N_{bat} = number of batchs per day to lipid material and to açaí seed in [-]; P_{KW} = power of the distillation colum in [KW]; t = distillation operation time during one day in [h]; P_{KWh} = price of the KWh in [US$/KWh].

2.4.11 Tax

$$T = \frac{\%T \ . \ SP_{bio}}{100} \tag{16}$$

T = tax in [US$/L]; $\%T$ = percentage of tax in [%]; SP_{bio} = sale price to the biofuels produced with lipid material and açaí seed [US$/L];

2.4.12 Total profit per day

$$TP = D_{bio} \cdot \ (SP_{biol} - TE) \ + \ m_{coke} \ + \ m_{gas} \tag{17}$$

TP = total profit per day [US$/day]; D_{bio} = distillated biofuel [L/day]; SP_{biol} = sale price of biofuel [US$/L]; TE = total expenses [US$/L];

2.4.13 Homogenization

This calculation is applied to the Table 5.9 (Revenues and expenses using lipid material as raw material).

$$H_c = \frac{N_{bat} \cdot P_{KW} \cdot t \ \cdot P_{KWh}}{(D_{bio} + m_{coke} + m_{gas})} \tag{18}$$

H_c = homogenization cost in [US$/L]; N_{bat} = number of batchs per day to the lipid material in [-]; P_{KW} = power of the homogenization system in [KW]; t = homogenization operation time per batch in [h] ; P_{KWh} = price of the KWh in [US$/KWh].

2.4.14 Dehydration

This calculation is applied to the Table 5.9 (Revenues and expenses using lipid material as raw material).

$$C_{deh} = \frac{P_{deh} \cdot f_{KWh} \cdot t_{deh} \cdot N_{deh} \ \cdot P_{kwh}}{(D_{bio} + m_{coke} + m_{gas})} \tag{19}$$

C_{deh} = cost of dehydration [US$/L]; P_{deh} = power of the boiler in [cal]; f_{KWh} = factor of conversion from calories (cal) to KWh in [KWh/cal]; t_{deh} = time of dehydration per batch [h]; N_{deh} = number of dehydration batch per day [-]; P_{KWh} = price of the KWh in [US$/KWh].

2.4.15 Drying

This calculation is applied to the Table 5.20 (Revenues and expenses using açaí seed as raw material).

$$C_{dry} = \frac{P_{dry} \cdot t_{dry} \cdot N_{dry} \ \cdot P_{kwh}}{(D_{bio} + m_{coke} + m_{gas})} \tag{19}$$

C_{dry} = cost of drying [US$/L]; P_{dry} = power of the equipment in [KW]; t_{dry} = time of Drying per day [h]; N_{dry} = number of drying batch per day [-]; P_{KWh} = price of the KWh in [US$/KWh].

2.4.16 Comminution

This calculation is applied to the Table 5.20 (Revenues and expenses using açaí seed as raw material).

$$C_{com} = \frac{P_{com} \cdot t_{com} \cdot N_{com} \ \cdot P_{kwh}}{(D_{bio} + m_{coke} + m_{gas})} \tag{19}$$

C_{com} = cost of comminution [US$/L]; P_{com} = power of the equipment (3) in [KW]; t_{com} = time of comminution (1) per batch [h]; N_{com} = number of comminution batch per day (27) [-]; P_{KWh} = price of the KWh in [US$/KWh].

2.4.17 Cost of Impregnation

This calculation is applied to the Table 5.20 (Revenues and expenses using açaí seeds as raw material). The solution used to impregnate the raw material had the concentration of sodium hydroxide of 2 mol/L. For each 32 kg of açaí seed it was used 64 L of sodium hydroxide solution.

$$C_{imp} = \frac{64 \,.\, Q \,.\, N_{mol} \cdot M_{mol} \cdot V_{sol} \cdot P_{NaOH}}{32 \,.\, 10^3 \,(D_{bio} + m_{coke} + m_{gas})} \tag{20}$$

C_{imp} = cost of impregnation in [R$/L]; P_{NaOH} = price of sodium hydroxide [US$/L]; N_{mol} = number of moles [moles/L]; M_{mol} = molecular mass of sodium hydroxide is 40 [Kg/Kgmol]; V_{sol} = sodium hydroxide solution volume it was [L].

3. Results

3.1 Lipid-base material

The results presented is this work were those from the pyrolysis of the lipid-base material (Experiment 1) with 10% (wt.) of catalyst (Na_2CO_3) carried out in pilot scale. The results presented by ALMEIDA [1], for the yields of reaction products by pyrolysis and distillation, are shown in Table 2.

Table 2: Yields of reaction products by pyrolysis of lipid-base material and distillation process [1].

Pyrolysis/Distillation	50.00%
Organic Liquid Product/Bio-oil	68.73%
Solid product (coke)	5.03%
Gaseous product (Biogas)	26.24%
Distillation yield	15.07%

Table 3 presents the results of physicochemical characterization of the lipid material used as raw material in the pyrolysis pilot unit. It can be observed that the saponification index is in agreement with the values reported in the literature by RATTON [34], which found an average value of 189 mg KOH/g. The saponification index indicates that sample presents large amounts of fatty material, with great potential to form soap to be used in the pyrolysis process. The acidity index indicates the presence of free fatty acids.

Table 3: Physicochemical characterization of the lipid-base material used as feed [1].

Physico-chemical properties	Values
Density [g/cm³]	0.98
Acidity index [mg KOH/g]	72.73
Kinematic viscosity [cSt]	9.4
Saponification index [mg KOH/g]	120.19

The physicochemical characterization of the bio-oil are presents on the Table 4 and were compared with the specifications of the resolution Nº 65 of the Petroleum National Agency, Natural Gas and Biofuels, for petroleum-derived diesel. The result of acidity index is low and presented value of 14.97 mg KOH/g, which is in agreement with similar data reported in the literature (PRADO and FILHO, 2009). The results of density and the flash point are in agreement with the ANP Nº 65. The results of the saponification index reduced from 120.19 mg KOH/g (pre-treated lipid-base material) to 24.22 mg KOH/g (bio-oil) and the kinematic viscosity reduced from 9.4 cSt (pre-treated lipid-base material) to 3.29 cSt (bio-oil).

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Table 4: Physicochemical properties of the organic liquid product (bio-oil) produced pyrolysis of lipid-base material [1].

Properties	Bio-oil	ANP Nº 65
Density [g/cm³]	0.82	0.829
Acidity Index [mg KOH/g]	14.97	-
Refractive index [-]	1.45	-
Flash point [°C]	65	$\geq$ 38
Kinematic viscosity [cSt]	3.29	2.0-4.5
Saponification index [mg KOH/g]	24.22	-
Corrosiveness [1A]	1	1
Aspect	No approved	approved
Sulphur [mg/Kg]	39	10
Color [ASTM]	5	4

Table 5 presents the composition results of the organic liquid product (bio-oil) obtained by pyrolysis process, using 10% (wt.) sodium carbonate as catalyst at 440 °C. It is possible to confirm an effective deoxygenation of the bio-oil resulting from the cracking reaction with the use of catalyst sodium carbonate, indicated by high percentage of hydrocarbons of 78.98% (wt.), as well as the low concentration of oxygenated compounds equal to 15.72% (wt.).

Table 5: Composition of chemical compounds present in organic liquid product (bio-oil) with 10% (wt.) de Na_2CO_3 (experiment 1).

Compounds	**Content [wt.%]**
Hydrocarbons	**79.98**
Paraffins	31.91
Olefins	41.45
Aromatics	1.50
Naphthenics	4.12
Oxygenated	21.02
Alcohols	1.90
Ketones	6.98
Acids	6.84
Others	5.30

Table 6 presents the percentual composition of hydrocarbons and oxygenated compounds of green-kerosene obtained by pyrolysis of lipid-base with 10% (wt.) of Na2CO3 at 440 °C (experiment 1). It can be observed a high concentration of hydrocarbons (92.64 %), with the highest percentages of olefinic hydrocarbons (44.99 %) and paraffin hydrocarbons (29.61 %), and absence of oxygenated compounds [1].

Table 6: Composition of the green kerosene (175 °C – 235 °C) of experiment 1 [1].

Compounds	**Content [wt.%]**
Hydrocarbons	**92.64**
Paraffins	29.61
Olefins	44.99
Aromatics	7.58
Naphthenico	10.46
Others	7.36

Table 7 presents the composition of light diesel (235 °C – 305 °C) by pyrolysis of lipid-base with 10% (wt.) of Na2CO3 at 440 °C (experiment 1). It can be observed that the hydrocarbons of the light diesel obtained are paraffins, olefins, aromatics and naphthenic. These results shows that the highest percentages of hydrocarbons are of olefins (47.12 %) and paraffins (33.92 %). Furthermore, this fraction of diesel obtained from the distillation of the organic liquid product (bio-oil) it does not produce oxygenated compounds in the form of carboxylic acids, only in the form of alcohols (9.79 %) [1].

Table 7: Composition of light diesel (235º C – 305 ºC) of experiment 1.

Compounds	**Content [wt.%]**
Hydrocarbons	**90.21**
Paraffins	33.92
Olefins	47.12
Aromatics	1.40
Naphthenic	7.77
Oxygenated	**9.79**
Alcohols	9.79

Table 8 presents the composition of heavy diesel (305 °C – 400 °C) by pyrolysis of lipid-base with 10% (wt.) of Na_2CO_3 at 440 °C (experiment 1). It can be observed that the hydrocarbons of the light diesel obtained are paraffins, olefins, aromatics and naphthenics. These results show that the highest percentages of hydrocarbons are olefins (32.61%) and paraffins (25.20%). Aromatic and naphthenics hydrocarbons are presented in small percentage, around 5% (wt.).

Table 8: Composition of heavy diesel (305 °C – 400 °C) of experiment 1.

Compounds	**Content [%]**
Hydrocarbons	**79.98**
Paraffins	25.2
Olefins	32.61
Aromatics	5.18
Naphthenics	5.86
Oxygenated	**25,83**
Others	5,22

Table 9 presents the economic parameters for discounted cash flow analysis. The total project investment is US$ 91803.95 (ninety-one thousand eight hundred and three dollars and ninety five cents) and corresponds to the initial investment of the cash flow, based on the similar data reported in the literature [40].

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Table 9: Economic Parameters for Discounted Cash Flow Analysis.

Plant life	5	years
Plant size / biomass feed rate (lipid material, açaí seed) respectively.	1775.51; 906.04	L/day
Discount rate	10	% per year
Financing	100	% equity
Plant recovery period	5	years
Federal tax rate	10	%
Feedstock cost (lipid material, açaí seed) respectively.	1.295; 0.027	US$/L
Availability (lipid material, açaí seed)	50; 93.75	%
On stream time	4320; 8100	h
Reference year	2021	
Electricity price	0.2186	US$/KWh
Total purchased equipment costs (TPEC)	30951.37	US$
Direct costs (including equip installation, instruments and controls, piping electrical and misc. buildings)	18880.33	US$ (61% TPEC)
Total installed equipment cost (TIEC)	49831.70	US$ (61% TPEC + TPEC)
Warehouse	747.48	US$ (1,5% TIEC)
Site development	2242.43	US$ (4,5% TIEC)
Total installed cost (TIC)	52821.60	US$ (TIEC + warehouse + site development)
Indirect Field Costs (IFC)		
- field expenses	10564.32	US$ (20% TIC)
- home office & construction fee	13205.40	US$ (25% TIC)
- Project contingency	1584.65	US$ (3% TIC)
-Prorateable costs	5282.16	US$ (10%TIC)
Total capital investment (TCI)	83458.13	US$ (TIC + IFC)
Other costs (startup, permits, etc.)	8345.81	US$ (10% TCI)
Total Project Investment (TPI)	91803.95	US$ (TCI+ Other costs)

Table 10 presents the total revenue, total expense and the annual profit of US$ 36692.0 (thirty-six thousand six hundred and ninety two dollars) per year. The minimum fuel selling price (MFSP) obtained is this work for the biofuels was 1.34 US$/L (Currently practiced in Brazil). The literature mentioned in this work presents values of 0.68 up to 0.98 (US$/L).

Table 10: Revenues and expenses of using lipid-base material as feed.

Revenue		
Feed rate_50 % (Availability)_Cracking	1775.51	L/day d = 0.98 kg/m^3
Organic Liquid Product/Bio-oil_68.73%	1220.31	L/day (feed distilled)
Solid product (coke)_5.03%	27.04	US$/day
Gaseous product (Biogas)_26.24%	16.28	US$/day
Distilled biofuel_15.07%	183.9	L/day
Sale price of biofuel	1.34	US$/L
Total expense	**1.02**	**US$/L**
Raw material (lipid material)	0.245	US$/L
Homogenization (4 KW)	0.005	US$/L
Dehydration (96.000 Kcal) (2h)	0.156	US$/L
Catalyst_ 10%	0.046	US$/L
Liquefied petroleum gas (LPG)_10%	0.045	US$/L
Manpower	0.026	US$/L
Distillation (Heating)_5 KW	0.364	US$/L
Federal tax rate 10%	0.134	US$/L
Profit margin	0.32	US$/L
Total profit per day	102.5	US$/day
Total profit per month	3076	US$/month
Total profit per year	36916	US$/year

Table 11 shows the cash flow for the investment analysis through the simple payback criterion. It can be concluded that in the third year, the investment is fully recovered, totaling US$ 18942.86 (eighteen thousand nine hundred forty-two dollars and eight-six cents). In this case, the project is considered economically viable within the horizon of analysis of 5 years.

Table 11: Annual cash flow for the lipid material and simple payback analysis.

Year	0	1	2	3	4	5
Cash Flow	-91803.95	36915.60	36915.60	36915.60	36915.60	36915.60
Accumulated Value	-91803.95	-54888.35	-17972.74	18942.86	55858.46	92774.06

Table 12 shows the cash flow for the investment analysis considering the discounted payback criterion, the net present value (NPV) criterion, the internal rate return (IRR) criterion, and the profitability index. For the discounted payback criterion, it can be concluded that in the third year, the investment is fully recovered. The cash flow discount rate was 10% p.y. In this case, the project is considered economically viable because five years is considered the analysis horizon of the evaluation of the project. For the net present value (NPV) criterion, it can be concluded that in the third year, there is a capital increase of US$ 48135.23 (fourty-eight thousand one hundred and thirty-five dollars and twenty-three cents) of profit. The cash flow discount rate was 10 % p.y. In this case, the project is considered economically viable because the net present value is positive within the horizon of analysis of 5 years. For the internal rate return (IRR) criterion, it can be concluded that in the second year, the accumulated is zero, which represents the IRR of the project as 10.0% p.y. In this case, the IRR is equal than the minimum attractiveness of the project (10.0 % p.y), which means that the project is economically viable. THILAKARATNE et al. [44] obtained a minimum fuel selling price (MFSP) of $3.69 per gal (0,98 R$ / L) is estimated assuming 10% internal rate of return. Finally, for the profitability index, it is possible to obtain the value of 1.52 (index of profitability). It means that for each dollar invested in the project a return of 1.52 dollars it will occur. According to the criteria of this index, the project is considered economically viable.

Table 12: Annual cash flow for the bio-oil produced by pyrolysis of lipid-base material and discounted payback analysis, net present value (NPV) analysis, internal rate of return (IRR) analysis, profitability index analysis.

Year	0	1	2	3	4	5
Cash Flow	-91803.95	36915.60	36915.60	36915.60	36915.60	36915.60
Present value	-91803.95	33559.64	30508.76	27735.24	25213.85	22921.68
Accumulated Value	-91803.95	-58244.31	-27735.50	0	25213.54	48135.23

Figure 3 corresponds of the sensitivity analysis for 1775 L/day, to reach the baseline transportation fuel MFSP of 1.34 US$/L, the 10% facility IRR is assumed. It is clear that the distillation yield and bio-oil yield are the most significative variable that affect the MFSP. These results are in agreement with BROWN et al. [9].

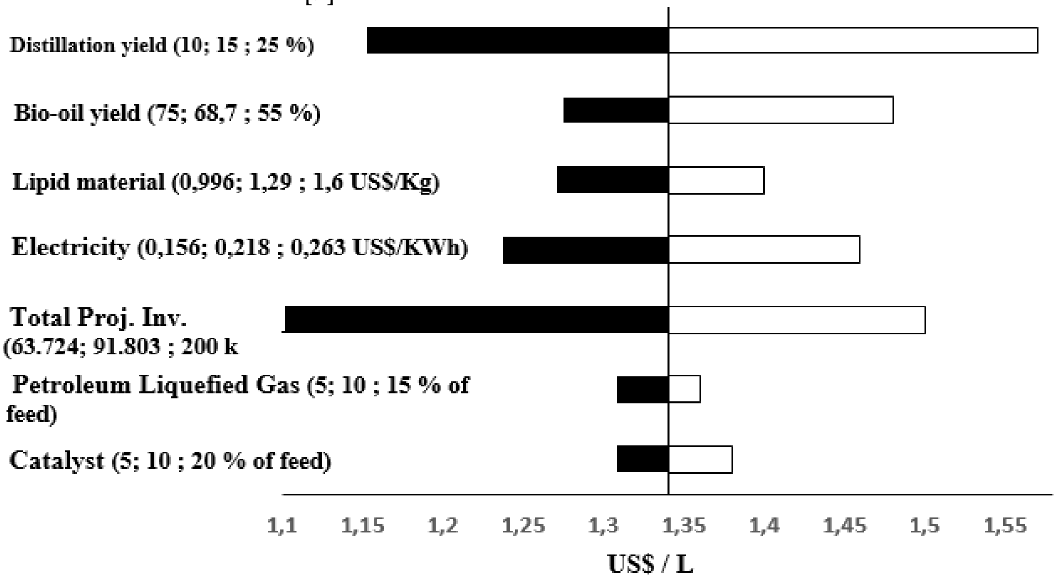

Figure 3: Sensitivity analysis for 1775 L/day, to reach the baseline transportation fuel MFSP of 1.34 US$/L, the 10% facility IRR is assumed.

Operation cost, payback period (PBP) and breakeven analysis is used to investigate the relationships between the planned project cost and the rate of return. The breakeven point (BEP) is the point at which total cost and total revenue are equal, which means there is a balance of the profit and loss [22]. Table 13 presents the cash flow in which the total cost is equal the total revenues and corresponds to nil in the fifth year of cash flow. The value of MFSP obtained was of 1.30 US$/L.

Table 13: Breakeven point calculation.

Year	0	1	2	3	4	5
Cash Flow	-91803.95	24217.65	24217.65	24.217,65	24217.65	24217.65
Present value	-91803.95	22016.05	20014.59	18195.08	16540.98	15037.26
Accumulated Value	-91803.95	-69787.90	-49773.31	-31578.23	-15037.25	0.00

3.2 Lignin-cellulose-base material

The results presented is this work were those obtained by pyrolysis of açai seed (*Euterpe Oleracea, Mart.)* at 450 °C carried out in pilot unit. The results presented by CASTRO [10], for the yields of reaction products are shown in Table 14.

Table 14: Yields of reaction products by pyrolysis of açaí seed *(Euterpe oleracea, Mart.)* and distillation process of bio-oils [10].

Pyrolysis Availability	93.75%
Organic Liquid Product / Bio-oil	7.20%
Solid product (Coke)	41.00%
Gaseous product (Biogas)	32.03%
Distillation yield	90%

The knowledge of the physicochemical characteristics of lignocellulosic raw materials helps the selection of biomasses for thermos-chemical processing in order to obtain products with high added value [10]. Table 15 shows the physical characterization of the açaí seeds, after drying at 105 °C.

Table 15: Physical characteristics of the açaí seed used as raw material to produce bio-oils [10].

Physicochemical properties	Values
Moisture [%]	12.45
Volatile material content [%]	85.98
Asch content [%]	0.42
Fixed carbon [%]	13.60
High calorific value [MJ/mg]	18.21

Table 16 presents the physicochemical characterization of the organic liquid product (bio-oil) obtained by pyrolysis of açaí seed (*Euterpe Oleracea, Mart.)*.

Table 16: Physicochemical characterization of the bio-oil obtained from the açaí seed (*Euterpe Oleracea, Mart.) [10].*

Properties	SANOH 450 °C
Acidity index [mg KOH/g]	19.44
Density [g/cm^3]	1.0225
Kinematic viscosity [mm^2/s]	56.55
Refractive index	No detected

Table 17 presents the yields of pre-treatment of raw material including drying, comminution and sieving processes, as well as the total yield of the pre-treatment process carried out for each batch. The results demonstrated that raw material collected presented 40% (wt.) moisture in biomass. This is due to the pulping process using water for juice extraction and inappropriate disposal of seeds in the environment [10].

Table 17: Yields pre-treatment processes (drying, comminution and sieving).

Data	Drying	Comminution	Sieving	Total Yield
Initial mass [kg]	150	88.38	83.38	150
Final Mass [kg]	88.28	83.38	70.26	70.26
Yield [%]	58.92	94.34	84.26	46.84
Moisture [%]	41.08%			

After pre-treatments, yields associated with seed moisture cab be seen (drying) as mass losses during the process (comminution), as well as the separation of excess fibers (sieving). In addition, the seeds were submitted to chemical impregnation in order to improve the efficiency of pyrolysis processes in terms of yield and quality of biofuel products. According to studies reported in the literature [26], the treatment with sodium hydroxide directly effects the reduction of hemicellulose and lignin in the biomass structure, as it activates the cellulose hydroxyls.

Table 18 shows the composition of the bio-oil obtained by pyrolysis of açaí seed *in nature*. By analyzing the bio-oil obtained by pyrolysis of açaí seeds *in* *nature* at 450 °C, the chemical compounds identified were aliphatic hydrocarbons (alkanes, alkenes, cycloalkanes and cycloalkenes), aromatics (benzenes and naphthalenes) oxygenated compounds (esters, ethers, carboxylic acids, ketones and aldehydes) (CASTRO, 2019). It can be observed the presence of 19.804% (area.) aromatic hydrocarbons, 38.081% (area.) aliphatic hydrocarbons, and 39.552% (area.) oxygenates. It can be also observed percentages of nitrogenous and chlorinated compounds below than 3% (area.).

Table 18: Composition of the bio-oil obtained by pyrolysis of açaí seed *in nature*.

Chemical functions	Bio-oil (SANOH 450ºC) Composition [%]
Aromatic hydrocarbons	19.804
Aliphatic hydrocarbons	38.081
Ketones	3.618
Alcohols	11.738
Esters	1.441
Ether	1.27
Aldehydes	5.582
Carboxylic acid	2.019
Other oxygenates	13.885
Nitrogenous and chlorinated	2.563

Regarding the procedure of chemical impregnation, it was observed a high obtention of hydrocarbons (increase of 36,36 % when compared with the absence of impregnation) and reduction in formation of oxygenated compounds of 42,59 % when is used açaí seed in nature [10].

Table 19 shows the identification and quantification of the organic groups presents in the fraction of bio-kerosene QVA (175 °C– 235 °C) obtained by distillation of bio-oils. The biokerosene contains aromatics (47.283 %), aliphatics (34.072 %), ketones (0685 %), alcohols (7.077 %) and phenols (10.882 %).

Table 19: Composition of the biokerosene (175 – 235 ºC) obtained from the distillation of bio-oil.

Chemical function	Biokerosene (175 °C– 235 °C) [%]
Aromatic hydrocarbons	47.283
Aliphatic hydrocarbons	34.072
Ketones	0.685
Alcohols	7.077
Esters	-
Ether	-
Aldehydes	-
Carboxylic acid	-
Phenol	10,882
Other oxygenates	-
Nitrogenous and chlorinated	-

Table 20 shows the identification and quantification of the organic groups presents in the fraction of light green diesel DVAL (235 °C – 315 °C) obtained by distillation of bio-oils. The light green diesel contains aromatics (78.326 %), aliphatics (10.081 %), ketones (4.058 %), alcohols (4.201 %) and phenols (3.334 %).

Table 20: Composition of the light green diesel (235 °C – 315 °C) obtained by distillation of bio-oil.

Chemical functions	Light green diesel (235 °C – 315 °C) [%]
Aromatic hydrocarbons	78.326
Aliphatic hydrocarbons	10.081
Ketones	4.058
Alcohols	4.201
Esters	-
Ether	-
Aldehydes	-
Carboxylic acid	-
Phenol	3.334
Other oxygenates	-
Nitrogenous and chlorinated	-

Table 21 presents the analysis of the revenues and expenses by pyrolysis of açaí seeds (*Euterpe Oleracea) in nature* fallowed by distillation. It is clear that the impregnation of the açaí seeds with sodium hydroxide (2 mol L^{-1}) presented an extremely high cost 1.767 US$/L, while the price of sale of the biofuels it is 1.34 US$/L. Another high cost was drying 0.421 US$/L, which contributes to the unfeasibility of project. Studies presented by CASTRO [10], presents the same study (pyrolysis followed distillation of açaí seeds *in nature*) without impregnation, which can be used to economic feasibility studies futures.

Table 21: Revenues and expenses by pyrolysis of açaí seeds (*Euterpe Oleracea, Mart.) in nature* to produce biofuels.

Revenue		
Feed rate_93.75% (Availability)_Cracking	906.04	L/day
Organic liquid product (Bio-oil) _7.20%	65.23	L/day (feed distilled)
Solid product (coke)_41.0%	112.46	US$/day
Gaseous product (Biogas)_32.03%	10.14	US$/day
Distilled biofuel _90%	58.7	L/day
Sale price of biofuel	1.34	US$/L
Total expenses	2.78	US$/L
Raw material (açaí seed)	0.056	US$/L
Drying_3 KW	0.421	US$/L
Comminution_2 KW (1h)	0.009	US$/L
Impregnation NaOH_2 mol L^{-1}	1.767	US$/L
Liquefied petroleum gas (LPG)_10%	0.100	US$/L
Manpower	0.114	US$/L
Distillation (Heating)_5 KW	0.175	US$/L
Federal tax rate_10%	0.134	US$/L
Profit margin	-1.43	US$/L

4. Conclusions

Starting from the feasibility project criteria indicators, it is possible to confirm the feasibility of thermal catalytic cracking of lipid-base material (from fat retention box of the University restaurant of the UFPA) for the production of biofuels, coke and methane gas.

The availability used for the project evaluation criteria with the crude palm oil was of 50%. This means that for each shift of 8 hours of work, 4 hours it will be used to load and unload the equipment. With this, the results of the project´s

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evaluation indicators can be all improved, starting from the optimization of the pilot plant availability.

Considering the viable process, the minimum fuel selling price (MFSP) obtained is this work for the biofuels was US$ 1.34/L (Currently practiced in Brazil). The literature mentioned in this work presents values from 0.68 up to 0.98 (US$/L). By considering the viable process, it was obtained the IRR of the project as 10 % p.y. In this case, the IRR is equal the minimum attractiveness of the project (10% p.y), which means that the project is economically viable. THILAKARATNE *et al.* [44], obtained 10% internal rate of return.

Sensibility analysis demonstrated the pyrolysis yield and distillation yield are the parameters that most affect the MFSP. The breakeven point obtained was 1.30 US$/L.

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